A DIGITAL PROTOTYPE FOR COLLABORATIVE CONCEPTUAL DESIGN IN THE THAI AEC SECTOR

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Table of Contents

List of Tables

List of Figures

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List of abbreviations

AIA	Architecture Institute of America
AIACC	Architecture Institute of America, California Council
ACT	Architecture Council of Thailand
AEC	Architecture Engineering and Construction
ASA	Association of Siamese Architects under Royal Patronage
BIM	Building Information Modelling
CAD	Computer Aided Design
CIC	Construction Industry Council
CM	Construction manager
CMPD	Construction Management Project Delivery
DB	Design-Build
DBB	Design-Bid-Build
ECMA	European Computer Manufacturers Association
EIT	Engineering Institute of Thailand
E-Mail	Electronic Mail
GDP	Gross Domestic Product
GMP	Guaranteed Maximum Price
HPB	High-performance building
HVAC	Heat Ventilation and Air Conditioning
ICT	Information Communication Technology
IFC	Industry Foundation Class
IM	Instant Message
IPD	Integrated Project Delivery
OTTV	Overall Transfer Value
RTTV	Roof Transfer Value
SUS	Software Usability Scale
UK	United Kingdom
UKOGC	United Kingdom's Office of Government Commerce
USA	United State of America

Abstract

The construction industry is currently driving to reach a high level of achievement for future sustainable built environments. The UK and USA models for the building design and construction process have been developed to enable relevant stakeholders to work closely from the beginning of a project. Indeed, design production is particularly significant, particularly at the concept design stage, as design decisions cost less to change and there is greater opportunity for change at the concept design stage. These are important considerations for this study. In addition, collaboration can significantly reduce redundant loops of performance in the subsequent processes leading to savings both in cost and time. However, the traditional design phases in the USA and Thailand have faced barriers due to silos of effort, a lack of overall project awareness, inefficient collaboration between silos, and poor communication among silos due to the fragmentation of the functional disciplines involved.

Furthermore, stakeholders working in partnership in the AEC industry are connected together in a complex way so information sharing is not straightforward; however, they are now supported by digital tools and communication technology, which can mediate this collaborative process. Effective collaboration can be promoted by technology through existing digital tools, for example, CAD or BIM. These tools can enable important increases in productivity through the strategic sharing of information. However, these are not appropriate tools for the concept design stage due to the complex information involved and the difficult user interfaces. This difficult interface leads to consumption of memory and an obstruction of the mental workflow, which does not support designers at the concept design stage. Moreover, the purpose of collaboration among multidisciplinary and multi-functional teams is to enable the integration of other disciplines, to maintain and sustain knowledge and information sharing, and to predict colleague behaviour. Knowledge sources and the retrieval of knowledge and information are significant; however, communication has pros and cons, and current tools, such as email or instant messaging, are difficult to use for the purpose of collaboration.

Therefore, this research has developed an innovative digital tool to facilitate collaboration and support designers at the concept design stage. This tool enhances the creative thinking process by emphasising the streaming of the cognitive workload. In addition, collaborative communication supports the creation and structure of contents, posts and replies and supports designers to retrieve information. Collaborators/stakeholders can therefore share space and information. The research methodology for this study was designed to collect data in Thailand; it included the design and development of a prototype, and an evaluation of a case study in Thailand. The prototype is the first pilot of the digital tool to support designers at the concept design stage and could be further developed for use in practice.

CHAPTER 1:
RESEARCH INTRODUCTION AND BACKGROUND

1.1 Introduction

This chapter presents the introduction and background of the research undertaken; it identifies the research problem, outlines the research challenge, and proposes several justifications for the study. The aim and objectives are explained to confirm the direction of the research before an outline of the structure of the thesis is given. In addition, the chapter includes the proposed stages of the research, from the introduction, background, development of the research problem, literature review, research methodology, the first data collection, the prototype design and development, the evaluation stages, and the conclusion. Finally, an outline of the thesis is included through a summary of each chapter.

1.2 Background

The construction industry has frequently faced problems, which affect efficiency, quality, cost and time of its projects; these arise due to the complexity of its multidisciplinary and multi-functional collaborative partnership environment (Egan, 1998; Makulsawatudom, Emsley, & Sinthawanarong, 2004). One of its key problems is the fragmentation of the industry, which usually manifests in any potential collaboration. These issues emerge due to the nature of its traditional sequential process that involves different disciplines and expertise (Coyne & Snodgrass, 1993; Bertelsen, 2003; Zimina et al., 2012 cited in Gomes, Tzortzopoulos, & Kagioglou, 2017). The Architecture, Engineering, and Construction (AEC) sectors have focused on improving their efficiency, conductivity, safety, the quality of their design, and their sustainability (Egan, 2011; AIA, 2007, 2014) by promoting effective collaboration. This occurs by framing project delivery approaches through the promotion of technology in order to maintain sustainable development.

The USA and UK Architecture Engineering and Construction (AEC) sectors have focused on improving their efficiency, conductivity, safety, the quality of their design, and sustainability (Egan, 2011; AIA, 2007 and 2014) in order to maintain sustainable development. Collaboration has become a key achievement for these AEC sectors. In the USA, the AIA (2007, 2014) has developed an Integrated Project Delivery (IPD) approach, while in the UK, the 'RIBA Plan of Work 2013' published a plan that aligned with the Construction Industry Council's (CICs) theme. Both the IPD and the RIBA Work Plan 2013 adopt concept design collaboration and each multidisciplinary discipline can be united within the collaboration process that includes relevant stakeholders.

In Thailand, the current AEC sector industry is fragmented, comprising professionals or firms who work together under contracts without an official united framework for project delivery. There is no longer a formal project delivery system for collaboration from the beginning to the completion of a construction process. However, the Architect Council of Thailand (2015) has promoted the design-bid-build process, which is similar in frame to the USA traditional design process that starts with the pre-design phase and moves through to the construction phase. Each professional executes tasks that align with the codes or responsibilities of each professional council, such as engineers and architects. This design process is used to overlay a common agreement and collaboration under the design-bid-build and construction management approaches; furthermore, the Architect Council of Thailand (2015) endorses both approaches. Although the design build model is not declared, it is separately executed through a specific contract under the design process.

Collaboration has been studied at many stages of the AEC sector with the aim of developing methodologies and tools to efficiently solve its associated problems. The focus of this research is the concept design stage. A UK example of successful support is provided by Foster+Partners in London who encourage a participatory environment in each team from the initial through to the final phase in order to develop a collaborative working platform (Olsen & Mac, 2014). Moreover, multidisciplinary professionals are merged at the beginning of the design stage when architects and engineers start to work closely together which continues throughout the project process (Olsen & Mac, 2014). This practice is supported by Toth, Fernando, Salim, Drogemuller, Burry, Burry and Frazer (2009) who found that multidisciplinary teams provided a great opportunity to achieve accomplished projects. They confirm that this is due to the collaborative outcome within concept design that leads to the final goal, and enables the project to profit from the close cooperation amongst professionals. Significantly, Sinclair (2013) and Hsu & Lui (2000) also argue that the concept design stage is not only crucial due to the ability to lower the cost of any subsequent change, but also provides more opportunities for change. In addition, Leon and Laing (2013a) also suggest that collaboration in concept design can help relevant stakeholders to reduce the working loops of drawing design and construction detail design, which leads to savings in both cost and time.

Fragmentation is a root case of construction industry's underperformance amongst the multiple professional disciplines in Thailand. Affected by inefficiencies in communication and limited collaboration between professionals, its results lead to incomplete designs within the early construction phases. These problems originate at the concept design phase and emerge at other stages of the design process, such as construction (Makulsawatudom, Emsley, & Sinthawanarong, 2004; Charoenpornpattana, 2015). This confirms the importance of the concept design phase in addressing inherent construction problems. Thus, the concept design phase provides an appropriate context to solve such problems in order reduce redesign and increase productivity.

The collaboration of stakeholders in the AEC sector is supported by computer tools, which can help to reduce errors and increase productivity. Communication mediated by collaboration among relevant stakeholders is driven by current technology, which provides useful support when talking, writing, and using images including shared 2D and 3D computer files (Woo et al., 2001). Current technology and computer software released in this period consists of information communication technology (ICT), 2D and 3D Computer Assisted Design (CAD), and Building Information Modelling (BIM) tools, which are widely used for the development of prototypes in all teams and significantly help them to work collaboratively. This is one of the important factors that affect a typical information-sharing model among professional stakeholders. Traditional practice in the AEC sector follows a pattern of information sharing from one to another or others without a central project model; however, this existing pattern is now changing to adopt a new model that promotes the use of central information. Similarly, as explained by Whyte and Levitt (2011, p.17) "...new digital tools and processes increase the coupling between the various disciplines involved in design, implying wider organizational changes across firm boundaries". This provides an impetus to significantly change traditional practice in order to increase efficiency and productivity; however both pros and cons exist in terms of the use of these digital tools. One of the major advantages is the increased speed, the reliability of consistent data and improved decision-making (Benning, Dumoulin, Dehlin, Tulke, Åberg, Laine, Jaeger, & Brandt, 2010). Furthermore, these computational tools can usually help to save cost and time in the operational process.

Nevertheless, a major drawback of these digital tools, is their obstruction of the mental workflows, which increases the cognitive load of designers. This consumes their time and memory resources at a stage when they are also addressing visual processes (Coates, Arayici, Koskela, Kagioglou, Usher, & Reilly, 2010; Bueno & Turkienicz, 2013). Moreover, BIM and

CAD tools have limitations when dealing with complex information as they both have difficult interfaces and can obstruct an individual's mental workflow (Coates et al., 2010; Bueno & Turkienicz, 2013); they also involve a steep learning curve (Denzer & Gardzelewski, 2011). Thus, existing modern tools can be arduous for designers at the concept design stage (Ibrahim & Rahimian, 2010). Moreover, designers struggle with modern tools which better support them in creating concrete objects more than with abstract objects; however, this is problematic for concept design where the natural development of a design problem travels from an abstract object to a concrete object. Due to the modelling process, the creation of a concrete object consumes memory resources and time, which can also lead to deficient outcomes (Ibrahim, 2010; Denzer & Gardzelewski, 2011). As such, in simultaneously creating a concrete object and thinking through a design problem, designers are no longer able to produce efficient concept designs (Still & Dark, 2013). Consequently, there is evidence that modern tools obstruct mental workflows and increase the cognitive loads for designers, which consume time and memory resources when dealing with visual processes.

For Thai professionals, traditional collaborative design is fragmented and adopts a linear approach that depends on the contracts among the range of designers involved. Usually, architects initially design the conceptual and schematic design process and then, for small building projects, the design is shared with other disciplines at the next design stage. However, complex or large building project involve intensive collaboration among other disciplines (such as the structural engineer), within the schematic design stage through to other stages. These professionals traditionally work independently and discuss or negotiate in face-to-face meetings. Carrara (2017) pointed out that traditional collaboration methodologies and techniques based on face-to-face meetings, which are convened for discussion, are inefficient when a large number of professionals work together. Knowledge and experience can be lost forever without a record of discussions in the face-to-face meetings. Thus, the nature of collaboration among multiple disciplines in Thailand is inefficient (Makulsawatudom et al., 2004; Charoenpornpattana, 2015). This leads to the emergence of problems in the construction phase due to a lack of collaboration, limited failure awareness, poor communication, and traditional barriers (AIA, 2007), which includes the limited sharing of experience and knowledge to collaboratively build knowledge (Charoenpornpattana, 2015). Thus, collaboration within the Thai AEC sector can bring together multiple disciplines at the conceptual and schematic design stages, and use technology to increase efficiency and productivity (AIA, 2007).

According to the IPD and RIBA Plan of Work 2013, the work plan notes opportunities for collaboration. As the nature of collaboration among multiple disciplines within the concept design stage is complex, IPD uses co-location whilst RIBA encourages the arrangement of workshops to support collaboration throughout its processes. However, complex collaboration is not always sufficient; there is also a need to retrieve experience and knowledge, to consider distance, and resolve misunderstanding. Collaboration in the AEC industry involves multiple disciplines with unique experiences and knowledge. Thus, individuals have to integrate across the boundaries of other disciplines and evaluate both their own solutions and the holistic system of work (Carrara, 2012). Working together to achieve the goal of collaboration is complicated, as participants needs to build and sustain their own knowledge or mental structure (Gautier, Bassanino, Fernando, & Kubaski, 2009). Furthermore, they need to understand whatever is shared when participating across multidisciplinary boundaries of knowledge. At the same time, participants also need to share experience and knowledge with other colleagues, although it can be difficult to retrieve these exchanges. However, due to the current impact of globalisation, modern collaboration has been further shifted from synchronisation to desynchronization and delocation. Moreover, the desynchronization of information exchanges presents more complex problems for communication in terms of collaboration (Carrara, 2012). In addition, developing a landscape of innovative collaboration can prove problematic due to the social problems that emerge from several specialists working across cultural boundaries (Carrara, 2012). It can lead to the additional problems associated with misinformation and the misunderstanding of messages, which complicates the exchange of design information and increases the potential for conflict (Carrara, 2012; Poole, 2011 cited in Sun, Mollaoglu, Miller, & Manata, 2015).

The above review has identified the research problems, which can be summarised as follows:

1. The concept design stage is a crucial for any project due to its potential for managing the cost and time spent in subsequent changes; furthermore, there are greater opportunity for change within this stage.
2. Poor communication and a lack of collaboration and failure awareness are key issues in the Thai AEC industry. Although some collaboration methodologies have been used, there are limitations associated with existing digital tools that support collaboration and communication for the design team within the concept design stage.
3. The lack of tools to enable communication and the recording of discussion content among professionals represents a weakness for collaborative design in that it obstructs

the sharing of experience and knowledge that occurs within discussions. Although it is important to retrieve experience and knowledge, a collaborative communication tool has not yet been developed to enable this within the concept design stage.

This research investigates the definition of a digital prototype for collaborative conceptual design in Thailand. Design process models within the UK and USA are explored as well as example of innovative collaboration, which are considered templates for Thai collaboration. These form part of the requirements in developing a digital prototype for this research. In addition, the study aims to capture the experiences and requirements of disciplines involved within concept design. The results of the data collection confirm that Thai professionals require ICT technology and a new collaborative tool for concept design that can support them in both collaboration and communication. This suggests the need for a digital tool that aims to enable these disciplines to communicate and work together within the concept design. Thus, this study aims to develop and evaluate such a prototype.

1.3 The research challenge and opportunity

The background has provided a critical review of information, which has raised awareness and identified several problems; however, an exploration of how to solve these problems is required. Importantly, the nature of collaboration among multiple disciplines is not always efficient within the Thai AEC sector, due to fragmented collaboration and problematic communication among the silos. Moreover, the AIA (2007) recommended the improvement of bids by bringing constructors and other professionals together at a much earlier stage, namely within concept and schematic design. Thus, proposing a technology that has been developed as a digital prototype to connect diverse disciplines through a Computer-Mediated and Face-to-Face Communication Channel could enhance collaboration and communication among multiple disciplines. This would help to overcome distant, support collaborative design, propose design solutions/ideas through co-located and de-located collaboration, and enable discussion within concept design in order to build knowledge together and to understand the contributions that are shared. However, there are no digital tools currently available for collaborative communication within concept design in Thailand that enable close collaborative design through communication, interpretation, understanding, development, suggestion and/or proposal, and discussion (Carrara, 2012). Therefore, the next step is to identify and outline the proposed solutions to solve these problems; and these are detailed as follows:

Firstly, collaboration in concept design needs a tool to support communication, suggestions, and discussion for multidisciplinary designers in order to collect sources of knowledge and solve the problems that emerge, so that each discipline can adapt to achieve their collaborative goal. Thus, it is necessary to select and integrate a type of communication media that supports the classification of design problem contents, enables problem solving to enhance collaboration, and monitors any cultural problems.

Secondly, the collaboration involved in the concept design process requires a tool to support a designer's thinking process that also enables the development and sharing of their own design ideas and proposals with the collaborative design team. Current tools do not meet this need due to their complex user interfaces. Thus, an intuitive user interface would provide a foundation to reduce cognitive loads and support the streaming of the mental workflows. This could potentially be achieved by using sketches. In addition, enabling connections to each stakeholder through the use of Cloud technology would support the collaboration process; this would meet the needs of both co-located users and those based in different work places, working at different or the same time.

Developing an innovative digital tool can enable these potential solutions and thus demonstrate a new research direction. Therefore, the purpose of this research is to identify a prototype model and evaluate the potential of a prototype for the collaborative conceptual design team. Thus, a digital prototype is developed for the design and development process. In the design process, a model of creative and critical thinking in problem solving for design is developed for the prototype user interface design. Lawson's problem solving, Ellis Paul Torrance's concept, and general critical thinking tools influence this development. Thai professionals were invited to contribute to the first data collection and, after the prototype was completed, and to participate in the prototype evaluation. The research employs qualitative research to explore current collaborative design and to provide an evaluation process. This aims to answer the following research questions:

1. What is the situation for collaborative conceptual design teams in Thailand?
2. What is the architecture of a digital tool for collaborative conceptual design teams?
3. What are the results when professionals evaluate the prototype tool for real-time collaboration and communication?
4. How do professionals recommend the adoption of digital prototypes for collaborative conceptual design teams?

1.4 Aim and objectives

In this research, the contents of multidisciplinary collaboration within the concept design process and technology intersect. These are the subjects of innovation through the design research methodology. Thus, it is proposed that this research can provide a new tool to enhance multidisciplinary practice, which can be achieved through the following aim and objectives:

Research aim:

To investigate how electronic sketching could improve conceptual design team collaboration in the Thai AEC industry.

Research objectives:

1) To critically analyse current design team collaboration by identifying challenges and opportunities.
2) To identify the existing tools and technology used for conceptual design team collaboration.
3) To develop a methodological approach for the design and development of a digital prototype to improve conceptual design team collaboration in Thailand.
4) To design and develop a digital prototype to improve conceptual design team collaboration in Thailand.
5) To provide recommendations to improve conceptual design team collaboration in Thailand.

1.5 Methodological approach

This research investigates the subjective use of electronic sketching and its support for conceptual design team collaboration in Thailand. The study subjectively examines 'how things really are' and objectively investigates 'how things really work' (Saunders, Lewis & Thornhill, 2016). Moreover, in examining how things really are, this research identifies models for a collaborative tool for conceptual design teams and collects research participants' recommendations for the prototypes. By investigating how things really work, the study observes and measures participants' tests of the digital prototype.

This research advocates a pragmatic position in terms of its epistemology, and applies an abductive research approach. The abductive approach to the data collection builds a conceptual framework, which is tested through the research methodology and is based on a case study; it adopts appropriate techniques and procedures for analysis. Thus, the research methodology adopts a case study strategy, which includes the three phases (see Figure 1.1) described below.

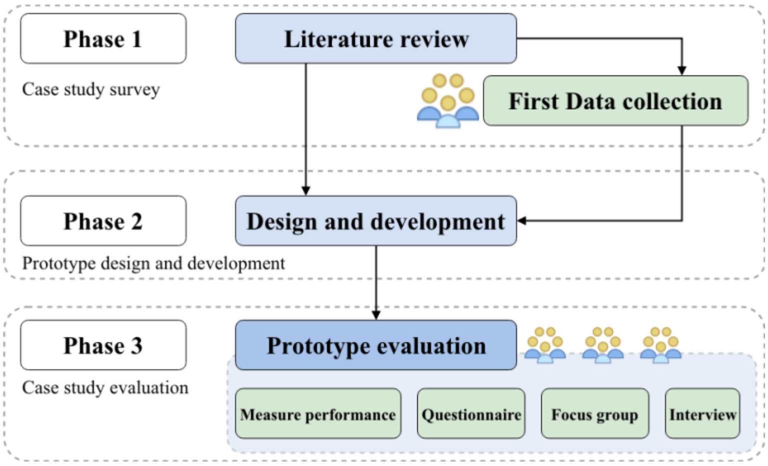


Figure 1.1 The research methodology
(Source: Research's own)

Phase one: A case study survey is carried out to explore the current circumstances within concept design and collaboration, and to examine relevant tools and technologies. The literature review is undertaken to define the meaning of design and concept design. The current design process approaches in the USA, UK, and Thailand are explored in terms of collaboration, problems in collaboration, and the involvement of stakeholders in concept design. The advantages of the UK and USA design process approaches are captured to form recommendations for the Thai design process. Design and communication tools are also investigated regarding the pros and cons, which include the adoption of these tools in Thailand in order to identify and understand their limitations for concept design. This phase contains the first primary data collection stage in which Thai relevant professionals involved in concept design are invited to undertake a qualitative questionnaire. According to the literature review, 'Sketch' can provide low consumption of memory resources and cognitive load meaning it is generally accepted as a powerful tool to capture creative ideas from the limited resources of the human brain.

Phase Two: The requirements specification is defined after the analysis of the first data collection when a conceptual model is confirmed. The model of creative and critical thinking in problem solving for design is developed and applied for the user interface design of the prototype. From this, a digital prototype is developed through a design and development methodology, at which point the prototyping model is modified to support the researcher to incrementally develop the prototype. The digital prototype is divided into segments and each is gradually developed under the method until the prototype is complete.

Phase Three: The case study evaluation is carried out in Thailand where groups of relevant professionals in concept design are invited to participate in the evaluation. The completed version of the digital prototype is demonstrated and tested, via the Software Usability Scale (SUS) Questionnaire, to measure its performance in terms of its usability. At this stage, the research participants engage in a focus group that uses the six thinking hats technique (De Bono, 2017) to collect their recommendations. Furthermore, some are also invited to a subsequent interview concerning the entire evaluation process. Finally, all of the processes are summarised in the conclusion.

1.6 Thesis outline

The framework of the research is provided through the structure of the thesis, and a diagrammatic outline is presented in Figure 1.2.

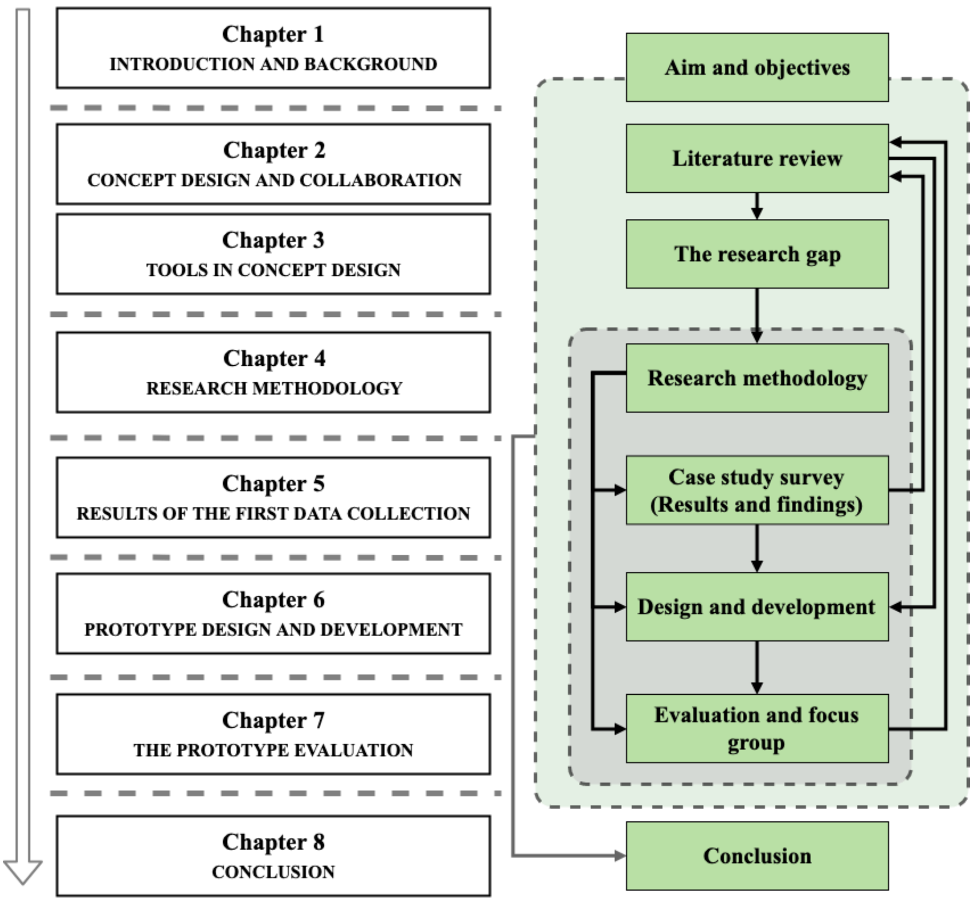


Figure 1.2 Thesis Outline
(Source: Researcher's own)

- Chapter 1 explains the background and problems identified within the research, including the challenges, aim and objectives. In addition, an outline of the methodological steps and the structure of the thesis chapters are presented.
- Chapter 2 presents a critical review and an evaluation of the published literature available on concept design. The definitions and meanings of design and concept design are discussed in depth, whilst the UK, USA, and Thai design process approaches are investigated from the initial through to the completion phases. The UK and USA design processes represent innovative approaches and are therefore explored so that their advantages can be applied as recommendations for design process approach in Thailand. An examination of collaboration then focuses on concept design in the UK, USA, and Thailand, which includes an exploration of the problems associated with collaboration.
- Chapter 3 presents the tools used in the concept design process. The thinking design tool is explored in terms of critical and creative thinking and visual thinking. Both the traditional and modern tools (including those used in communication) that are used in concept design are critically examined by focusing on the problems experienced in practice. The adoption of these tools in Thailand is also discussed through the first data collection phase in the chapter 5. At the close of the chapter, the research gap is defined.
- Chapter 4 presents the research path and methodology used to design the data collection instrument and collect the data. The research philosophy is presented and the study positioned, whilst the research approach is identified in relation to the methodological choice and research strategy. Three phases are explained in the adoption of the research methods, which present the techniques and procedures from the fifth to the seventh chapter.
- Chapter 5 is the first data collection and analysis phase. The chapter presents information to understand the overall views of the survey participants. Results from the qualitative questionnaire are presented; this chapter continues to develop the findings from the first data collection.
- Chapter 6 is the second phase of the methodological approach, and outlines the design and development of a digital prototype. The model of creative and critical thinking in problem solving for design is applied when developing the prototype's user interface. The Software Development Lifecycle (SDLC) is explored to understand the different

types of design and development, after which the approach is chosen and adapted for this research. The prototype presents the model and describes its use.

- Chapter 7 is the third phase of the methodological approach and involves the prototype evaluation. Four sections comprising the performance measurement, SUS questionnaire, focus group, and interview are described in detail. Following this, the results of each section are presented.
- Chapter 8 concludes the research with reflections on the research gap, the limitations encountered within the study, and recommendations for future research.

1.7 Summary

This chapter introduced the research problem and explored the research issues and challenges through an introductory background literature review. It also identified the aim and objectives of the research and the methodological approaches through three phases; case study survey, prototype design and development, and case study evaluation. In addition, this chapter also provides a summary description of the contents of each of the eight.

CHAPTER 2:
CONCEPT DESIGN AND COLLABORATION

2.1 Introduction

All existing ancient artefacts that have remained in the world, whether small or substantial, such as a stone axe, Stonehenge, the Pyramids, the Acropolis of Athens or the Coliseum, have been developed and built by craftsmen and chief craftsmen (Thompson, 2012). In Ancient Greece, the chief craftsman was called the ‘Archikton’, whilst during the Middle Ages (about 1000 to 1400 AD) they were called the ‘Architect’ or ‘Master Builder’. The chief craftsman would have many skills, such as artistry, mathematics, and engineering, which would enable them to create ideas, known as designs or plans, and to engage craftsmen and labourers to build the artefacts.

In 1716, civil engineering was established in France to build roads and bridges. Moreover, after 1750, during the Industrial Revolution, the engineer became the main professional to build infrastructure, such as roads, bridges, canals, or mills. In their approach, Thompson (2012) explains that the engineer preferred to use their scientific skill to calculate a design for new materials, such as reinforced concrete and steel, whilst the architect was most likely to use the 'rule of thumb' to enable their artistic skills. Furthermore, architects tended to use traditional materials, such as masonry and timber, which use the ‘rules of thumb’ and previous experience of problem solving in architectural design (Reinhart & Fitz, 2006). In some countries, including Britain, architects and engineers were considered to occupy a joint profession (Thompson, 2012). When buildings became more complex comprising a variety of components, materials and services, architects relinquished the design of some functions to other disciplines, such as mechanical and electrical engineers, and quantity surveyors. Currently, the AEC industry involves shared responsibility amongst multidisciplinary teams. Moreover, those involved in design now often need to build a team of multiple disciplines so that each can share their particular skills to co-design the artefact (see Collaboration in the Design Process Approach, p.64).

Design is now the main part of a building artefact and its outcome describes how the artefact can be built to all specifications; moreover, the concept is the most important part of the design (see Discussion of concept design, p.54). Thus, in this chapter, it is important to define design and the design concept in order to understand its significance and impact. Therefore, the design processes will be amplified for exploration in the UK, USA, and Thailand, whilst the final section will focus on collaboration to consider its meaning and relevance for the study.

2.2 Design and Concept Definition

The terms design and concept design will be used in many parts of this thesis. Thus, this section will focus on the two words, concept and design, to explore their roots and meaning, and to study patterns of conceptual design in thinking models. Moreover, exploring the words 'concept' and 'design' will help to understand the term 'concept design'. These keywords are reviewed through dictionary definitions, whilst the meanings are assumed by the AEC industry, and by existing academic sources. They are then evaluated to determine their boundaries and for integration within a research methodology.

The general dictionary definitions of 'concept' and 'design' are (Dictionary, n.d.) as follows:

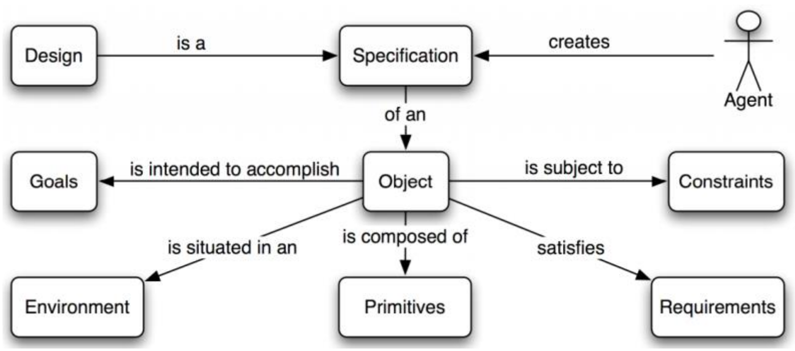
> 'Design' (noun)
>
> 1. an outline, sketch, or plan, as [in] the form and structure of a work of art, an edifice, or a machine to be executed or constructed. or
> 2. [the] structure of formal elements in a work of art; composition (Design, n.d.).
>
> 'Concept' (noun) an idea of something formed by mentally combining all its characteristics or particulars,
>
> 'Concept' (adjective) functioning as a prototype or model of new product or innovation,
>
> 'Conceptual' (adjective) pertaining to concepts or to the forming of concepts (Concept, n.d.a).

The word design also derives from the Latin word 'dēsignāre', which can be traced back to the 1540s and can mean to mark out, devise, choose, designate, or appoint (Design, n.d.). In addition, the word 'desseign' appeared around the 1580s in the Middle French period, and can mean to be attached or to designate; thus, many modern uses of design are metaphoric extensions (Design, n.d.).

According to the Dictionary(n.d.) meaning, the word concept also derives from the Latin word 'concepttum', and dates from between 1550-1560 (Concept, n.d.). It is defined as something conceived or the origin. Concept design generally means an innovated outline of a special object executed or constructed from ideas formed by mentally combining characteristics or particulars (Margolis & Stephen, 2011). The outline initially referenced may be vague or incomplete, but the abstract is sufficient for further development (Margolis & Laurence, 2007; Margolis & Stephen, 2011).

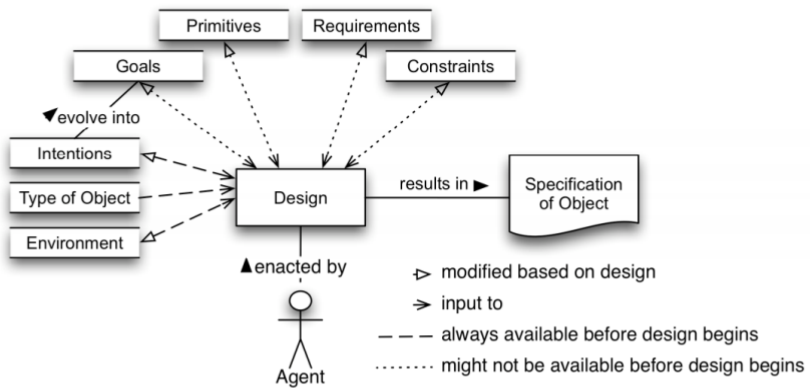
Ralph and Wand (2009) provide a starting point to explore the meaning of 'concept design', as used in AEC industry projects. As there is no single agreed definition, a review of the existing definition of 'design' from the interdisciplinary fields of engineering, architecture, design, and the science of design was conducted between 1964 and 2007. The frequency of keywords and meanings within these sources was analysed and developed into a conceptual model of 'design' which Ralph and Wan (2009, p.103) characterised as:

> Design (noun) a specification of an object, manifested by some agent, intended to accomplish goals, in a particular environment, using a set of primitive components, satisfying a set of requirements, subject to some constraints;
>
> Design (verb, transitive) to create a design, in an environment (where the designer operates)



Design as Noun

Figure 2.1: Meaning of Design - Design as Noun
(Source: Ralph & Wand, 2009, pp.108-109)



Design as Verb

Figure 2.2 Meaning of Design – Design as Verb
(Source: Ralph & Wand, 2009, pp.108-109)

Design is the specification of an object created by an agent. Design (shown in Figures 2.1 and 2.2) involves five components through which it is intended that a specified object will accomplish its goals. It is situated in an environment that provides the context, whether physical object or abstract; moreover, it is composed of primitives or sub ideas. It satisfies requirements or needs as materials of agent for design, and is subject to constraints, which may be structural or behavioural, or regulatory (Ralph & Wand, 2009). In addition, Ralph and Wand (2009) defined design in as a verb (Figure 2.1), that is intentionally enacted by an agent and results in the specification of an object that is modified based on, and as input to, goals, primitives, needs, an environment, and constraints. Thus, its outcome tends to be appropriately designed as a particular type of object.

Table 2.1: Summarising component definitions
(Source: Ralph & Wand, 2009)

Concept	Meaning
Design Specification	Definitions characterise design as planning rather than building. The properties of a design object can be created many types, such as a symbolic representation or logo, an architectural blueprint, a picture in a mind, or artefact objects. A specification is the outcome properties of a design and provides a detailed description.
Design Object	The design object is the entity being designed, such as a home or building design, a prototype of a pen, software, or a policy.
Design Agent	The design agent is the entity, or group of entities, that can develop the structural properties of the design object.
Environment	The environment is the context in which the object is intended to exist (physical objects) or operate (abstracts), such as the surroundings of a site, or an organisational context.
Goals	Goals are what the design object should achieve; goals are optative (i.e. indicating a wish) statements. Designers or actors must have intentionality to serve the goals and create the design.
Primitives	Primitives, or sub-ideas, are the set of elements from which the design object may be composed (usually defined in terms of the types of components assumed to be available).
Requirements	A requirement or need is the material for an actor or group of actors to design. It can be a structural or behavioural property that a design object must possess, such as an engineering requirement, or an architectural need. A structural property is the property of a physical body such as shape, size, weight and material. A behavioural property is the desired response to achieve a goal.
Constraints	A constraint is a structural or behavioural restriction or regulation on a design. It has the same meaning as a limitation.

Ralph and Wand (2009) also explored previous research to consider design as a process (design as verb and noun) for which the outcome executed provides the specification, such as architectural design, structural engineering design, or building service design. Thus, the planning, rather than the building, depends on the actors, goals, context, sub-ideas, needs, and constraints, which are all inputted to the process. The actor, or a group of actors, can be multidisciplinary professionals, such as architects, engineers, and/or stakeholders, who have responsibility for the design in the construction project. These actors can mainly manipulate three components, namely requirements, environment, and goals. Moreover, they can adhere to the components (constraints and primitives) to create appropriate solutions. The five critical components are goals, context, needs, sub-ideas, and constraints; these can become design problems and thus generate ideas within the process.

In addition, the design problems are a critical part of the overall process; as such, there may be a need to provide an 'idea generating station' to solve design problems. This tends to be open-ended and poorly structured, although each design problem has its own boundary and structure. Silk, Daly, Jablokow, Yilmaz, and Berg (2014, p.14) found that well-formed design problems include at least three minimum components:

a. A brief **context** about for whom and for what purpose a solution is needed;
b. A statement of the **need** that specifies the functional requirements and constraints on acceptable solutions;
c. A description of the **goal**, including the general instructions and criteria to use in evaluating ideas.

In their findings, they concluded that these main components (context, need, and goal) are the essential components for problem statements in the design problem. After a particular design problem is developed, the remaining components form the constraints and criteria of the problem. These are manipulated with the other main components in the design process.

This interpretation conforms to that of Laseau (2001) who stated that the project information underpins the process. Laseau emphasises needs, context, and form, which are transformed to represent the space problem; this intersects with the major design components in architectural concept design. Laseau's components can mean the goals that the designers develop, which are subject to limitations, regulations, or constraints. Furthermore, many other criteria concerning design may also arise in the subconscious concerning design thinking, such as green issues, energy, and universal design; these may also be developed in the concept process. These criteria can become what Ralph and Wand (2009) call the primitives, or sub-, ideas. These components, as initial variables, are input to the problem solving models developed by Pahl and Beitz (2007) and Lawson (2006), which will be explored further.

The design process is a highly complex mental process, which Pahl and Beitz (2007) and Lawson (2006) have illustrated by developing various visual models. Although, these models demonstrate different characteristics between the 'general process of a solution finding model' (illustrated in Figure 2.3) and 'the map of Lawson's design process' (illustrated in Figure 2.4), some of the keywords are the same. Pahl and Beitz (2007) defined a process loop, which is a systematic approach to the design process. In this model, both the main and sub-loop contribute to decision-making. The perspective of their model can be summarised as a general approach to determine solutions, which consists of: information, definition, creation, evaluation, and decision. This is illustrated in Figure 2.3.

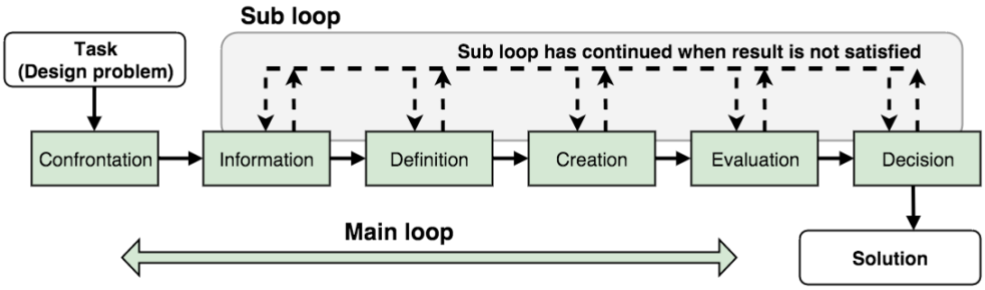


Figure 2.3 General Solutions Finding Process (modified)
(Source: modified from Pahl & Beitz, 2007)

In addition, Pahl and Beitz (2007) noted that their method is a systematic approach, during which the following main conditions need to be satisfied:

Define goals	The overall goal/goals, the sub-goals and their importance should be defined. This gives insight to the problem and motivates a solution.
Clarify conditions	The initial and boundary constraints should be defined.
Dispel prejudice	In order to develop a wide variety of solutions, prejudices should be dispelled.
Search for variants	A number of solutions or combinations of solutions should be presented to have a wide range of suggestions from which the best can be chosen.
Evaluate	The suggestions should be evaluated based on the goals and conditions.

Make decisions	Objective decisions should be made together with experience in order for progress in the process to be made.

According to Figure 2.3, the design problem loop starts in the sub-tasks, between the definition and the evaluation, and is triggered when these outcomes are not satisfied. To start the design problem task, it is necessary to first define what the problem is. The information task aims to explore and assemble relevant information and other methods that form its outcomes. Sets of information are delivered to analyse the definition task. If these sets are not clear, or if the outcomes of this task are not listed or analysed, the process will start again in order to rework the previous task. Next, the sets of defined information are passed to the creation task for synthesis with the next task – namely the evaluation – which then leads to the decision task and finally to the solution. The same loop pattern can start from one stage and move to a previous stage for re-work; thus, the loop will stop when there is a satisfactory result.

In contrast with this systematic approach, Lawson (2006) proposed a conceptual design process map consisting of the problem, solution, analysis, synthesis, evaluation, and solution in the design process. These are the explicit parts of the problem-solving process in the field of architecture, which are considered and condensed without optional elements (Lawson, 2006). In nature, the differences between scientific and architectural strategies exists in the sequence of patterns. Ordinarily, the process of science involves: analysis, synthesis, and evaluation; however, experiments are also considered. Examples of these experiments include: Eastman's realistic experiment in 1970, interviews with a designer, or Rowe's 1987 experiment (Lawson, 2006). These studies discovered that there were distinct patterns from the inherent structural scientific pattern.

For example, an unexpected result from a laboratory study within architecture involving postgraduate science students concluded that they use different strategies to solve problems (Lawson, 2006). Whilst some architectural students tended to identify both the problem and solution through the synthesis of the analysis, others tended to adopt a linear process with an inherent cognitive style. This difference could relate to their diverse study backgrounds, where architecture students are usually taught to adopt an analysis strategy through synthesis. Moreover, architecture students generally study a problem through attempts to create a solution rather than, through deliberately planning and separating the study of the problem itself (Lawson, 2006).

Lawson described his map as an attempt to make a simplified diagram (Figure 2.4) to understand an extremely complex mental process. Lawson's map emphasises the negotiation that occurs between the problem and solution. He stated that:

> The activities of analysis, synthesis and evaluation are certainly involved in this negotiation, but the map does not indicate any starting and finishing points or the direction of flow from one activity to another. (Lawson, 2006, p.48)

Lawson's phases of analysis, synthesis, and evaluation are necessary stages that also appear in Pahl and Beitz' s (2007) approach as the dense loop between tasks. These phases are neither separated nor arranged as a sequence; this is because they need inexorable interdependence. In addition, the design problem and solution should remain interlinked, because, "In design, problems may suggest certain features of solutions but these solutions in turn create new and different problems" (Lawson, 2006, p.118).

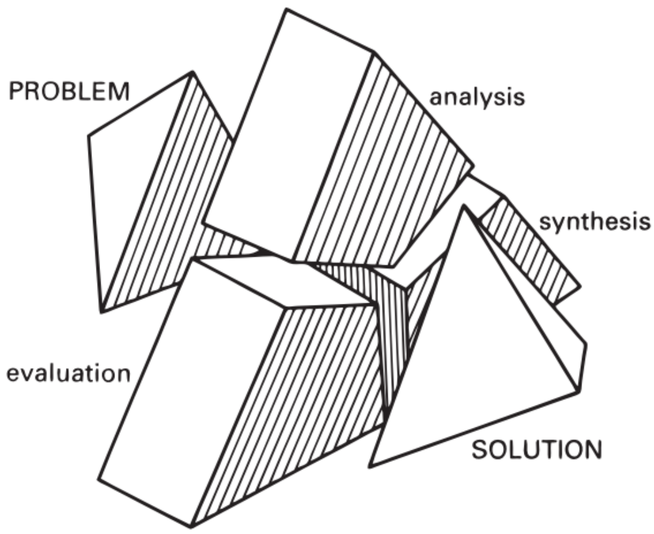


Figure 2.4: The map of Lawson's design process
(Source: Lawson, 2006)

Below are definitions associated with Lawson's design process map:

Analysis This involves the exploration of relationships, looking for patterns in the information available, and the classification of objectives. Analysis entails the ordering and structuring of the problem.

Synthesis This is characterised by an attempt to move forward and create a response to the problem – the generation of solutions.

Evaluation This involves the critical evaluation of suggested solutions against the objectives identified in the analysis phase.

Therefore, Lawson, and Pahl & Beitz's approaches involve many agents (Ralph & Wand, 2009) and collaboration as a team, can be summarised as a need to set the overall goal/goals and sub-goals to clarify the boundaries. As a result, constraints can be clearly defined and limitations identified which can enable the teams and stakeholders to perform in tandem. The objective decisions should be set as part of the project's boundaries to help the team consider the solutions that they have chosen. These outcomes, or combined solutions, should be fairly created and consider the alternatives without any prejudice in order to minimise the risk of any missed solutions between performances. Collaborative work can be promoted to co-consider and negotiate the best outcome (Laseau, 2000) from a wide variety of solutions. This can be enabled through the evaluation and decisions conducted in consideration of the goals, conditions, and objective decisions (Pahl & Beitz, 2007). Thus, design could be defined as:

> …consisting of a goal or including sub ideas, requirements, and environment under constraints is the creation of a design for which the problem and solution are reflected in each other and are intensively driven by analysis, synthesis, and evaluation (Pahl & Beitz, 2007).

Margolis and Stephen's (2011) define 'concept' as an abstraction or abstract object, which is a referent of something, whether an existing object in the real world or an idea. Abstraction is helpful in solving problems and means ignoring the details and incidentals in order to avoid fixating on the gathering of ideas to lead to a 'crux task' (Chueng-Nainby, 2010). Asimow (1962) noted that 'design' is a process; it is defined as the abstract-to-concrete progress of the creative concept (Asimow, 1962, cited by Chueng-Nainby, 2010). An abstraction process is relevant for a thinking process as it distances the idea from the object, such that concrete details are left vague or undefined in order to maintain simplification. Thus, a concept can be defined as:

1. The extension of a sub-process in the design, which is initiated by needs perceptions, intentions, and ideas. Furthermore, 'concept design' can be defined as

the process of developing a design from abstract to concrete ideas by ignoring concrete details.

2. The concept is defined as abstraction, which is used to design or solve problems by ignoring the details. ‘Concept design’ or ‘conceptual design’ can be defined as design thinking or the process of problem solving that enables the development of abstract to concrete ideas (without detail) when gathering ideas or finding solutions.

According to the above discussion, and within the context of this research, ‘concept design’ can be considered in both the initial stage of the design process and in the problem-solving phase performed by a collaborative team. The latter aims to develop creative ideas at the abstract-to-concrete level through a reflection on the problem and by solving the problem. This is intensively driven by analysis, synthesis, and evaluation, which helps to achieve a satisfactory outcome with a set of goals or sub ideas that consider the requirements and environment under the noted constraints.

2.3 Design Process

Modern design process models have been provided to support all designers in the AEC industry and to encourage individuals to work together so that they can become more productive in terms of efficiency, time and cost. This also considers the environment by reducing CO2 emissions and energy consumption. Each design process is unique; it can be represented as a number of steps, which depend on a project’s complexity and the strategies of each institute. The UK and USA will be explored in the design process models, methods, and procurement routes in order to build an understanding of each model. After that, the design process and methods in Thailand will be described to outline their current use. All cases will focus on and discuss the terms of conceptual design.

2.3.1 RIBA Work Plan in the UK

In 2017, construction contributed around £113 billion to the UK economy, comprising 6% of the total contribution (Rhodes, 2018). Rhodes illustrated that, in 2018, the UK construction industry created 6.8% of all jobs with the country, comprising around 2.4 million employment opportunities in the third quarter. Furthermore, the government’s strategy, Construction 2025, aimed to reduce both the initial cost of construction, the whole life cost of assets, the overall time from inception to completion, and greenhouse gas emissions from the built environment (Rhodes, 2018).

Since 1963, participants in AEC projects have considered many versions of the Work Plan. The latest published version is the RIBA Work Plan 2013, which was adapted from the RIBA Work Plan 2007 and arranged to fit with the CIC work stages (see Figure 2.5). There are some changes from Work Plan 2007 to Work Plan 2013, as all stages have subsequently been grouped into three sections, namely the design brief section, design section, and the construction section.

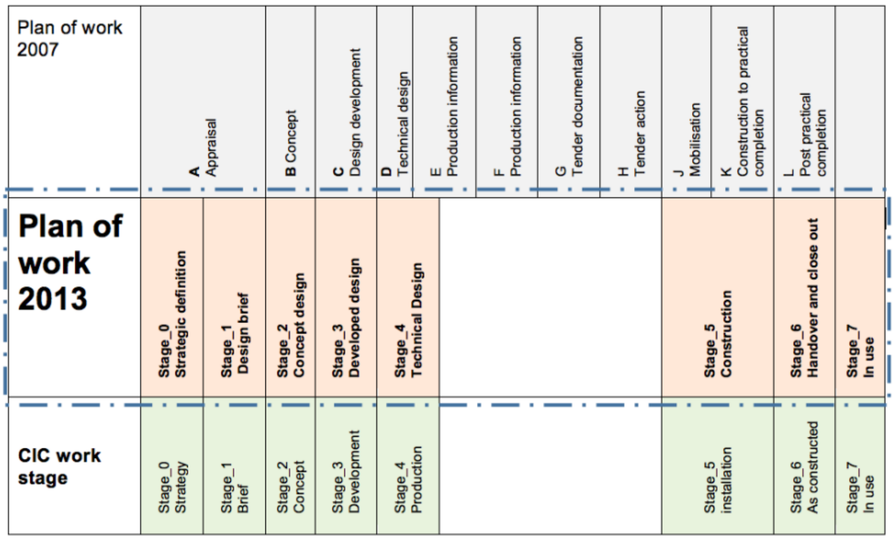


Figure 2.5 Comparison of the RIBA Work Plans of 2007 and 2013, and the CIC work stage (Source: Summarised by Researcher)

The activities in the RIBA Work Plan 2013 framework can be comprehended as three sections, and seven stages. Activities support the process at each stage through strategies, and are measured by the project outcomes (see Figure 2.6).

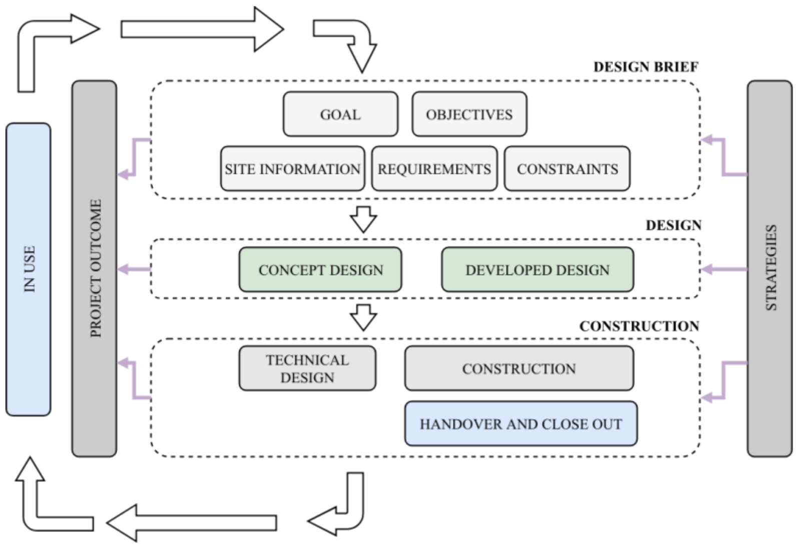


Figure 2.6 Summarising the RIBA Work Plane 2013 (Source: Summarised by researcher)

This framework supports projects using traditional and non-traditional project delivery and offers a feedback loop. Thus, the information regarding the building's performance and its post-occupancy can be delivered to the new projects and reflected in the project created by the design team through their future strategies. All strategies at each stage are established to enhance the design, construction, and activities of all stakeholders through its key contributors, which include all licenced architects, who totalled 34,300 licenced architects in 2014 (Mirza & Nacey, 2015). Thus, the project can be measured in terms of quality and quantity to reflect its achievement from design to in-use.

2.3.1.1 Design Brief Section: Stages 7, 0 and 1

A design brief section consists of three stages; however stages 7 (in-use), 0 (strategy definition), and 1, (designing brief stage), involve both general and specific information. Although in-use is the last stage of the Work Plan rather than a design or construction, it can deliver important information concerning a building's maintenance that aligns with the strategy definition at the initial stage of the RIBA Work Plan. In addition, both the strategy definition (stage 0) and the brief design (stage 1) shape the design information. This includes a vision or statement of need (the client's goal), plus the requirements, and environment for any design and development.

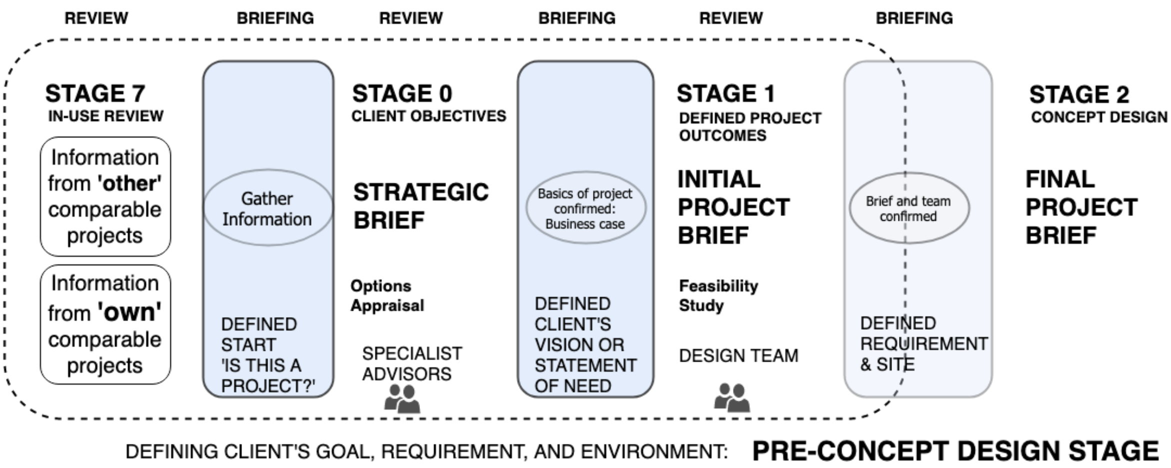


Figure 2.7 The Pre-Concept Design Stages
(Source: Fletcher & Satchwell, 2015)

Firstly, the in-use stage (7) gathers evidence and information on a building's performance, which is measured and understood by the physical performance of the project. This is then addressed by: refining and improving its effective performance; evaluating the building's performance and post-occupancy; capturing knowledge through research and development; and delivery at the strategy definition stage for the benefit of new projects or opportunities

(Fletcher & Satchwell, 2015). The operation and maintenance outcome impacts clients and users; thus, it builds an understanding of the project's environment in which individuals or groups live or work. The client is expected to be responsible for the task of operating and maintaining the built project at this stage.

Secondly, the strategy definition stage (0) aims to understand the client's strategic need and identify an aspect of the project, its potentiality, and the possible sites or identified locations. The key purpose at this stage is to develop a strategic brief; furthermore, the main focus is to develop and test a business case and to shape an idea and/or define problems to solve through a vision and strategic options. The vision and strategic options consider valuable information from stage 7, which is understood to improve and develop a project in terms of an existing system, design, procurement, and operation (Fairhead, 2015). From this, the client assembles an advisory team to determine the vision or statement of need. The independent client adviser may be an architect, surveyor, design advisor or another specialist who may also advise at future stages or only at this stage of the project. The advisory team typically involves the client adviser, project leader, and architect at this stage (RIBA, 2013). On smaller projects, the client can perform some, or all, of the key roles, whilst experts are needed for specific advice on more complex or large projects.

The next stage (1) of the design brief involves the intensive preparation of the initial project brief and all relevant information. It comprises of the project objectives and other parameters or constraints in a documentary format. It also includes feasibility studies and a review of the site information. A project vision and strategic brief are developed as part of Stage 0, which will be converted to clear project objectives and project outcomes. In addition, collaboration is developed between the client, client adviser, project leader, architect and cost consultant at this stage (RIBA, 2013). Moreover, the initial project brief involving the information exchange will be transferred to the next stage.

The gathered information concerning the building's performance and post-occupancy from stage 7 becomes significant when addressing or reporting results concerning design. This is returned to designers for the project evaluation. The information is assessed at the first stage of the RIBA Work Plan 2013 to generate a project's strategy at stage 0 when the client is assisted in defining the project. The client's vision or statement of need is identified, and other details are manipulated for the information exchange at stage 0 (the strategic brief). Then, the project objectives and project outcomes are developed to prepare for an evaluation and to test the strategic brief. The feasibility and site information are prepared so that program requirements can be completed at the next stage (the concept design stage). In addition, all information at this stage is included in the exchange within stage 1 (the initial project brief) for delivery within the next stage.

2.3.1.2 Design Section: Stages 2 and 3

A design section consists of stage 2 (the concept design stage), and stage 3 (the developed design stage). The concept design and the developed design stages involve the development from an abstract to a completely concrete idea (Knotten, Svalestuen, Hansen, &Lædre, 2015). Moreover, Bailey (2015) summarised from that an information brief, specifically the goal, requirement, and information site from the previous stage, becomes the resource for this section and a completely concrete idea will be prepared for next section (see Figure 2.8).

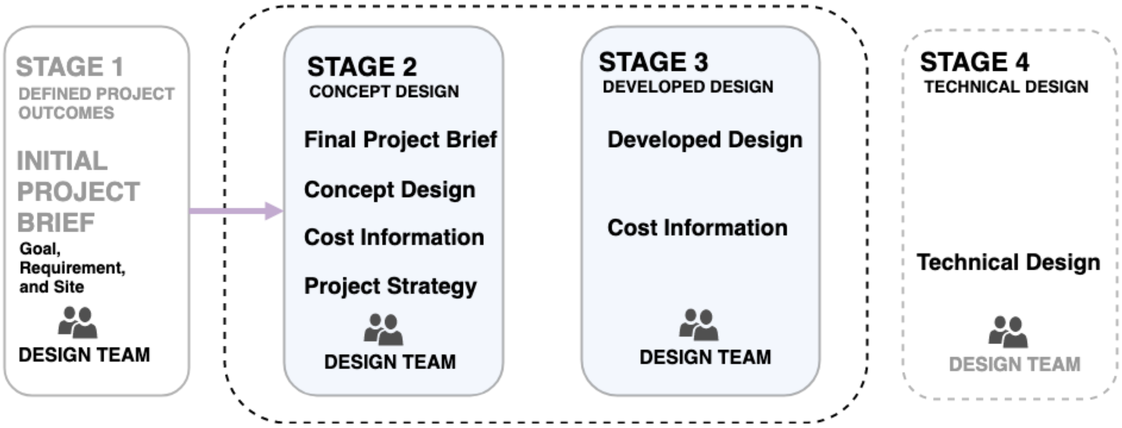


Figure 2.8 The Design Stage
(Source: Summarised from Bailey, 2015)

Firstly, stage 2 (or concept design stage in the context of the RIBA Work Plan 2013) involves the development of a concept design. This will be generated, developed, and eventually tested the context, including the site conditions, against the initial project brief. The concept design will be used in the decision-making process and within the investigation of each activity by the design team (Bailey, 2015). The design team comprise the client's adviser, the project lead, a lead designer, architects, engineers, a cost consultant, and a construction lead. In addition, the design team will develop the outline structural design, building service systems, and other information for delivery at the next stage. This includes the cost information, final project brief, and project strategies. In the concept design stage, creative ideas will be sufficiently developed to provide concrete ideas for communication and testing. Sometimes, the concept design can be loose, and exploratory and experimental without the exact scale or dimensions; however, it can be effective enough for the client brief (Bailey, 2015).

The next developed design stage (or stage 3) continues to develop the concept design and outlines the structural design and building service systems from the previous stage. The intention is to complete the design by the end of the stage. In addition, the cost information and project strategies will also be continuously reviewed and updated. At this stage, the developed design becomes more detailed and accurate than the concept design from the previous stage; thus, the design will be clearer in its scope (Bailey, 2015). Furthermore, the developed design and updated cost information are exchanged.

These ideas are created and developed in accordance with the strategies, goals, and requirements for testing within the environment and site conditions. Iterative designs can emerge in the process to solve any problems identified by team members, within the client commentary or from external advice (Bailey, 2015). After the client agrees the concept design, it is further developed in the developed design stage (or stage 2) and continuously developed to reach the complete design. The team members will use the coordinated design according to the dimensional fit and spatial compatibility between the elements of the project (Bailey, 2015).

2.3.1.3 Construction Section: Stages 4, 5 and 6

As shown in Figure 2.9, the construction section consists of stage 4 (or the technical design stage), stage 5 (or the construction stage), and stage 6 (or the handover and close out stage). The section sees the development of architect's technical details, building service, and structural engineering design, to complete the construction and deliver the building to the client (Holden, 2015).

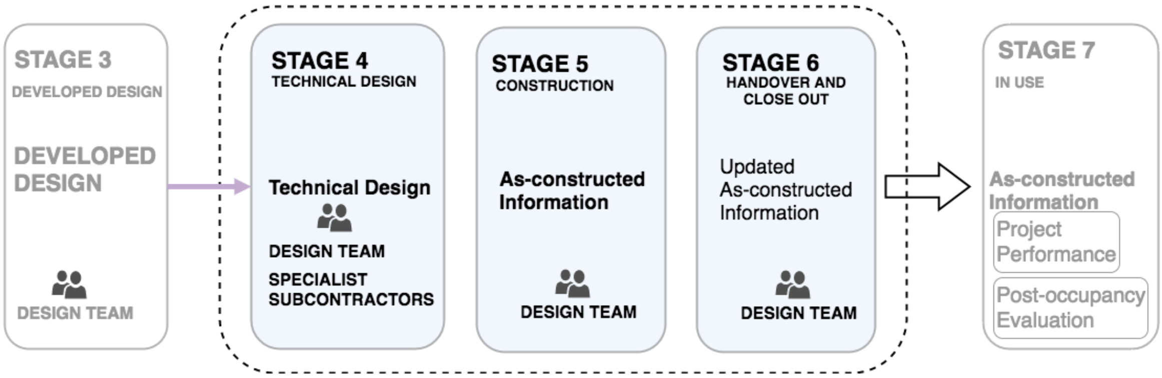


Figure 2.9 The Construction Section
(Source: Summarised from Holden, 2015)

Firstly, the technical design stage (4) is achieved by preparing the technical detail designs and specification information, which are produced by the design team and/or specialist subcontractors for the building construction (RIBA, 2013). This stage will have condensed the collaboration, which needs to clarify responsibilities, manage a schedule, and consider the documents, such as the tender, procurement and contract, in the development of information for the technical design (Holden, 2015).

Secondly, the construction stage supports the activities of the rest of the design team after the commencement of construction on site (Holden, 2015, p. 99). This aligns with the technical design information and the construction programme developed by the contractor. The design team inspects the work and deals with any design queries that emerge during construction. The quality and progress will be inspected against the contractor's construction programme and the design team will address any design queries arising from the site works (Holden, 2015).

Next, the handover and close-out stage (stage 6) is reached which aims to achieve a successful handover of the building to the client and complete the construction contract (Holden, 2015). The installed equipment will be tested, the service installations will be witnessed, and the constructed building will be investigated for quality compliance by the rest of the design team, namely the project lead, architects, building service engineers and cost consultant.

The construction design focuses on the technical design stage process (stage 4). Technical designs and specifications are created and developed to complete the information exchange of the technical design with the full engagement of the design team and specialist subcontractors. In addition, the technical design is prepared and submitted in accordance with the Building Regulation submission and other third-party submissions, which require consent for the construction phase. During the construction stage (5), the construction process is initially performed on-site from the technical design information and construction programme. This stage will support the use of offsite manufacturing and onsite construction processes in accordance with the construction programme and the resolution of design queries from the project site (RIBA, 2013). After the building is complete, the handover and close out stage (stage 6) commences which supports the inspection of the construction work, deals with the service equipment installation, and prepares the post-occupancy evaluation for the client to ensure it is ready for the in-use stage (stage 7).

2.3.1.4 Procurement Routes in the UK

The RIBA work plan is not a contractual document, but rather offers tools and supplementary core documents for use by project teams. It relates to professional services contracts, schedules of service and project protocols, and various common building contracts (Sinclair, 2013b). In the RIBA work of plan, procurement routes are a common form of contract, which includes traditional, design and build, and construction management contracts. The specific tendering and procurement activities can occur at each stage, from the concept to the technical design stages in relation to the chosen procurement route (Sinclair, 2013b). The contracts are developed at the stage 1 (or designing brief stage in the RIBA work plan 2013) for the chosen design team, whilst other contracts are developed between stage 3 (concept design) and stage 4 (technical design) for specialists, contractors, and other relevant job positions.

In 2012, a RIBA (2013c) members' online survey, explored and analysed the frequent use of common procurement routes; traditional, design build, and management contract. They found that the traditional or design-bid-build contract was used by 86 percent of the following common procurement routes which is more than design-build and management contracts. The design-build procurement route is second most commonly used route. Moreover, the single stage design and build was selected by 41 percent, whilst the two stage design and build was chosen by 39 percentage. The least commonly used amongst the sample was the management contract, which was only selected by 18 percent (RIBA, 2013c).

2.3.1.4.1 Traditional contract

The traditional contract is a sequential process of appointment and the preferred option for customers when a project's financial value is not a significant large amount (Towey, 2013). The customer usually appoints an architect to prepare a concept design and a consultant quantity surveyor/cost manager for the preliminary cost advice; after this, the design team is set up.

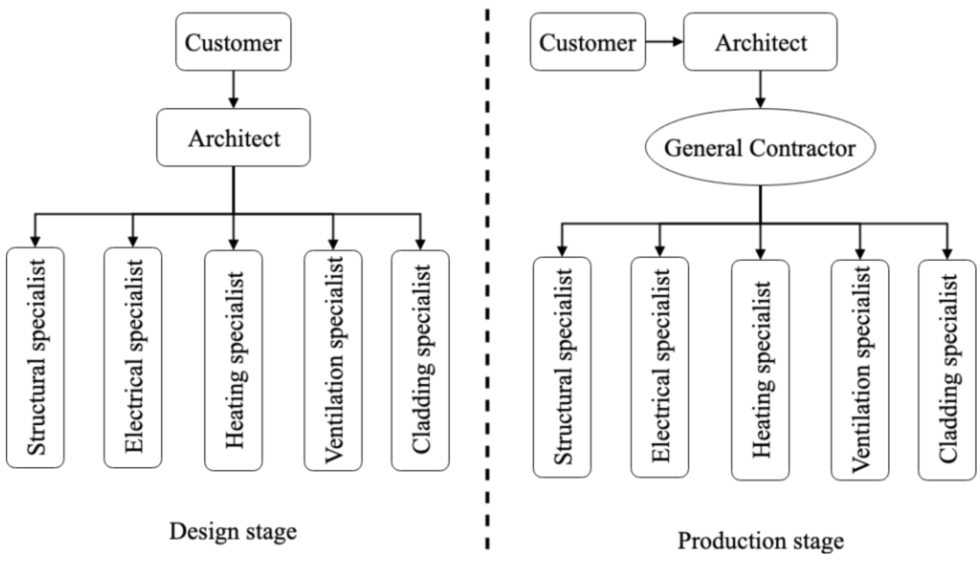


Figure 2.10 Traditional contract in the UK
(Source: Radosavljevic & Bennett, 2012, p. 128)

Traditionally, the architect plays a role in controlling all design details and works with specialist construction companies. Their knowledge and skills help to guide the architect in producing practical design details (see Figure 2.10 left). Then, the specialist construction companies are rewarded for their work outing as a design consultant with a word of the contract to carry out the required works (see Figure 2.10 right) (Radosavljevic & Bennett, 2012). Radosavljevic and Bennett (2012) noted that this approach requires the specialist construction companies to undertake design on trust, based on the expectation that they will subsequently be employed to carry out the production work.

2.3.1.4.2 Design and Build

Design and Build is a procurement route that emerged following interest from customers in 1980s. Within this route, a design is first initiated after which the construction is carried out; this is often used for commercial projects, such as factories, warehouses, and office buildings. The approach avoids the fragmented set of relationships and promises greater certainty in terms of quality, time and cost (Radosavljevic & Bennett, 2012; Towey, 2013). Its advantage is security in relation to time and price, but its disadvantage is that the customer cannot check a priced bill of quantities or the developing design. Moreover, they cannot monitor the construction phase but instead work with a degree of entrusted faith (Towey, 2013). Nevertheless, this approach is often judged to be more efficient than traditional construction.

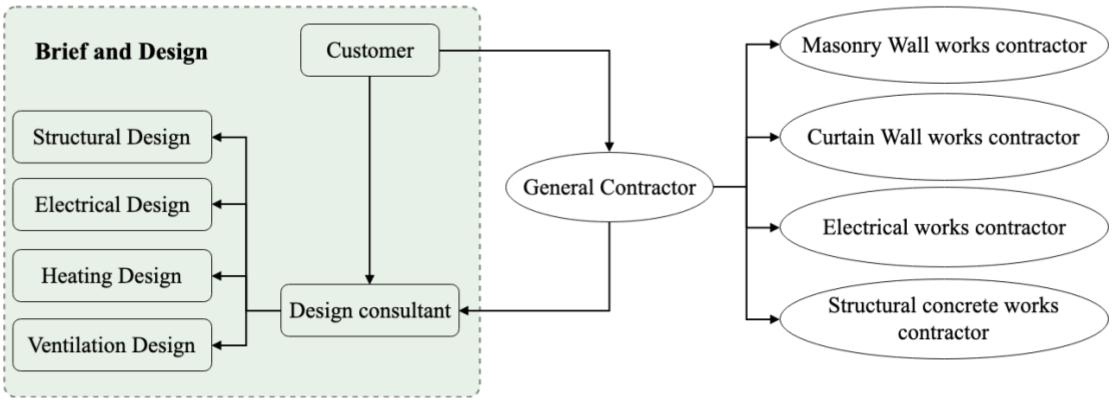


Figure 2.11 Common Design and Build approach in the UK
(Source: Radosavljevic & Bennett, 2012, p.140)

A design consultant is widely used who takes over the employment of the customer's consultants as a selected contractor. They produce the brief and design so that the customer understands their new building and receives realistic estimates of the cost and completion date. Then, a general contractor is selected, who acts as a design build company. They develop the design and provides the customer with a single point of responsibility for the completion of the project. The consultants work with the design build company to complete the design details (see Figure 2.11). Nonetheless, Radosavljevic and Bennett (2012) pointed out that the outcomes tend to be dogged by muddled responsibilities among the consultants and contractors. Furthermore, this approach generally provides poor outcomes for relevant stakeholders; it is typically known as the “two stage-design and build”.

Develop and Construct represents another approach (Radosavljevic & Bennett, 2012), and is otherwise known as the ‘one stage-design and build’. After the customer and consultants decide on the exact kind of building required, a design build company is employed following negotiation or competitive bids and takes direct responsibility for completing the brief and design (see Figure 2.12).

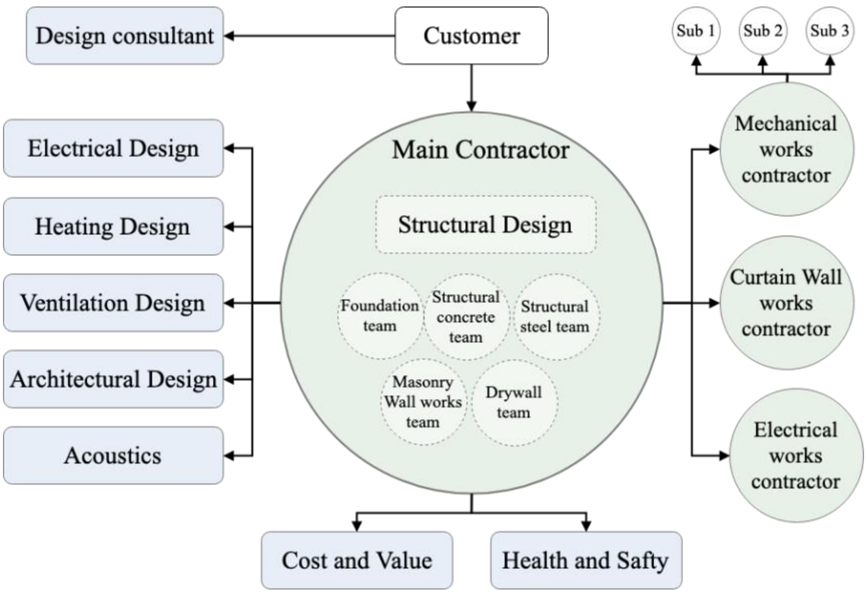


Figure 2.12 Develop and Construct Approach to Design and Build
(Source: Radosavljevic & Bennett, 2012, p.141)

According to Figure 2.12, the company carries out all subsequent stages of the project, does not take over the employment of the customer’s consultants, and directly employs staff or selects their own choice of design consultants and subcontractors to undertake the project to an agreed cost and completion date. The design build company employs all the knowledge and skills required to undertake a construction project. This is based on evaluation of the risks, effectiveness, market conditions and many other factors. The customer’s consultants keep track to ensure the company meets their contractual commitments.

2.3.1.4.3 Construction Management

The Construction Management route became popular in the 1980s and is used to control and enable work from the beginning of a design to the end of construction in order to ensure the best value against price and delivery (Towey, 2013). It is suitable for complex or large projects where the customer wants high-quality architecture that may run for a long period, and with a significant financial value. The key characteristic of this route is the pack of contract pack, where each trade package contract is agreed between the customer and trade contractor (see Figure 2.13). The customer is responsible for reimbursing each trade contractor; thus, construction management only acts in a control and supervisory capacity without contractual links with the trade contractors. The construction management will therefore make a recommendation to the customer when the trade contractor's requests for payment is received. A construction management company becomes the contractor for a project and provides leadership by establishing the overall objectives of a project, selecting companies to provide the design and management teams in order to plan and control quality, time, and cost, and by arranging the finance. The management team work closely with the customer and designers to ensure the designs can be manufactured at time and cost that meets the customer's requirements.

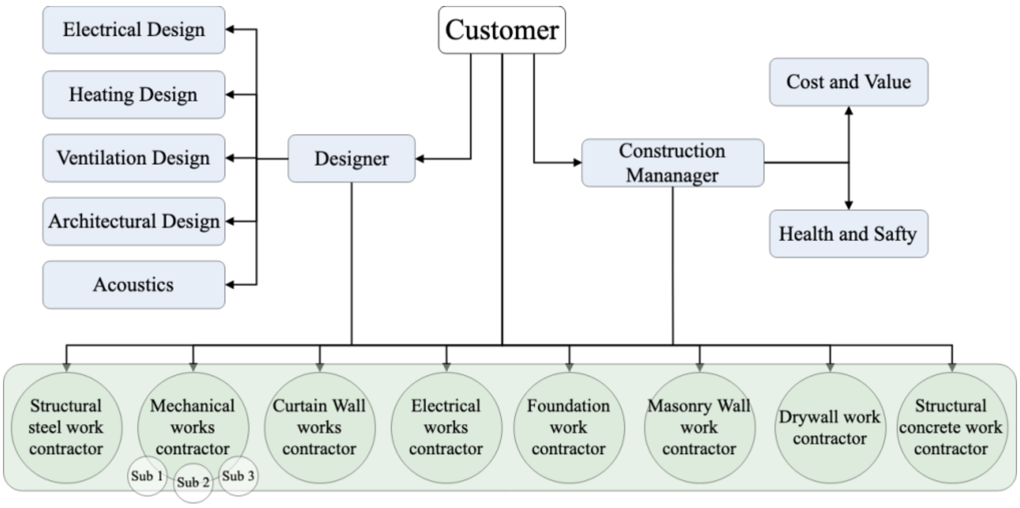


Figure 2.13 Construction Management Organization
(Source: Radosavljevic & Bennett, 2012)

An experienced architect who works with the customer and construction manager leads the design team. This approach differs greatly between the USA and UK. In the USA, the architect leaves much of the detail design to special manufacturing and production companies. However, in the UK, the architect remains involved and responsible for the detail design. Radosavljevic and Bennett (2012) state that this represents the strength of the best UK buildings, which have a real depth of quality and qualify as great architecture. Radosavljevic and Bennett (2012) noted that all the key teams have a direct contractual relationship with the customer rather than each other, and this is a distinctive characteristic of the UK construction management approach (Oyegoke, 2001). The customer, designer and construction manager consider alternative design concepts and construction technologies together so that the schematic design and project plan are agreed and thus meet the best customer's requirements. From this basis, the works contractors are selected through competitive bids to produce the detail design.

Nevertheless, there is also a variant of construction management, namely construction management at risk. This approach allows for a guaranteed maximum price (GMP) for the manufacturing, production and commissioning to ensure that the design and the new building are completed and produced within the guaranteed maximum price. The construction management at risk company employs subcontractors in cooperation with the customer and design team, and manages the manufacturing, production, and commissioning. The customer pays all costs up to a limit set by the guaranteed maximum price, which is managed through the 'construction management at risk' company. The principle advantage is that the new buildings are also produced faster than in traditional construction procurement (Radosavljevic & Bennett, 2012).

2.3.2 Project Delivery in the USA

Between 1999 and 2015 in the USA, both residential and non-residential construction investment varied. It comprised 9.4 percent of the real gross domestic product (GDP) in 1999 and 5.1 percent in 2010 and 2011. Furthermore, in 2015 and 2016, construction investment totalled 6.2 percent of USA GDP (Markstein, 2017). Moreover, O' Brien (2014) illustrated that employment in architecture and engineering increased from its earlier peak at 1,245 million people in 2003 to 1,469.4 million in 2009. After this point, it dropped significantly to 1260.8 million in 2008 but gradually increased to 1,376.6 million between 2013 and 2014 (O' Brien, 2014). Furthermore, the Survey of Architectural Registration Boards reported that the number of architects licensed in the USA rose to 113,554 in 2017 (NCARB, 2018).

According to the American Institute of Architects (AIA), project delivery services have been developed since the 1970s, since the launch of the first traditional delivery approach or 'design bid build'. At this point, construction management was used for large construction projects, such as hospitals and airports which needed to operate and plan beyond design and construction. 'Design build' became one solution to deal with inefficiencies in the design-bid-build process and brought design and construction professionals closer together to work under a single contract with the owner. Furthermore, in 2007, Integrated Project Delivery was launched by the AIA and AIACC (American Institute of Architects, California Council); this proposed an efficient approach to project delivery (AIACC, 2007). Both of these models are explored to outline how they can be adopted.

2.3.2.1 Traditional design process and Methods of Project Delivery

According to the American Institute of Architects (2014), a design service standard is defined according to two groups within the AIA Document B101TM–2007. Generally, there are six phases of project delivery. The first entails additional services, which include the pre-design phase and post-construction phases. Another is a series of five phases (traditional design process), which includes the following (AIA, 2014):

1. **Pre-design:** This involves the optional services of the project delivery phases. Almost all customers have a need for design consultation prior to the development of a schematic design. Goals and visioning sessions, scenario planning, strategic planning, master planning, project definition, site selection, feasibility studies, cost estimation, programming and other activities are required for the customer. The programming becomes an important tool for the next phase of design (AIA, 2014).
2. **Schematic design:** This is the first project phase to understand and synthesise design information and establish the goal and generative logic of a project so that the information can be used for subsequent phases. The preliminary system concepts (structural, mechanical electrical, and enclosure systems) are analysed, project objectives are developed, the environment is studied, the ground rules are understood, and the concept proposals are developed. In addition, sustainability issues are established during this phase. This phase begins to explore alternatives, which will judge the design that best meets the need of the project objectives. The schematic design of the project determines its size, scale, scope, and site orientation. By the close of this phase, the site plan, floor plan, elevation, preliminary construction cost, and relevant information are produced for development in the next phase (AIA, 2014).
3. **Design development:** The second phase begins to review the project goal, priorities, and generative logic established in the schematic design, and may refine the design solutions and the project cost to continue the design process. The size, scale, and scope of the project are refined, and the building systems are determined and integrated. Sustainable building strategies are identified, and key building details are developed.

The major building materials are chosen and considered in terms of their specifications and performance requirements. The construction cost estimate is updated on the current project design. The outline specification develops a summary of the technical specification for review and comment. The outcomes of this phase are similar to those provided at end of the schematic design, but far greater detail is included. Finally, all the documentation describes the integration of the building systems and the coordination with allied consultants (AIA, 2014).

4. **Construction documents:** All outcomes and documentation are fully detailed and specified during the construction document phase including drawings, reference documents, technical specifications and contractual administrative requirements for the project. Technical specifications will be completed for all building products and systems and a detailed cost estimate will also be updated to ensure the project remains 'on course'. In addition, bidding documents will be created for contractors during this phase. At the end of this phase, the documents are complete for the construction contractor to consider the price of the project construction (AIA, 2014).
5. **Permit, Bidding and negotiation:** Designs and documents are given to the contractors who will negotiate with the owner, or owner's representative, to make a final selection before the beginning of construction (AIA, 2014). The completed design and documents require authorisation.
6. **Construction:** The contractor specified within the contract must involve the registered architect during construction to ensure a professional seal. The AIA documents require the architect to visit the site at appropriate intervals throughout the construction phase. The design architect provides the contract administration service, which is the final agreement for execution after the contractors are chosen. It includes the drawings and technical specifications, and becomes the legal contract used to fulfill key contractual responsibilities during construction (AIA, 2014, p.663). The contract administration helps the owner to understand the importance and associated benefits of having the architect-on-record involved within the construction phase, and update the owner. During construction, the architect communicates directly with the owner, consultants, and contractor, whilst they deal indirectly (through the contractor) with the subcontractors. In comparison, the owner's consultants will only coordinate with the architect and contractor, whilst the owner indirectly communicates with the contractor.
7. **Post-construction**: When the construction phase is completed, the traditionally post-occupancy evaluation and building commissioning are offered in the post-construction

service which is an optional service. However, more services are increasingly offered after construction, including maintenance scheduling, space planning, renovations, energy analysis and monitoring, disaster planning, tenant improvement, forensic analysis, code analysis, and space scheduling.

The USA construction industry, as a whole, has operated through the design-bid-build method for a very long time. A 2011 RSMeans Reed Construction Data Market Intelligence report analysed the use of the design-bid-build method, the design-build method, and CM at Risk from 2005 to 2010 (AIA, 2014).

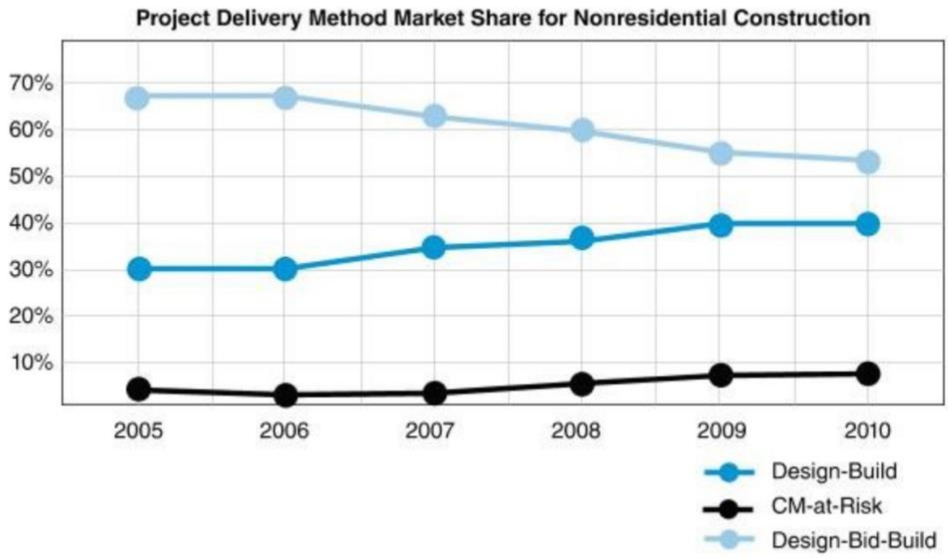


Figure 2.14 Project Delivery Method Market Share for Non-residential Construction in the USA (Source: AIA, 2014, p.554)

According to Figure 2.14, the AIA found that the design-bid-build method was popular and in 2010 was used in more than 50 percent of non-residential construction projects. Moreover, this represented a 10 increase since 2005, when the same method was used on more than 40 percent of projects. In comparison, CM at Risk, it was used on less than 10 percent in 2010, which was a slight increase from 2005 (AIA, 2014). However, the AIA (2014) claim that the design-build approach is intended to represent best-value in that it considers the combined design and price alongside trade-off, risk, and decisions.

These delivery methods (or primary methods), namely design-bid-build or traditional, construction management, and design-build delivery, can be considered the basic methods of project delivery. These delivery methods are options (AIA, 2014, p. 516) as follows (see Figure 2.15):

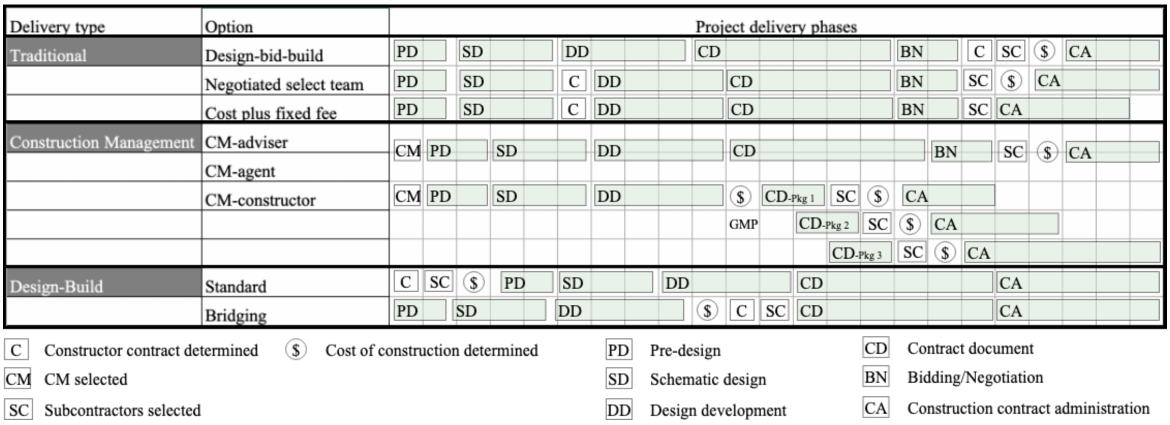


Figure 2.15 Sequence and Project Delivery Methods in the USA
(Source: AIA, 2014, p.516)

2.3.2.2 Design-bid-build or traditional type

The traditional project delivery method is often considered the base delivery process. It is the most prevalent approach for construction projects in the USA construction industry. There are generally three options, which are: design-bid-build, negotiated select team, and cost-plus fixed fee. These follow a similar arrangement of phases, from pre-design to construction, but differ in detail.

The first is “the design-bid-build” approach, which is a linear design sequence and offers the owner a market of open competition through separate bid and construction phases. Initially, the customer begins to enter into a contract with an architect for their design service and can work with designers to develop their project requirements in the pre-design phase, which is an additional service. Moreover, this can continue from the schematic design to the construction document phase (AIA, 2014). The architect and engineering companies work together to complete a full set of design documents (Lahdenperä, 2001). The customer selects a constructor for the project after the biding/negotiation phase, following which the subcontracts and cost construction are determined before construction commences (AIA, 2007) (see Figure 2.16). In practice, the cost control is not as certain as it would appear to be, time is difficult to control, and an adversarial relationship between the architect and constructor can easily arise with the customer caught in the middle.

A variation of the design-bid-build is ‘the negotiated select team’ approach, sometimes called the ‘design-assist’ approach, in which there are separate contracts for the design and construction. The customer selects the architect and informally chooses the constructor; moreover, they negotiate the cost of each under a separate contract. It is common for the customer, architects, and constructors to work together regularly. Design and documentation are completed by the architect and the contractor often provides scheduling, cost estimating, phasing and system evaluations. This method allows the constructor to advise on materials, methods, systems, and costs during the design phase and, when design is complete, the final construction cost is negotiated through bids from the constructor's subcontractors (AIACC, 2014a). The customer can require the constructor to provide multiple bids for each subcontract within the project to ensure that competition is considered in the cost before the construction phase is started. Nevertheless, the AIACC (2014a) outlines the advantages and disadvantages of this approach. Its advantages are that: parties are encouraged to work together; the construction expertise is available for input during design phase; there is generally a reduction in the adversarial relationship between the designer and constructor; and there is less potential for litigation. In contrast, the disadvantages are that: there is less competitive bidding from the general contractor and the process can be confusing due to the ambiguity amongst roles, responsibilities, and phasings between the architect and the constructor (AIACC, 2014a).

Another variation of the traditional approach is the 'cost plus fixed fee'. This process is similar to the negotiated select team approach but pays actual labour and material costs, plus the overheads for construction for the coordination of trades on site. In addition, a fixed service fee is paid that disconnects the contractor's profit from any increase in the project costs, and the added incentives fee is only paid if the project is finished early or under the original budget.

2.3.2.2.1 Design-build type

This delivery method provides the customer with a single-point responsibility for both the design and construction. For this type, there are two common variations; "Standard design-build" and "Bridging design-build" (see Figures 2.15 and 2.16).

Firstly, the standard design-build is a form of project delivery in which the customer contracts with a single entity to provide both the design and construction services. The design-build entity may be a single firm, a consortium of experts, or a joint-venture undertaking, which typically includes an architect and a contractor who may be partners or one subcontractor. This involves a single contract that includes a fixed price for both the design services and construction cost. The architect enters into an agreement with the designers and the contractor through 'design-build agreements', which share responsibility by forming a single party for all design and construction services. Before the design process begins, all parties are selected, and the construction cost is determined. The AIACC (2014a) describes its advantages and disadvantages:

1. The advantages of the standard design-build are:
    a. A single point of responsibility which minimises the owner's risk in order to reduce the likelihood of changes to orders, and also reduces construction delays;
    b. The potential to assemble otherwise independent phases and save time.
2. The disadvantages of the standard design-build are:
    a. The complexity of the method,
    b. A lack of direct connection between the customer and architect, and
    c. The potential for cost-saving strategies to negatively affect the quality of the design and construction (AIACC, 2014a).

Another variation is 'Bridging design-build', which is derived from project teams. It includes both a design architect, who creates the design concept, and a production architect, who determines technical elements and generates the construction contract documents in design-build team. AIA (2014) state that these designers work in concert to develop and execute the design in two parts. Firstly, the architect prepares a preliminary design for the building and establishes detailed criteria, which are typically based on the design development drawings and specifications. The design architect plays an advisory role to the owner by reviewing and critiquing the design and construction based on the design and criteria package. After that, the technical architect in the design-build team provides detailed technical documentation for construction, when the completed design concept and criteria package are passed to design-build team who provide both the technical architectural and construction capabilities (AIA, 2014). This method helps the customer to achieve their goal and meet their expectations, whilst a full set of drawings and specifications are given to the design-builder to continue the process. AIACC (2014a) outlined the advantages and disadvantages of this approach:

1. The advantages of the bridging design-build are:
    a. The design issues remain the focus of attention,
    b. A competitive bidding process is used to ensure cost effectiveness, and
    c. A single point of responsibility is maintained during the design documentation and construction phase, which may change between the design documentation and construction phases.
2. The disadvantages of the bridging design-build are:
    a. Its complexity,
    b. A lack of extensive management by the customer,

c. Possible conflicts between the customer's architect and the designer-builder, and
d. The potential for short-term cost-saving strategies to outweigh the quality of the building and construction (AIACC, 2014a).

2.3.2.2.2 Construction management

When projects are larger and more complex, and customers demand detailed and technically advised construction earlier in the design process (AIA, 2014), the construction management method becomes an appropriate choice. This approach helps to manage the budget or schedule, which must be closely monitored, alongside the extensive coordination of consultants, subcontractors, or technology. Construction management (CM) is therefore appropriate for public and private projects of almost any scale as it can better oversee such elements as schedule, cost, construction, project management, or building technology. The Construction Manager may have a background in architecture, contracting, engineering, or development, thus they may be trained in a range of diverse areas; moreover, CM is not a licensed activity in the USA. Nevertheless, a Construction Manager can serve in different capacities, depending upon how the project is structured. They can adopt different roles depending on project need (see Figure 2.16); for example, as advisor to the owner (CM as Advisor), as the owner's agent (CM as Agent), or as the builder (CM as Constructor) (AIACC, 2014a).

When the Construction Manager adopts an advisor role (CM as Advisor or CM-Multi-Prime), they will not build the building. Instead, the CM provides constructability services and cost management consultancy to the customer during the design and construction process (AIA, 2014). The customer selects the CM, architect, and constructor in the design process, from pre-design to biding/negotiation; then the subcontractors are selected in consideration of the project's cost. Finally, the sub-contractors construct the project whilst the CM oversees the building process. AIACC (2014a) noted the advantages and disadvantages of the CM approach. Its principle advantages are: the direct contractual relationships between the customer and the architect and builder; the careful monitoring of costs and schedule; and the ease in which the owner can manage the continuous oversight of the process. In contrast, its disadvantages are: the added cost for the consultancy service; confusion regarding traditional roles, particularly when the customer receives advice from more than one source; and potential ambiguity over the CM's authority to make decisions. The latter can result in an extended process due to the time needed to select a CM and the lengthened chain of communication; this can mean more complex relationships among the parties.

In comparison, the Construction Manager as Agent (CM as Agent) provides early consulting service and may assemble and coordinate the construction trades prior to, and during, construction. Within this approach, the CM provides their service for a fix fee and assumes no risk for the actual construction costs but passes on both savings and overruns directly to the customer (AIA, 2014). This process is similar to the CM as Advisor and it is appropriate for absentee customers and/or private customers who do not intend to be involved in the day-to-day responsibilities of the design and construction. AIACC (2014a) noted the following advantages: it gives customers a single point of responsibility; the process is easy for customers to track; and the management expertise of the customer's agent can shorten the project timeline. However, its disadvantages include: increased cost and time in selecting the additional consultant; the suppression of direct communication between the customer and architect or contractor; and the overlapping roles of the customer and CM, which can complicate decision-making and communication.

Another approach is the Construction Manager as Constructor (CM as Constructor), which is also known as the 'Construction Manager at Risk'. This includes the use of a 'guaranteed maximum price (GMP)' which means an evolving cost target for the project; the GMP is sustained throughout construction in order to maintain flexibility with the customer about the final cost of the project (AIA, 2014). Typical characteristics of the CM at Risk approach include overlapping phases, design and build (fast track), and the presence of a construction manager who is hired during the design phase. The CM works as both a contractor and estimator, as cost decisions which are made early in design affect the CM's cost (and profitability) later in construction. The CM-constructor may be hired by bidding in order to deliver the building for a guaranteed maximum price or by creating multiple bid packages (AIACC, 2014a). This method has separate contracts for the owner-architect and owner-CM at Risk whilst there is no contractual relationship between the architect and constructor, as in the Design-build delivery type (see Figure 2.16). AIACC (2014a) detailed its advantages and disadvantages, which are as follows:

1. The advantages include:
    a. An initial focus on design issues,
    b. Construction advice during the design process,
    c. Careful oversight of cost and schedule,
    d. Early cost commitments, and
    e. Opportunities to shorten the overall project schedule.

2. However, the disadvantages entail:
    a. The potential for adversarial relationships, and change orders, and delay claims from the customer, plus low-bidding prime or sub-contractors,
    b. The reduced ability of the owner to control construction quality, and
    c. The CM role is not licensed in the USA (AIACC, 2014a).

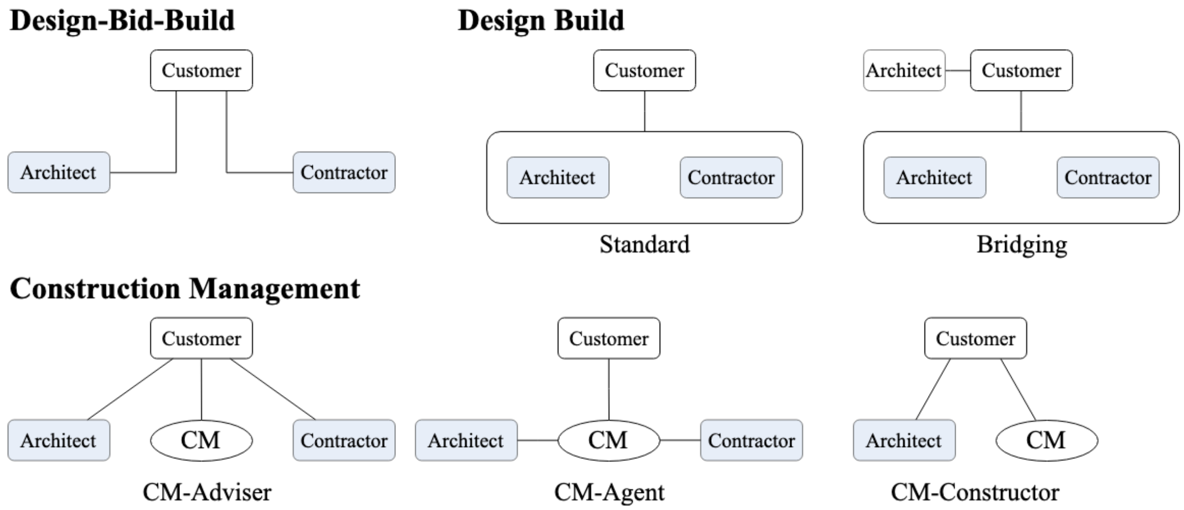


Figure 2.16 Relationships of Project Participants in Project Delivery methods (Source: AIA, 2014a)

2.3.2.3 Integrated Project Delivery (IPD)

Matthews and Howell (2005) presented the IPD concept to resolve the systemic problems of traditional contractual approaches from a construction project's contractual structure and setting. Thus, the primary team consists of the architect, key technical consultants, a general contractor, and key subcontractors who deal with problems and completely share the responsibility for the entire project. They have a single goal and no competition amongst themselves for profit or recognition (Matthews & Howell, 2005). The American Institute of Architects (AIACC, 2007, p.2) defined IPD as:

> … a project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction.

In addition, AIACC (2014b) defined the Integrated Project Delivery method stating that, at a minimum, it should consider:

- The continuous involvement of the owner and key designers and builders from the early design through to the project completion;

- That the business interests are aligned through shared risk/rewards, including the financial gain/risk that is dependent upon project outcomes;
- Joint project control by the owner and key designers and builders;
- A multi-party agreement or equal interlocking agreements; and
- Limited liability among the owner and key designers and builders.

2.3.2.3.1 Agreements of Integrated Project Delivery

An IPD approach to agreements aims to create and structure the contractual relationships among participants involved to jointly share in the achievement and failure of the project. They commit to a single agreement under which there are multi-party and poly-party contracts (AIA, 2014a). The customer becomes one of the relevant participants in the IPD process. Moreover, Fischer, Khanzode, Ashcraft, and Reed (2017) defined the sub-division of agreements types into the following:

- **Multi-party contract**: This is an approach to bind the owner, primary designer, and contractor on the ground of risk/reward, whilst sub-agreements are added for subcontractors and consultants. Some consultants and subcontractors who are outside of the risk/reward group can be contracted traditionally and aligned with the primary designer and the contract. The consultants and subcontractors must jointly make decisions with the aligned party.
- **Poly-party contract**: This brings more team members into the shared risk/reward group to sign a single IPD agreement. This can be set up at the beginning and/or via sequential arrangement, which can be added through agreements. All participants stand on an equal contractual footing, including the customer, architect, contractor, trade contractor, and consultants, with the intention of improving communication and commitment among all participants. This is similar to the multi-party contract in that the parties outside the risk/reward group can still sign traditional consulting agreements with the prime designer or contractor (Fischer et al., 2017).

2.3.2.3.2 A Roadmap of Integrated Project Delivery

The Integrated Project Delivery approach is useful for all project sizes. Moreover, IPD is typically appropriate for hospital building types because the owner is familiar with the construction, its complex building systems, and existing technologies. The approach can also be used with other building types, such as commercial and institutional projects; thus, IPD might be suitable and useful for any project – small or large, simple or complex (AIA, 2014a).

The value, goal, and end users are paramount in enabling the design and construction team to understand the users' goal and vision for building. Integrated Project Delivery is usually adopted to meet the requirements of high-performance buildings (HPB), which are:

- **Usable:** A building must support the core function of the building and its occupants and enable the most effective use of layout, flexibility, and atmosphere.
- **Buildable:** It must be safely assembled, comparatively easier to assemble within the time, materials, and cost available, and constructed using the best available methods and practices.
- **Operable:** All operations and maintenance requirements are considered early on during the design phase. It must gather all systems and be easily maintained and fixed to enable the building manager to create the right environment for the occupants.
- **Sustainable:** It must work in harmony with the natural, social, and economic contexts, allow the client's management team to sustain its business, reduce waste, and manage both the environmental impact and disposal cost. In addition, it must be less costly to operate and enable owners to remain competitive (Fischer et al., 2017).

These criteria are aggressive performance goals that need to be achieved within the IPD process through the integrated components of information, organisation, process, and systems (see Figure 2.17). Fischer et al. (2017) further defined the following criteria:

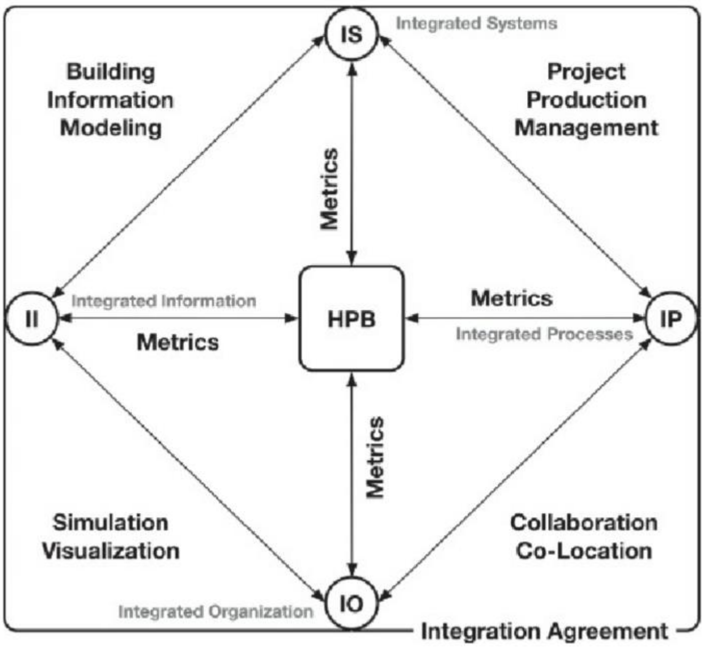


Figure 2.17 The components of an integrated component (Source: Fischer et al., 2017)

1. **Integrated system (IS):** All systems are combined within a building to work together in harmony. These systems are often complex and specialised, such as air-conditioning (HVAC) systems, lighting, medical gas systems for hospitals, or an exterior building skin system that affects the construction and the building performance costs. The integrated team needs to build the model to predict the behaviour of the building systems and consider its usability, such as the simulation of the inside building temperature. The key challenges are to ensure a comfortable space (usable) that is affordable (buildable) with foreseeable circumstances (operable) and consuming as little energy as possible (sustainable).
2. **Integrated process (IP)**: Within this approach, project team members must work together and take multiple, integrated criteria into account. This includes the energy consumption, structure of the building, the aesthetics, and natural light or air ventilation. Professionals, namely architects, mechanical engineers, interior designers, and workflow specialists, must all give their input to the final design if the system is to work together. In this integrated process, four main stages of the building's life cycle are considered in enabling collaboration among the customer and relevant professionals. These stages are: 1) definition of user value, 2) design, 3) building, and 4) operation. First, the customer and designers must work together through many iterative designs until each party can clearly meet the value and goals of the project. Then, the design is provided in greater detailed at which stage engineers, subcontractors, and other parties must be involved to complete the end design and meet the established goals. Finally, the end design must be built and in operation.
3. **Integrated Organisation (IO)**: The 'right people' means that every discipline needs to work together to share common goals, knowledge, and experience; these are important alongside the openness to work together as an integrated team. The key understanding is 'for the good of the project' thus everyone must understand that the project is the main focus, and should be considered before the interests of an organisation or individual. Parties have to be empowered and trusted to be responsible for their own work and for that of the team as a whole.
4. **Integrated Information (II)**: This means that project information needs to be organised and made readily available to all project participants. Integrated information can avoid scattered information, different formats, information located on different

systems, and out of date information. It is critical to overcome silo issues and address information that is not understandable to other project participants. Therefore, integrated information becomes the central, neural system of an integrated project delivery (Fischer et al., 2017).

2.3.2.3.3 Integrated Project Delivery Phases

A set of seven IPD phases can be compared within the traditional design process (see Figure 2.18). Integrated Project Delivery requires all parties to optimise design solutions, increase efficiency over the building's lifetime, or to provide a fast-track schedule and higher performance so that the decisions made consider the best outcomes for the project, rather than individual interests. The IPD phases are framed without additional service phases; thus, they differ from the traditional phases in that they take advantage of two critical factors. Firstly, they consider design and construction expertise, which are expected throughout the design process, from conceptualization to closeout. Secondly, Building Information Modelling (BIM) tools and processes are adopted to enable the team to integrate in order to provide effective support for design decisions (AIACC, 2014b). The IPD phases are as follows:

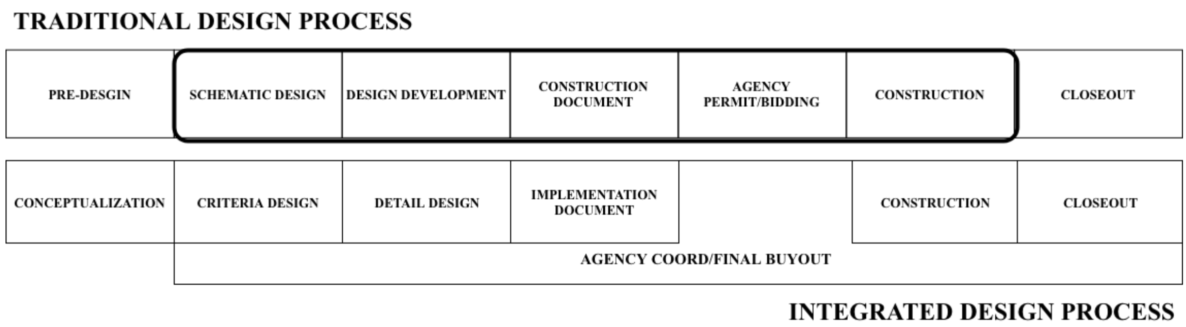


Figure 2.18 Comparison of Traditional and Integrated Design Processes in the USA (Source: AIACC, 2014b)

1. **Conceptualisation:** The first phase begins to assign the design built. The key stakeholders are the owner, designer, designer consultants, and builders. The stakeholders are involved in the programming process. They gather key project parameters, such as size, schedule, sustainability/green criteria or goals, performance metrics (economic, energy, maintenance efficiency, operational, etc.), an initial cost structure, and the preliminary schedule.
2. **Criteria design:** The project defines its scope and design in basic detail, including massing, elevations, and floor plans. The basic design becomes an important resource to develop target costs, an overall schedule, the building components for prefabrication

and the sustainability targets. In this phase, all key trade contractors are engaged in the basic design. A procurement schedule is developed, and a cost structure is refined that enables the team to use the cost information to guide the design.

3. **Detail design:** The detail design phase is longer and more intense than for traditional design development. All problems are expected to be resolved during this phase to ensure that changes during construction will not cause issues and, as a result, the design will be fully completed and without ambiguity. All building elements are defined, such as the building systems and specifications. Moreover, all building systems are designed and coordinated in this phase. This is a key advantage of IPD, which allows for the coordination of the final system. In addition, specifications are developed to follow agreements and prescribed systems.
4. **Implementation document:** This phase focuses on the creation of all relevant documents to describe how the completed design of an entire building and all its systems will be implemented. This phase is shorter than the traditional construction document phase. The traditional shop drawing process is merged and designed with the contractors', trade contractors', and suppliers' documents to comprise the entire construction intent of the building systems and components. As the design is fixed, the prefabrication of some systems can begin, such as the details. In addition, specifications are developed and all documents are gathered, such as financing, procurement, permits, and implementation documents. These include the assembly, layout, detailed schedule, procedural information (testing, commissioning), and legal requirements (whatever needs to be included to be legally binding).
5. **Agency review and final buyout**: This phase runs concurrently with the criteria design, detailed design, and implementation documents that regulatory agencies provide as high-level compliance information. They work with the team to develop an agreeable schedule for relevant stakeholders, such as builders and trade builders, in order to prepare and respond to agency comments. The buyout is usually limited to obtaining price commitments from any remaining suppliers and subcontractors.
6. **Construction:** Some elements of the IPD construction administration remain similar to traditional practice. But in IPD, this 'final design stage' is completed during the 'Detail Design and Implementation Documents' phases. The construction administration will primarily offer a quality control and cost monitoring function.

7. **Closeout:** The closeout of an Integrated Project is similar to a traditional project, such as the finalisation of the as-built models or other documentation, a punch list correction, warranty obligations, and notifications of occupancy and completion.

2.3.3 Design process and Project delivery methods in Thailand

2.3.3.1 Overview of Thai AEC Sector

Porntepkasemsant and Charoenpornpattana (2015) illustrated that construction is a one of main industrial sectors of Thailand, and an important part of the Thai economic system. Investment into large-scale construction projects aims to support the economic development, such as improvements to the transportation network and logistic systems, or airport construction. The construction sectors have shown a significant contribution to the economy that, in 2013, it comprised around 2.6% of the GDP by sector. This included both public and private construction, and recorded a total value of 314,181 million Bath in 2013 (where £1 = 40.48 Bath, on 19 May 2019) (Porntepkasemsant & Charoenpornpattana, 2015). The Thai construction industry has been dominated by a small number of large firms (>1,000 employees) representing around 0.2% of the sector and a large number of small firms (<20 employees) representing around 68.1%. In 1999, 17,512 organizations were recorded within Thailand's construction industry, whilst employment comprised approximately 1.28 million of the 33 million workers available (Makulsawatudom, Emsley, & Akintoye, 2001).

The Thai AEC sector is fragmented into many parts although there are three main professional representatives: the Architect Council of Thailand (ACT), the Engineering Institute of Thailand (EIT), and the Thai Constructors Association. Professionals in AEC sectors are required to be licensed within their discipline; architects and engineers are licenced by the ACT and EIT respectively. Furthermore, in 2019, 945 architectural design offices were registered on the ACT database in 2019 (ACT, 2019) although, in 2016, there were 21,260 Thai licenced architects engaged in the sector (Supaokit & Tachakitkachorn, 2018). In comparison, in 2019, the EIT recorded 128,079 licenced Thai engineering professionals in the construction sector, amongst whom 63,827 are civil engineers, 27,891 are mechanical engineers, and 36,361 are electrical engineers.

2.3.3.2 Design process in Thailand

The Architect Council of Thailand's Announcement (2015) guides professional practice; moreover, the design service standard contains six phases, which reflect the traditional phases adopted within the USA. The conceptual and schematic design phases are the same as the schematic design phase in the traditional approach of the AIA (AIA, 2014) and the concept design phase in the RIBA Work Plan 2013. Firstly, the optional services are provided for the pre-design phase. Secondly, for the detailed design process phases (Architect Council of Thailand, 2015), the following phases are adopted:

1. **Pre-design**: The optional services depend on a contract between the designers and the owner. This addresses: feasibility; programming; project planning; coordination with a relevant government or private sector; a relevant project regulation study; a concept design study of architecture; an environment and energy study followed by a study on regulations; materials and instruments for the relevant project in terms of its architectural design; and basic project cost estimates.
2. **Conceptual design:** This entails a summary of the initial architectural character from the owner's view, the area requirements and the area relationship. It aims to generate a basic design to respond to the purposes, function, and budget. At its most fundamental, a concept design includes: conceptual planning, the concept design brief of the building (floor plans, elevation, section, and scale), an initial budget, and a summary report of the concept design.
3. **Schematic design:** The concept design continues to develop more detail from the brief, such as the proportions, materials and the relationship amongst the architectural components including an improved budget. A draft of the layout, floor plans, elevations, and sections are required within the proposal to the owner. In addition, relevant information is included in the brief document, such as the area conclusion and updated budget.
4. **Design development:** The outcome from the schematic design phase aims to develop the complete design. The dimensions and positions of the main structures, walls, open spaces, and duct spaces are clearly identified on the floor plans. A preliminary design is completed, and the budget is improved.
5. **Construction document:** The traditional shop drawing is prepared to request for permission, bidding, and construction. All relevant documents are provided, such as the specification and detail designs of all systems, a bill of quantities, and the bidding documents.

6. **Tender:** Designers involve consultants who organise the documents, information and details for the owner, which are then used for the bidding by a selection of subcontractors.
7. **Construction:** Architects visit a construction site to inspect the construction built and materials used, and to provide suggestions so that the construction runs smoothly. When there are any changes from the original design, the architects advise in accordance with the regulations on construction and safety (ACT, 2015).

To reduce CO2 emissions and energy consumption in Thailand, consideration is given to the ministerial regulation entitled to define building type or size and standard, principle, and procedure in building design for Energy Conservation 2009 (Thai Ministerial Regulation, 2009). This controls some building types (more than 2,000 square metres), such as offices, hospitals, or complex buildings in terms of their OTTV (Overall Thermal Transfer Value) and RTTV (Roof Thermal Transfer Value), the building service systems (lighting, air condition, hot water systems), and the overall energy consumption (Thai Ministerial Regulation, 2009). Usually, a design project will consider the issue in the design development phase, which encourages intensive collaboration amongst professionals and experts.

2.3.3.3 Project Delivery Methods in Thailand

The project delivery methods support customers, designers (architect and engineers), and constructors including subcontractors of construction projects in Thailand. Moreover, it includes Traditional, Design Build, and Construction Management approaches (see Figures 2.15). These methods are chosen as the appropriate path for a customer's construction project. They travel from the contract to the build relationship between the customer and firms, designers, constructor and/or subcontractors, construction manager (see Figure 2.16).

2.3.3.3.1 Traditional method

The traditional method, or design-bid-build, can be deployed to support the customer, architect, and constructor and/or subcontractors. The customer draws up contracts with two main parties, namely the architect (for the design) and the constructors and/or subcontractors. The customer hires the architect to provide a project design and to assist the customer in the bidding process when selecting the constructor, Khumpaisal and Ratanawitoon (2015) conducted research into the current deployment of this method in Thailand. They investigated the risk assessments employed in the design-bid-build method for in condominium projects for large buildings (> 1000 m^2) and found that:

- Information for design was vague and insufficient. This led to frequent design changes, a lack of information, and the addition/reduction of works apart from those specified in the construction documents.
- The design was incomplete, and errors were not completely resolved until the construction phase.
- There was a lack of design details leading to mistakes in the cost estimates.
- The information was forwarded late from designers.
- There was a lack of collaboration among participants leading to conflicts amongst the project participants, including the architect, interior designer, and relevant engineers.
- There were many difficult issues and complexities in the contracts, such as vagueness, a lack of understanding, and injustice, amongst other concerns (Khumpaisal & Ratanawitoon, 2015).

2.3.3.3.2 Design and build

Although the ACT (2015) does not provide guidance on the design-build method, both the design-build standard and bridging have been deployed in Thailand and were first allowed in 1983 by the Thai government. The design-build method is well known due to its attempts to resolve the problems posed by the traditional method, in which issues emerge within design, bidding, and construction. These problems are different for each project due to the diverse cultures, collaboration, misunderstanding, and conflicts between designers and constructors and other parties (Chiranakorn, 2000).

In Thailand, the design-build standard method has been deployed for large buildings (>2000 m^2), infrastructure projects (Chiranakorn, 2000), and small and medium buildings (<2000 m^2). Boonchan (2010) conducted research into the risk management of building construction projects that adopted the design-build standard method, and found that, although the design-build method can reduce time taken, the following also occur:

- Design mistakes and incompletions, which directly affect the project in requiring rework and improvement;
- Inadequate collaboration in the design phase among designers and in the construction phases between the designer and contractor/subcontractors;
- Incomplete specification and design details leading to reworking and inaccurate estimates;
- The late delivery of construction material;

- Insufficient workers, which becomes an issue for subcontracts; and
- Inefficient subcontractors due to a lack of technical construction skills.

The bridging design-build method is generally used in small and medium construction projects, such homes/other small buildings (less than 1000 m^2), educational buildings, and non-complex factories. The customer hires the architect to design the project in accordance with the customer's requirements, whilst the architect designs and deals with the constructors in order to provide the design details and construction documents. After this, the constructor is hired to construct the designed building.

2.3.3.3.3 Construction Management

Despite the increasing size and complexity of buildings, construction projects are required to manage the planning, monitoring, and control in order to achieve the project objective on time, at the specified cost, and to the required quality. In Thailand, two types of construction management are deployed for large and complex building; these are known as: the CM as Advisor and the CM at Risk.

In Thailand, the CM as Adviser is often chosen by customers who require the construction manager to regularly consult the design team and contractor, and who need to control the specified cost, time, and quality of a construction project that comprises more than 2,000 and less than 10,000 m^2 in Thailand (Damrongraktham, 2004; Chantanasin, 2010). The construction manager assists the customer to control the cost, time, and quality but does not have a direct contractual relationship with the contractor. However, as there is no responsibility for the achievement of the project, the customer still faces the risk associated with increasing cost and time due to problems such as design changes in the construction phase (Damrongraktham, 2004). Chantanasin (2010) investigated the cause of delays in three large construction projects in Bangkok. These projects used the CM as Adviser to manage the building process and deal with the design team and contractor. Chantanasin (2010) noted that the main causes of these problems were:

- Insufficient workers in construction. Although there was an attempt to employ foreign workers, they often lacked the required knowledge and skills in construction;
- Inefficient management of construction materials, which was the main issue leading to delays;

- Problems within the design appeared in the construction phase, such as changing the design requested from the customer, incomplete designs, changing the specification, and redesign from the design team;
- Although the planning was defined, the contractor could not control the work and deal with any problems in order to ensure timely project planning;
- Coordination and communication caused problems due to the lack of experience, appropriate protocols, and appropriate communication tools (Chantanasin, 2010). There were in efficiencies in the coordination and communication between the design team and subcontractors. The issue increased when the design team adopted new construction techniques, but the subcontractors lacked sufficient understanding of the required techniques and could not coordinate and communicate with the design team on time.

In comparison, the CM at Risk method is deployed in large and complex construction projects, for which management is required to reduce cost, time, and any risks. The customer hires a design team (architect/engineer) and, at the same time, also hires a construction manager (CM) for consultation in the design phase. This method includes a guaranteed maximum price and a fast track option. The CM separates the project into parts on which each part can be bid; this enables the process to flow to the construction phase. The CM draws up a direct contract with the subcontractors and thus can fully control these parties. Damrongraktham (2004) conducted a study of fast track construction management on the architectural design process of a mega-project in Thailand, and found that:

- There were problems in terms of delay and time limitations. The design quality became an issue due to the urgency of time and this meant that problems arose in the construction phase.
- The work process was still separated and there was no connection between the parts.
- Design was incomplete, such as the detail design in the architectural design and the calculations in the engineering design.
- The contractor did not compromise and instead prioritised their own benefits over the common goal of the project.
- There was inefficient communication due to issues with information, language, and the channels of communication. More specifically, these issues related to;
    - Frequently changing information involving other parties that was unclear and incomplete.

- Language problems due to the involvement of several nationalities in the project.
- Overly formal channel of communication that emphasised the use of formal and documentary communication and thus lead to delays and late responses to messages.

2.3.4 Discussion of Conceptual design

The traditional process used in most projects is the Design-Bid-Build method, which began in the early 20th Century in the USA. In Thailand, the traditional design process also uses the Design-Bid-Build method for most projects. These phases support relevant stakeholders from fragmented teams to work together within a linear approach (AIA, 2007). The design is generated by the architect and delivered to other disciplines to follow the phases from a schematic design through to the construction phase. As most projects use the traditional design process, the AEC industry still suffers from lower productivity and efficiency (AIA, 2014).

Furthermore, the AIA Council of Architectural Component Executives (CACE) in the USA reports that almost 40 percent of projects that use traditional delivery models end up behind schedule and more than 60 percent complete over budget (AIA, 2014). These issues occur because the AEC industry is fragmented, inefficient, and adversarial where each team is responsible for their own work scope and attempts to protect their maximum individual profit (Lichtig, 2006; Pelberg, 2009 cited in Mihic, Sertic, & Zavrski, 2014). In addition, problems arise from the lack of communication within the solution development and the solution implementation phases in the construction project's life cycle (Mihic et al., 2014).

For integrated project delivery, its collaborative delivery model and a concurrent and multiple level problem-solving approach specifically aims to reduce delays and budget overspends, which differs from the traditional project delivery (AIA, 2014). The American Institute of Architects (2007) reported that an IPD results in greater efficiencies than the traditional design process; this accords with the estimate published by the United Kingdom's Office of Government Commerce (UKOGC) (AIA, 2007). UKOGC illustrated that up to 30% of construction costs can be saved when integrated teams are encouraged to continue improvements over a series of construction projects. In addition, UKOGC estimated that employing integrated supply teams in single projects could save 2-10 % of construction cost (AIA, 2007).

Bringing relevant integrated teams together and sharing responsibility with a single goal and no competition from the early design to the end result requires a high level of efficiency and productivity within the construction project (Matthews & Howell, 2005). MacLeamy developed a crucial diagram (see Figure 2.19) that illustrated the shift from intensive design team efforts to a desire to work together from the construction document phase to the schematic design phase for the new design processes (AIA, 2014). In Figure 2.19, the 'A' curve illustrates the decreasing ability to impact cost and functional capabilities, whilst the 'B' curve illustrates the increasing cost of design, which changes from the pre-design to the operation. Design changes or problems leading to iterative design or design improvements represent the high cost of design changes. These are revealed in other phases following the schematic design or concept design phase. In addition, the cost of the entire project construction reduces when the designs can be completed, and problems resolved from the beginning.

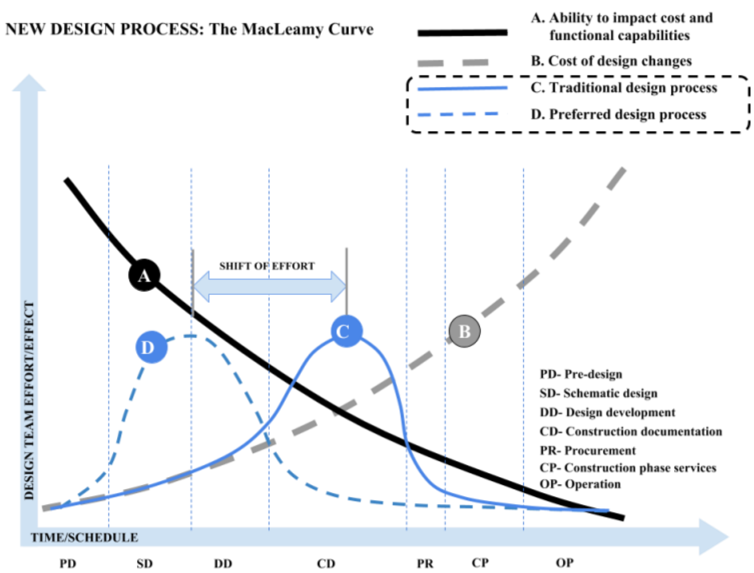


Figure 2.19 New Design Process: The MacLeamy Curve
(Source: Modified from AIA, 2014)

In the UK, the RIBA Work Plan 2013 brings relevant designers and other disciplines together to work intensively from the concept design to the closeout phase. The concept design phase is important for collaborative design or concurrent solving-problem amongst multiple disciplines. Concept designs will be created and developed from an abstract to a concrete idea for exploration and experimentation (Bailey, 2015). The impact of the final outcome in the concept design is impacted in the later phases of the design development. Furthermore, any disadvantages that occur during the later stages require an enormous number of design changing costs in order to address the shortcomings from decisions made at this stage (Leon & Laing, 2013). Moreover, the shortcomings that arise at other later stages lead to iterative loops and reduce the efficiency of the performance in terms of quality, time, and cost, whether due to mistakes or design changes. Pahl, Beitz, Feldhusen, and Grote (2007) argue that shortcomings exist in every system, and these are caused by ignorance, mistaken ideas, external disturbances, physical limitations and production errors. Redundant loops continuously arise; thus, more effective collaborative design during the project's conceptual stage could reduce the iterative loops involved with correcting the drawing design at the later stage of the process (Leon & Laing, 2013a). In addition, the concept design stage, which creates the frame of alliances among the disciplinary designers, can lead to greater innovation and the development of boundary-pushing proposals (Olsen & Namara, 2014).

Therefore, design process trends develop by gathering multiple-disciplines together to collaborate on the concept design. The concept design stage becomes the significant channel of opportunity whereby alternative concept designs should be considered and every aspect discussed with multiple disciplines/designers in order to enhance vital decision-making for design solutions.

2.4 Collaboration

Whilst disciplines work together in the design process, this has developed differently in each country; nevertheless, all disciplines need to collaborate with each other. Four parts comprise this section. Firstly, the meaning of collaboration is explored to understand its component factors. Secondly, a general view of communication addresses a common model of communication, and thirdly, the collaborative environment is explored to understand the channels and conditions of communication. Finally, design process collaboration is explored within the USA, UK, and Thailand

2.4.1 The Meaning of Collaboration

The fragmentation of the Architecture, Engineering, and Construction (AEC) sector means that a variety of stakeholders are required to participate, and this becomes particularly complex when working together. Collaboration was defined by Robbs (1996) as an agreement amongst specialists to share their abilities in a particular process, and to accomplish all the project's objectives, which are defined by the client, community, or society. Moreover, Beck (2005) stated that collaboration in the AEC industry is a data-centric activity where each participant must interactively share information across disciplines in order to achieve common objectives in collaborative design, which are based on shared knowledge. Information is shared across, and passed back and forth between, disciplines throughout the delivery process. Collaboration ensures that whatever is required is correctly communicated for a shared understanding of a common ground with respect to the relevance and meaning of information amongst the team members (Larsson, 2003).

Carrara (2012, p.124) stated that collaboration in the AEC industry design process is dependent on the capability of any actor (see Figure 2.20):

> …to integrate in his/her disciplinary and cultural domain other actors' solutions and to judge both the effect they have on his [/her] own solution and the way the whole system works, pointing out inconsistencies and/or suggesting proposals and that …it is based on the cycle of communication, interpretation, understanding, elaboration, suggestion and/or proposal, discussion and agreement.

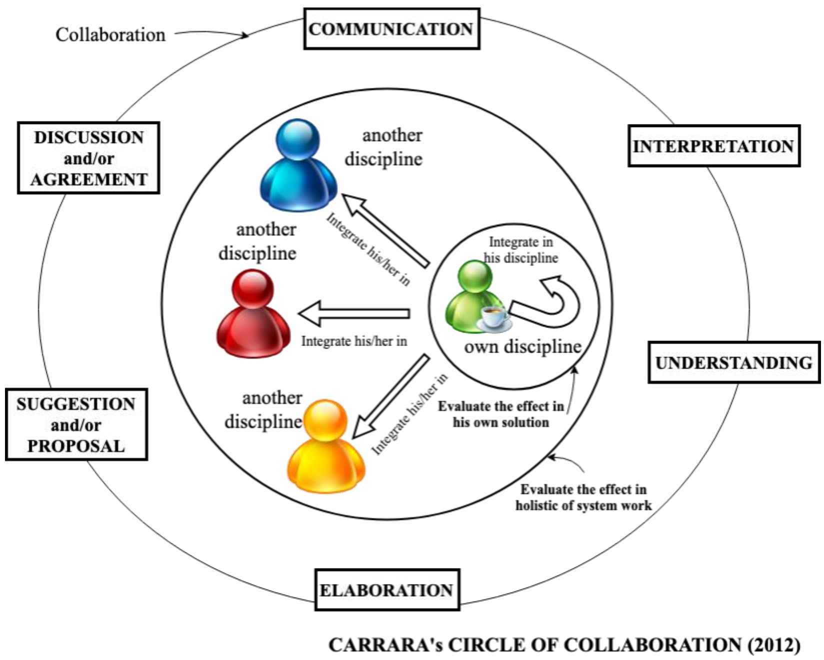


Figure 2.20 Carrara's collaboration cycle
(Source: Summarised from Carrara, 2012)

A collaborative working environment is essential during the AEC industry design process; furthermore, the two key groups consist of specialists (actors) and generalists. A specialist is an expert in their discipline or field, who, at the same time, may become a generalist by understanding and appreciating other disciplines, and vice versa (Carrara, 2012). For example, an architect is a professional specialist in architectural design, while engineers are able to study the design problems across other disciplines to become generalists who are able to elaborate their own solution by summarising a common ground and passing it to other actors and vice versa. Carrara (2012) suggests that, for collaboration to be effective, it is important for co-workers to share, understand, build on and shape each other's knowledge and understanding. This means that they build their own mental structures, called schemata, through experience and then modify the existing mental structure to record this in their long-term memory. These schemata are then reused and updated through reactions to new situations and by identifying analogies with similar existing experiences. This mechanical mental structure is crucial for each specialist to enable the prediction of others' behaviours and to better understand information shared by the team (Gautier, Bassanino, Fernando, & Kubaski, 2009).

According to Carrara's cycle of collaboration (Figure 2.20), a collaborative design approach can encourage the multiple disciplines within conceptual design to communicate and develop ideas and solutions to design problems. Moreover, they can build knowledge with each other through the cycle of collaboration, which comprises communication, interpretation, understanding, development, suggestion, discussion and agreement. Carrara (2017) explained the following terms:

- **Development:** A professional develops a solution to a design problem, or a design idea.
- **Communication:** An appropriate medium (channel) is used to transmit solutions to design problems or designs to other relevant professionals.
- **Interpretation:** The shared solution/design idea needs to be easy to understand or properly interpreted to enable the correct interpretation by relevant professionals.
- **Understanding:** These relevant professionals understand the meaning of the content in the solution/design.
- **Suggestion and Proposal:** Another professional can suggest a solution/design, propose a new solution/design and communicate this to other relevant professionals.
- **Discussion:** Relevant professionals discuss these alternative solutions or designs. The discussion becomes shared knowledge among professionals.
- **Agreement:** Finally, shared knowledge is mutually agreed and accepted to ensure that relevant professionals correctly and fully interpret and understand the shared meaning.

Carrara's collaboration cycle involves a communication process and knowledge building. These are required for actors to assist each other in building knowledge from a data-centric activity to one based on shared knowledge (Beck, 2005) (see Figure 2.20). The communication process (see Figure 2.21) comprises a medium to convey the messages between actors, interpretation, understanding, and feedback. The development of knowledge comprises the development of solutions or design ideas from analysis/synthesis/evaluation, suggestion/ proposal, and discussion.

In this research, collaboration is not limited to each actor trying to integrate other actors (specialist colleagues) into their own disciplinary and cultural field. Instead, they share and understand knowledge and assist other participants in shaping or sustaining their mental structures in order to achieve common ground. This helps to eliminate conflict and promote collaboration in order to overcome and rectify any design problems through a cycle of communication, interpretation, understanding, suggestion and/or proposal, discussion and agreement.

2.4.2 General view of Communication

Norouzi, Shabak, Embi, & Khan (2015) defined communication as a complex process that is dynamic in nature and facilitates the sharing of meaning in a particular social context including the trading of opinions, ideas, and goals. Communication is a process of transmitting information and of building a common understanding between the sender and receiver (Lunenburg, 2010). Lunenburg (2010) summarized that the sender or receiver encodes and decodes a transmitted message, which is conveyed by a medium and may be distorted by noise. The medium can be a face-to-face conversation, telephone call, written report, or computer-mediated tools or technology (Lunenburg, 2010; Norouzi et al., 2015). In addition, the feedback loop between the sender and receiver is a characteristic of the communication process. The feedback not only helps the receiver to respond to the sender's message, but also helps the sender to know whether the message has been received and understood (Lunenburg, 2010).

Taleb, Ismail, Wahab, & Rani (2017) mentioned that a function of communication is to create a common understanding, whilst Norouzi et al. (2015) also noted that its aim is to facilitate the achievement of common goals (Pietroforte, 1997 cited in Norouzi et al., 2015). There are two sub processes in both sending and receiving, which drive the communication process to reach a common understanding; these sub-processes are interpretation and understanding. Interpretation is a crucial function of the receiver as it involves interpreting the data after the message has been decoded (Schramm, 1954, cited in Bonnema, 2014). Nevertheless, a message can be interpreted from a context in different ways as a result of misinterpretation or a lack of congruent understanding (Gorse, Emmitt, & Lowis, 1999) in the communication process. Furthermore, Gorse et al., 1999 and Den Otter & Emmitt (2008 cited in Norouzi et al., 2015) imply that understanding is a function of the receiver, and enables them to recognise the meaning of information when interpreted from the decoded message.

This can be summarised in a model of communication in which the sender and receiver are within the boundary of a common goal (see Figure 2.21). The sender encodes the information into a message that is transmitted by a medium to the receiver to achieve a mutual goal for the sender and receiver. The receiver interprets and understands the meaning of the sender's information after the message is decoded. When the receiver responds, the sender can determine whether the receiver understands the message.

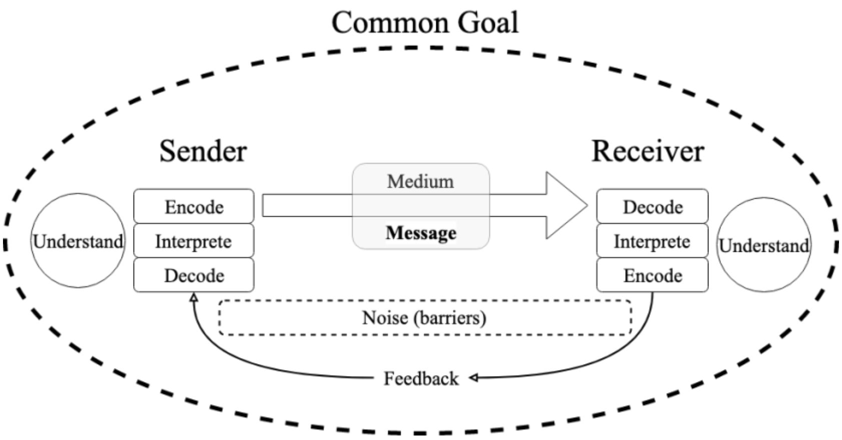


Figure 2.21 Communication model
(Source: Researcher own)

A communication process may be less effective or not achieve the common goal due to barriers that may occur within the process. The barriers can be classified under two categories (environmental and personal) and can block, filter, or distort a message in the communication process (Rakich & Darr, 2000, cited in Adu-Oppong & Agyin-Birikorang, 2014). In addition, Lee (1988) noted that sematic barriers and inappropriate medium/media (channels) (Shohamv & Pinchevski, 2001) impact on effective communication. The four barriers categories in the communication process are as follow:

1. **Environmental barriers:** environmental barriers involved factors such as distance, time and organisation (Adu-Oppong & Agyin-Birikorang, 2014). These factors are crucial in facilitating effective communication for both the sender and receiver. An environmental barrier is the main hurdle in effective communication within the workplace and involves all environmental circumstances (Norouzi et al., 2015).
2. **Personal barrier:** personal barriers involved communication skills, attitudes, knowledge, and the socio-cultural context (Lee, 1988; Adu-Oppong & Agyin-

Birikorang, 2014). The socio-cultural context relates to a social background, education, friends, and culture. In addition, Eisenberg (2010) mentioned that integrating and understanding others' backgrounds, attitudes, and differences are crucial factors for effective communication (Eisenberg, 2010 cited in Adu-Oppong & Agyin-Birikorang, 2014).

3. **Semantic barrier:** semantic barriers involve language types, which include graphics, jargon or different terminologies, symbolic language, or natural language (Lee, 1988). A vague meaning can be interpreted or the receiver may misinterpret the message leading to misunderstanding and the failure to achieve a mutual goal in the communication process.
4. **Medium barrier:** the medium can be critical in the communication process. There are two main channels: 1) traditional, including written letters and memos, telephone, and face-to-face conversation; and 2) computer mediated, including video conferences, email, chat room, instant messages, and social media, which are supported by ICT-Information and Communication Technology. The medium should be appropriately selected to transmit the message for an effective communication process (Lee, 1988; Lunenburg, 2010).

In AEC industry practice, communication among multiple-disciplines aims to achieve a common understanding in order to address (or avoid) the aforementioned barriers in the communication process. If the design team communication is ineffective, it contributes to waste and rework on building projects and increases project's risk, uncertainty, conflict, and failure (BSI, 2003; Designing Buildings, 2016; Love & Lopez, 2012; McGraw-Hill, 2014; PMI, 2013, cited in Awomolo, 2017)

2.4.3 Environment of collaborative design

Generally, professionals communicate their theories and design ideas/solutions through their achievements in the built environment. Individual design professionals have to tune their personal understanding of design content to achieve a shared understanding, and to propose a conceptual design within a team (Valkenburg & Dorst, 1998 cited in Gül & Maher, 2009) through an appropriate communication form and channels. The communication forms can be verbal and nonverbal. Verbal communication is the transition of messages through the written or spoken words, while non-verbal communication does not include words but instead incorporates signals, symbols, or drawings (Taleb, Ismail, & Wahab, 2017). In terms of the communication channel, an appropriately selected channel can encourage a design team to achieve their goal/s. In collaborative design, these can be categorised under two main channels (Gül & Maher, 2009; Lee, 2010), which are:

- **Face-to-face communication:** This channel is one of traditional communication channels. Face-to-face communication enables the sender and receiver to hear and see a non-verbal communication, such as body language and expression, and respond with immediate feedback (Lee, 2010). This channel claims to be effective and to fit with negotiation and the solving of intellective problems (problems that have correct answers) (Hollingshead, McGrath, & O'Connor, 1993, cited in Hatem, Kwan, & Miles, 2012). However, without recording or translating verbal messages into text or illustrations, the information is lost forever (Gabriel, 2000). In addition, this channel consumes time when used to communicate in team collaboration (Hatem et al., 2012), such as a meeting.
- **Computer-mediated communication:** This channel is based on the use of computers and ICT-Information and Communication Technology for data exchange. Computer-mediated communication has developed since mid-1990s and now provides an interactive channel allowing users to communicate with each other through two-way communication. This is an inexpensive way of information-seeking (Miller, 2009 cited in Lee, 2010). According to experiments by Hatem et al. (2012), this channel is more efficient than face-to-face communication in terms of productivity and time.
    - **Audio-video computer-mediated communication channel:** This channel is based on the use of audio and video, and supports remote communication. It includes video conferencing systems, videophones, and telecommunications applications. Tang and Issacs (1993, p.193 cited in Gabriel, 2000) concluded that audio is more critical, and high-quality audio is more important than high-quality video. This channel can be substituted for face-to-face interaction when making decisions (Credé & Sniezek, 2003).
    - **Text-based computer-mediated communication channel:** This channel of computer-mediated communication is based on the use of text in synchronous and asynchronous communication. The use of text and chat as synchronous interaction is more knowledge-rich and task-oriented (Hatem et al., 2012). In addition, Gergle, Millen, Kraut, and Fussell (2004) confirmed that a dialogue history increases efficient communication, which leads to faster and better task performance. For

asynchronous interaction, this channel provides slow feedback, but can offer the same advantages.

The use of different communication channels, such as those mentioned, produces different collaborative environments (Gabriel, 2000, cited in Gül & Maher, 2009). These collaborative environments depend on the location conditions; whether individuals are in a different or the same place, at different or the same time, (Germani, Mengoni, & Peruzzini, 2012). These are appropriately selected to facilitate the collaborative design team. The collaborative design environments can be categorised by location, specifically co-location and de-location:

- **Co-located Collaboration:** This environment provides collaborative design in the same physical location. It enables informal communication and provides adequate environmental conditions for decision-making, collaboration, trust between team members, and effective interpersonal relationships (Zenun, Loureiro, & Araujo, 2007). This can be categorised through the follow:
    - **Co-located and Synchronous Collaboration:** The collaborative design team works closely together and is involved in directed interaction in the same place and at the same time (Germani et al., 2012). The face-to-face communication channel is used to communicate in physical meetings, which are based on the physical exchange of documents, and on verbal and non-verbal discussion.
    - **Co-located and Asynchronous Collaboration:** This refers to the activities of routine design that occur inside the same workplace (Germani et al., 2012). The distance between team members should be no more than 25-30 metres. (Thomson, Stone, & Ion, 2007). In this environment, face-to-face and computer-mediated communication channels can be chosen (as appropriate) for communication, dependent on the collaborative design situation.
- **De-located Collaboration:** De-located or remote collaboration enables remote designers to share information with team members through computer-mediated communication channels. This environment includes routine design in the same workplace, at a distance of more than 30 metres (Thomson et al., 2007), or on different floors, buildings, and sites. This can be categorised by the following time condition:
    - **De-located and Synchronous Collaboration:** This refers to the activity of collaboration, which supports relevant de-located professionals to remotely communicate through computer-mediated communication channels, such as

simultaneous and spontaneous video conferencing from another location (Germani et al., 2012).

- **De-located and Asynchronous Collaboration:** This refers to the activities of routine design, which involves multiple companies or other professionals in different workplace locations (Germani et al., 2012). A text-based, computer-mediated communication channel is chosen to communicate in this environment, such as chat, a discussion board, or email in this environment.

Usually, traditional collaboration is based on a co-located and synchronous collaboration typically face-to-face meetings and directed interactions between relevant professionals and other stakeholders in form of discussion and the physical exchange of information. Co-location can be referred to as a setting designed to resolve a project issue in real time, such as a co-location office which provides a large enough space for relevant stakeholders to closely collaborate using an IT infrastructure and to adopt a face-to-face communication channel (Thompson & Ozbek, 2012). Co-location collaboration can refer to working together in the same place and depending on time, can be either synchronized and asynchronized. Co-located and asynchronous collaboration is generally the activity of routine design in organisations between 25-30 metres.

In the most cases, a large number of professionals work together, but in different workplaces or firms. De-location collaboration refers to remote collaboration or de-located and synchronous/asynchronous collaboration, where relevant professionals can work remotely together in different workplaces or at distances of more than 30 metres in the same workplace. Thus, a computer-mediated communication channel is necessary to communicate in collaborative design.

2.4.4 Collaboration in the Design Process Approach

The traditional approach is still used to frame collaboration in the USA, and in Thailand, where the design process approach is similar to the traditional approach. The Design Process Approach has been developed to enhance productivity and efficiency through collaboration. In the USA, the Integrated Design Process has promoted collaboration through the traditional, construction management and design build approaches, whilst in the UK, the RIBA Plan of Work 2013 now also supports collaboration amongst disciplines.

2.4.4.1 US Collaboration in Design-bid-build, CM, Design-build, and IPD approaches

According to project delivery methods in the USA, the primary methods (design-bid-build, construction management, and design-build methods) are based on phases of the traditional process. Furthermore, there are different sequences followed to select players (contract, subcontract, or construction manager), or to determine the cost of these methods (see Figure 2.15). These methods were addressed in the relationships amongst project participants shown in Figure 2.16.

Firstly, the traditional or design-bid-build method is typically performed through consultation between architects and engineers. The traditional design process frames relevant stakeholders (see Figure 2.22). A design team is initially brought into the process, whilst construction teams are introduced after the design team, from the bidding to the closeout phases.

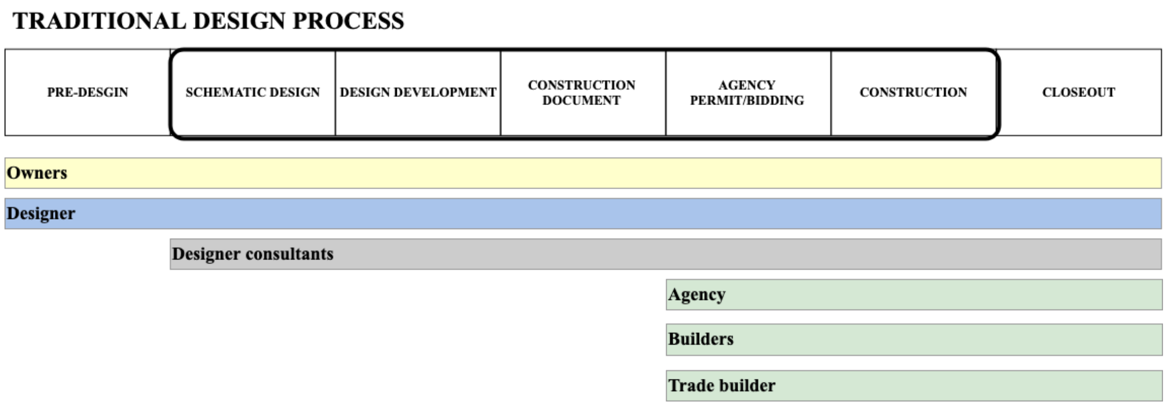


Figure 2.22 Collaboration in the Traditional Design Process
(Resource: Modified from AIACC, 2014b)

Usually, architects lead the schematic design phase in order to provide common deliverables at the end of the phase (AIA, 2014). Architects, engineers and other disciplines are intensively consulted and work together in the design development. Design consultants are brought together from the schematic to the closeout phases. For part of the construction process, builders and trade builders are separated from design; furthermore, builders and trade builders are chosen at the bidding phase and use all documents and specifications to construct and set the building instruments. Besides the design-bid-build option addressed, there are other traditional method options, which are: to the select negotiated team, and the cost-plus fixed free option. These provide greater opportunities for the contractor and design team to work together than the traditional (design-bid-build) option (AIA, 2014). The contractor is selected and brought to work with the design team before the design development in order to help the team to provide specifications and construction drawings. However, these options are different to the design-build method and do not fall within any single point of responsibility (AIA, 2007).

Moreover, construction management is based on a traditional approach, but the main player is no longer the architect. Instead, the construction manager is selected first, before the pre-design phase and they bring together the design team, which comprise; the architect, engineers, and specialists, and contractor or subcontractors (AIA, 2014). Similarly, in the traditional approach, the architect, engineers, and specialists work together in the design development whilst builders or trade builders, who are separated from the design, are chosen in the bidding phase to work on their scope of the construction phase (AIA, 2007).

In comparison, the design-build method is addressed under two options, which provide greater opportunities for collaboration than the traditional and CM methods. The first is the standard option, where the design and construction team form a single entity. They are selected and only deal with the customer in terms of the requirements and cost in the early design process. This helps to control the design, and time taken, and overall cost. Another option is bridging where the architect and design team work to first follow the customer's requirements. The customer is more involved in the process than the standard option; furthermore, the contractor and subcontractor are selected after the design and development phase and assist the design team in the construction document phase and in building the project (AIA, 2014).

Significantly, the design-build method is based on a single-point of responsibility for both the design and construction activities, and the designer and contractor are brought into the process. It is contractually very well-suited for increasing collaboration among the design and construction team members who have often self-selected to work together and already established a rapport and methodology for working together. Although its outcome aims to meet the minimal of cost and time, including responsibility, and the risk of silos, this (alongside a lack of innovation) can become its limitation (AIA, 2007). In addition, silos and communication resist, thereby reducing opportunities for close collaboration, which may be exacerbated, as these silos may not be located in the same office.

Many professionals in the AEC industry are dissatisfied with project outcomes and argue that projects employing the primary approaches (design-build, design-bid-build, and CM) often run over-schedule, over-budget, and are of low quality due to fragmentation, inefficiency, and adversity (Ghassemi & Becerik-Gerber, 2011). Barriers in the primary approaches are mainly identified through the silos of effort and failure awareness (AIA, 2007) including the protection of parties' own maximum profit (Ghassemi & Becerik-Gerber, 2011). All professions represent separated silos and tasks, and each represents a professional and employee who becomes inefficient whenever there is a hand-over to such groups. Typically, communication among silos is often referred to as the 'over the wall', which is due to the fragmentation of the functional disciplines involved (Evbuomwan & Anumba, 1998). Significantly, this increases when the successes of the participant and project are not related. Moreover, the AIA (2007) pointed out that, in these approaches, potential design conflicts may not be discovered until construction.

Finally, in comparison, Integrated Project Delivery (IDP), or the integrated approach, clearly differs from these primary approaches. A key characteristic of the integrated approach is to bring together design and construction expertise to encourage intensive collaboration from conceptualization to the end process (see Figure 2.23) under a multi-party or poly-party contract (see detail in p.43) that binds the owner, primary designer, and contractor/subcontractor together in a single IPD agreement.

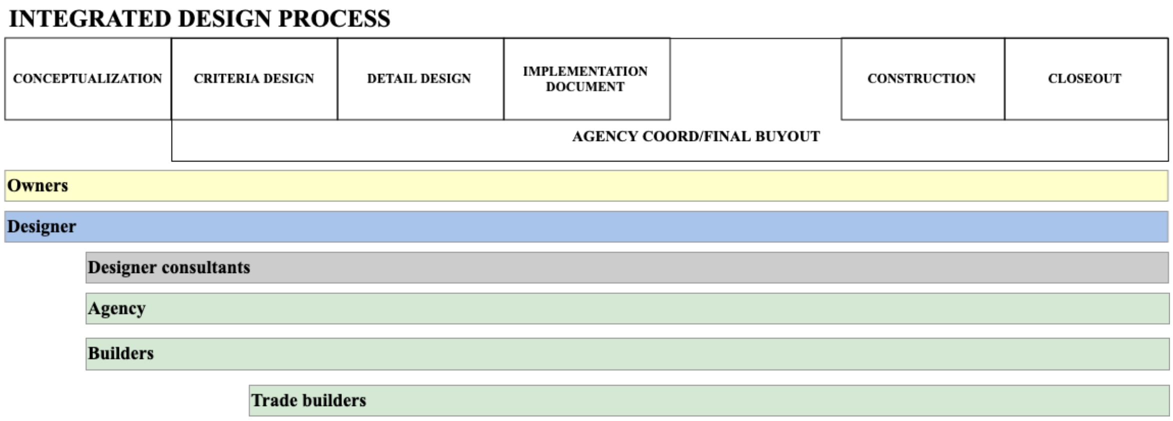


Figure 2.23 Collaboration in the Integrated Design Process
(Resource: Modified from AIACC, 2014b)

The integrated approach emphasises communication among the participants of the design teams. Thus, the design team requires effective communication and there has to be open trust and respect among all members (Kanters & Horvat, 2012). Kanters and Horvat (2012) describe a case study of collaboration in a design team (see Figure 2.24) and conclude that this differs from other approaches. All decisions from all team members become crucial in directing how the design is developed. This contrasts with the traditional, construction management, and design build approaches where the architect or engineer carry this responsibility.

Figure 2.24 A case study of collaboration in the design team
(Source: Kanters & Horvat, 2012)

Relevant members of the project team must closely collaborate to mutually commit with regard to respect and trust. This requires the organisation involved within the co-location collaboration to increase efficiencies in communication (AIA, 2007). Co-location offers an opportunity to enhance the project culture and provides a physical space that is separate from the main firm; it reduces the effect of corporate culture and supports the project identity with cross-functional unit workspaces (see Figure 2.25). However, it is also too expensive, particularly for small projects (Fischer et al., 2017). All team members are introduced to the design criteria, from which the basic design originates; furthermore, all design conflicts are solved at the beginning of the design process. Significantly, the BIM tool is promoted for use throughout the approach and Fischer et al. (2017) pointed out that IPD still needs to develop a tool and system for collaboration between colocation sites that can be as effective as direct physical contract.

Figure 2.25 A multidisciplinary "project implementation team" meeting in a colocation site.
(Source: Fischer et al., 2017)

2.4.4.2 The UK Collaboration in RIBA work plan 2013

According to the types of procurement prevalent in the UK, routes have been employed to support relevant stakeholders, such as the design team, construction manager, contractor, sub-contractor, and specialists, to work together to follow the customer's objectives. Usually, the design team comprises the architect and structural engineer, and a building service designer. The following roles may be supplementary: landscape, or interior designers, and quantity surveyor/cost manager (Towey, 2013).

In an overview of collaboration in traditional and CM approaches, the reward strategy is different from the US, and based on trust between the architect and specialists from construction teams as design consultants for all detail designs required both knowledge and skills regarding technique (Radosavljevic & Bennett, 2012). Meanwhile, a single-point of responsibility unites the designer, engineers, and/or specialists of the construction team. Thus, they work together to meet minimal construction costs in the quickest time in the design-build approach; this approach is the most commonly employed in the US. Radosavljevic and Bennett (2012) noted the following problems in these approaches for collaborative design:

- Problems emerge between the silos when collaborating, as architects and specialists are from different backgrounds than engineers.
- Fragments of relevant stakeholders becomes the collaboration issue when other teams cannot clearly understand and agree on a project's objectives; this leads to failures.
- Failures in communication lead to a lack of focus on the objectives and to misunderstandings.
- For collaboration in CM, it is natural to involve a large number of relevant participants in the process; thus, there can be a lot of meetings (Radosavljevic & Bennett, 2012).

The most appropriate procurement route is selected for integration into the RIBA Plan of Work 2013, between the second concept design stage and the fourth technical design stage. The Work Plan provides an opportunity to bring relevant key members into the concept design. In order to achieve the design, the stakeholders involved in the Work Plan are at least clients or client advisers, project leads, lead designers, architects, engineers, cost consultants, construction leads, contract administrators, and health and safety advisers (see Figure 2.26).

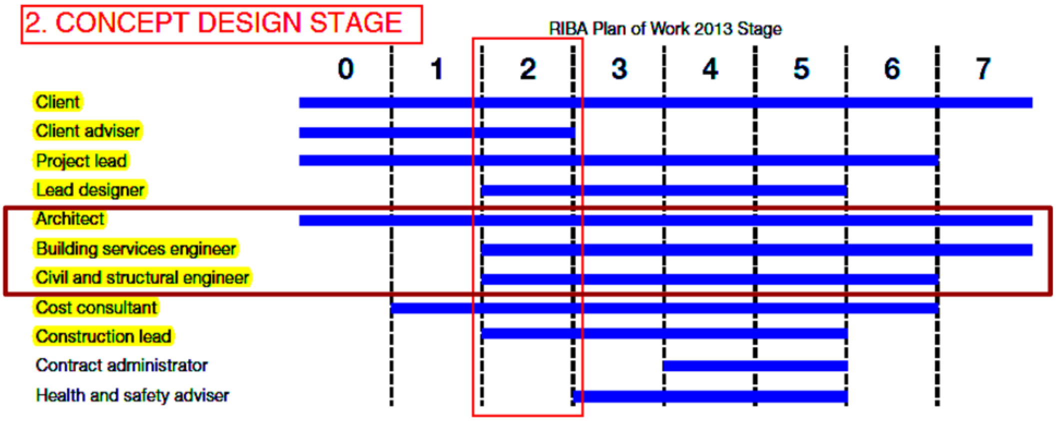


Figure 2.26 Overview of collaboration in the RIBA Work Plan 2013)
(Source: Modified from Sinclair, 2013)

Significantly, the key for the construction team is the construction lead who is integrated into the Work Plan in order to work with the design team from the concept design to the end of the fifth construction stage. Furthermore, by adding key construction team members, the RIBA Work Plan allows for the addition of other specialist areas for any project size: these include information management, master-planning, sustainability, landscaping, planning, fire engineering, external lighting, acoustics, interior design, or catering or other specialists. Moreover, a contractor is brought into the Work Plan between the second and fourth stage, and specialist subcontractors or suppliers employed by contractor are included into the fourth technical design stage to undertake their design work. The design team and specialists work together using the BIM tool to ensure their design works are available and suitable for design from the team. The BIM tool is used throughout the Work Plan, and most disciplines closely collaborate from stage 2 (or the concept design stage) until the end stage.

In the collaboration process, multiple disciplines are gathered to comprehend and evaluate the project brief and project strategies before preparing the concept design. The concept design is developed in coordination with the client, who will receive a work report and advise on decisions regarding the concept design prototype, which will depend on the plan selected in the client meeting. Concept designs are developed by an architect, a civil and structural engineer, and a building service engineer until they propose their design outcome with the remaining members at several design meetings and workshops (see Figure 2.27). They ensure they work together (RIBA Work Plan 2013, 2007) and exchange information in a collaborative process. The design may travel through the collaboration loop again in order to improve the prototype until the outcome is satisfactory. However, if the outcome is satisfactory and submitted with support from all members and the client, it will pass to the next step. The final concept design step, concerning the information exchange, is delivered to next stage, and the completed prototypes of all conceptual designs will be included with the final project brief, including the cost information, and project strategies (RIBA, 2008; RIBA, 2013).

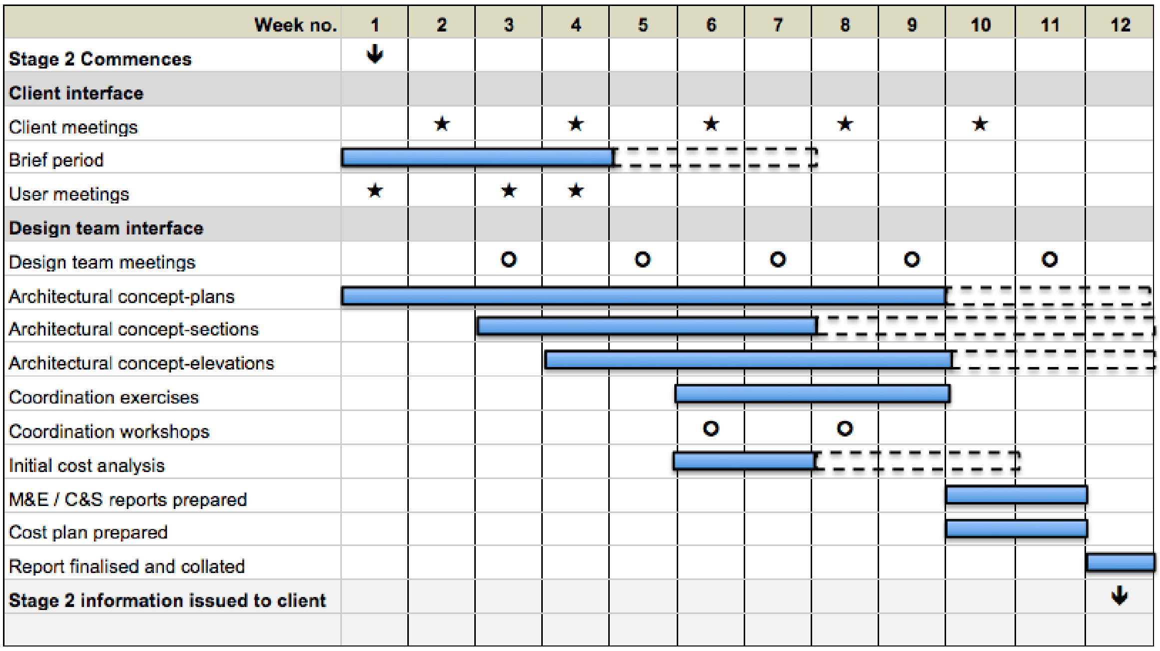


Figure 2.27 Example of a design program stage 2
(Source: Sinclair, 2013, p.10)

2.4.4.3 Thai Collaboration in Project Delivery Approaches

Relevant stakeholders are gradually included from the concept design and schematic design phases to the construction and closeout phase, which is similar to the traditional approach in the USA. Multiple disciplines work together through a contractual approach; however, this depends on their agreement. The Architecture Council of Thailand (ACT) (2015) only published a guide to traditional and construction management approaches for architectural practice.

Firstly, the traditional or design-bid-build approach is addressed as the Thai design process. The architect is the main designer; they play an important role and have responsibility from the beginning through to the construction phase (see Figure 2.28). In the concept design and schematic design phases, relevant designers, such as the key architect and architect assistants or draft architect team, work together to create abstract design ideas. They then develop their ideas with draft architects. By the end of the concept design phase, ideas are proposed to the owner, when the design is chosen and further developed in the schematic design phase. They can informally collaborate with other disciplines, depending on the complexity of the design project, in order to consult on specific issues; this might include engineers, energy experts, or interior experts in schematic design.

Usually, other disciplines are brought into the design development after the customer selects the design. Structural and building service engineers are invited to contribute their specialisms to the design and development phase to design their discipline scope, such as the structure or building systems in the design. After the tender phase, the owner chooses the builders, who then take responsibility for the construction and installation of the building instruments. In the construction phase, the architect inspects the design and construction, and sometimes gives advice about the design for construction (ACT, 2015). There are a lot of problems in the traditional process and collaboration is a part of the problems that emerge from the design phase. Khumpaisal and Ratanawitoon (2015) stated that design and its information are vague, and can result in errors, a lack of sufficient information, moreover, it can also be incomplete. In addition, there is a lack of collaboration among relevant designers, such as the architect, interior designer, and engineers, leading to conflicts (Khumpaisal & Ratanawitoon, 2015).

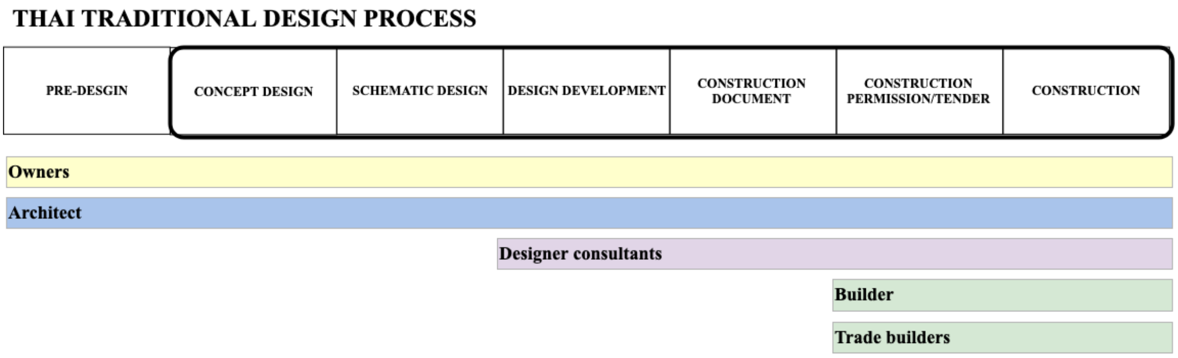


Figure 2.28 Collaboration in the Thai Traditional Approach
(Resource: Research's own)

The CM approach is used to support a customer who needs a construction manager to control the project. Therefore, they may focus on the goal and objective, schedule, cost, process, bidding, and mediation between the relevant project stakeholders in design and construction. In this approach (see Section 2.3.3.3.3), the construction manager selects and gathers the relevant designers and coordinates them in the traditional approach from the concept design to the construction document phase. The CM can bring the contractor into the process to prepare the specification, detail designs, and construction drawings, and other documents, and to manage the designers' and construction team's collaborative work. After the design is completed, the construction document requires authorisation, after which the bidding process is able to process. In Construction Management, the CM agent and the CM at risk have responsibility to control all works from the beginning to the end of construction. Chantanasin (2010) and Damrongraktham (2004) stated that coordination and communication are inefficient when they are not clear and/or incomplete. Chantanasin (2010) noted that there is still a lack of appropriate communication tools to support communication between the design team and construction team.

The design-build approach has been used to support the customer and design-build teams; this follows the design-build project delivery of the US in both the standard and bridging options. There is no difference in the employment of these options in Thailand. Sometimes, architects become confused and mistakenly use other options of design-bid-build project delivery options; for example, the negotiated select team and cost-plus fixed fee, instead of the bridging option. Some issues concerning collaboration are noted in the adoption of design build, where designs and/or specifications, or detail designs are often incomplete, and mistakes arise leading to rework and design improvements. Thus, Boonchan (2010) states that collaboration between the design team and construction team in the Thai design-build approach is not good enough in the design phase.

The construction industry in Thailand has experienced productivity problems like many other countries (Makulsawatudom et al., 2004). The barriers addressed include the impact of silos, failure awareness, and poor communication, which leads to problems in the construction phase. Makulsawatudom et al. (2004) and Charoenpornpattana (2015) pointed out that incomplete drawings, poor communication, and rework factors affect construction productivity, which directly relate to collaboration among the multiple disciplines involved in the early construction phase of the traditional design approach. In addition, silos or professionals are not successful in building knowledge of each other and this may be due to insufficient knowledge or the misreading of drawings, insufficient work skills, and an insufficient number of supervisors (Charoenpornpattana, 2015).

The Thai design process tends to be traditional and loosely collaborative among relevant disciplines. It is not easy to encourage professionals to work closely from the beginning nor is it straightforward to change the ‘over the wall’ syndrome and overcome barriers, such as physical (time mismatches or different workplaces) or communication impediments. Moreover, the results of the surveys conducted by Makulsawatudom et al. (2004) and Charoenpornpattana (2015), identify such existing problems. Essentially, the AEC industry is complex and fragmented; thus, although they are not based in the same workplace, all professionals should be supported in developing effective communication in order to achieve collaboration at the concept and schematic design phases. However, they still lack an appropriate communication tool (Chantanasin, 2010).

These barriers above similarly appear in the findings of this research. The findings surmised that the barriers to collaboration are caused by (see section 5.4.1):

- **Personal or internal issues:** Internal barriers, based on different backgrounds and experiences and attitudes, also affected by self-centredness.
- **Collaboration issue:** These consists of different workplace locations, time mismatches, and a lack of collaboration.
- **Communication issue:** This issue emerges from a difficulty in sharing and understanding the contents of communication among relevant stakeholders. It consists of misinterpretation, misunderstanding, language issue, a lack of communication, and incomplete contents.
- **Tool issue:** A lack of tools for collaboration or inappropriate communication tools to support synchronous and asynchronous collaborations (see section 5.4.2).

2.5 Discussion of collaboration

According to the RIBA Plan of Work 2013 and IPD, there are opportunities for collaboration; for example, gathering participants within design and construction in order to work together from the beginning to the end of workplan. Sinclair (2013) and the AIA (2014) pointed out that both of workplans increasingly condense collaboration at the beginning, particularly within the concept or schematic design, where design has the most of opportunities for change and carries the lowest cost. According to UKOGC, by increasing collaboration from the beginning amongst integrated design team members, around 2-10% of construction costs can be saved (AIA, 2014). IPD advocates a single approach to procurement but can include multi/poly party contracts, whilst the RIBA WP 2013 incorporates different procurement routes, including diverse service schedules and protocols. In addition, RIBA requires all relevant participants to develop design information, which becomes an important source for them in the project and throughout the Work Plan.

However, the nature of collaboration among multiple disciplines in concept design is complex and not always sufficient due to their experience and knowledge, and the challenges of distance, and misunderstanding. Collaboration in the AEC industry involves multiple disciplines with unique experiences and knowledge. They have to integrate across the boundaries of other disciplines and evaluate both their own solutions and the holistic system of work (Carrara, 2012). Working together to achieve the goal of collaboration is complicated, as each participant needs to build and sustain their own knowledge or mental structure (Gautier, Bassanino, Fernando, & Kubaski, 2009) and to understand whatever is shared when participating across multidisciplinary boundaries of knowledge.

At the same time, participants also need to share experience and knowledge with other colleagues, and it can be difficult to retrieve these exchanges. Moreover, due to the current impact of globalisation, modern collaboration has been further developed from synchronisation to desynchronization and delocation. The desynchronization of information exchanges present more complex problems for communication in terms of collaboration (Carrara, 2012). In addition, developing a landscape of innovative collaboration can prove problematic due to the social problems that emerge from several specialists working across cultural boundaries (Carrara, 2012). It can lead to the additional problems of misinformation and the misunderstanding of messages, which complicates the exchange of design information and increases the potential for conflict (Carrara, 2012; Poole, 2011 cited in Sun, Mollaoglu, Miller, & Manata, 2015).

In Thailand, collaboration is still traditional, and used with primary procurement methods, such as design-bid-build, CM, and design-build methods and contracts without the development of innovative collaboration. These collaborative methods can be recommended to the Thai AEC industry for adoption in part of their project delivery method or to invoke relevant Thai AEC representatives (ACT, EIT, and TCA) to create their own innovative work plan. This would be appropriate for the Thai environment of collaboration among relevant stakeholders or for international practice (globalization). Significantly, complex issues of collaboration in both the UK and US might be considered in the cycle of collaboration development, which needs to understand and address problems associated with the impact of globalization, social issues, and knowledge sharing.

2.6 Summary

The AEC sector suffers from inefficient design, which causes problems with productivity in terms of quality, cost and time. These problems are partly related to the concept design stage (the schematic design phase in the USA, or the concept and schematic design phases in

Thailand), This is where the initial design problems are passed through to the later stages from the design development to the construction and use stages. This chapter therefore discussed the definition of concept design and collaboration and the role of stakeholders at the early stages. Design processes are explored internationally, both in the UK and USA, as well as in Thailand. Furthermore, the integrated approach and the RIBA Work Plan 2013 have helped to develop the concept of collaboration by introducing other disciplines at the beginning of the design phase. On the other hand, the Thai approach, guided by the ACT, is similar to the USA's primary approaches in gradually including other disciplines for collaboration in the process, from the beginning to the construction phase. However, the IPD approach has been used in Thailand. In Thailand, existing problems arise in the design process and in traditional collaboration among relevant stakeholders. This can include incomplete drawings, reworks, and poor communication. The design conflicts or problems are revealed at the construction phase, which implies that the design process has not been approved and developed to emphasise collaboration. Thus, the Thai design process should be required to improve collaboration among relevant designers in its concept design to overcome existing problems. Having understood concept design, the next chapter will investigate and discuss existing tools that stakeholders can use to undertake conceptual design in a project.

CHAPTER 3:
TOOLS IN CONCEPT DESIGN

3.1 Introduction

In this part of the literature review, the focus is to examine existing evidence regarding the instruments adopted within concept design, including thinking, traditional and modern digital tools. Generating design ideas involves brain processes, from visual functions to thinking processes, and this relates to a designer's intuition. This literature review explores models to explain design thinking. Both traditional and digital tools are explored, and how they are adopted in early-stage design. In addition, this chapter also describes the employment of these instruments alongside communication tools, in the context of early-stage collaborative design teams. For in Thailand, the employment appears in the chapter 5. The gaps within the research are identified at the end of this chapter.

3.2 Thinking in Design

Design thinking is an intuitive process and relies on the incorporation of personal experience and subjective artistic judgment (Architecture Institute of America, 2014). The process involves visual data input, which influences the visual function in the brain to generate ideas. Creative, critical and visual thinking are explored to understand the process which is used in design thinking.

3.2.1 Creative and Critical Thinking

Creative and critical thinking are significant in design and play a role in conceptual design and architecture design processes. Creative and critical thinking are also known as the generation of ideas and rational thinking; creativity masters a process of making or producing, whilst criticality relates to a process of assessing or judging (Paul & Elder, 2004). Concept design will not be achieved without both of these processes. As a result, a concept design is generated from the designer's imagination and involves a balance of criteria: goal, requirements, primitives, constraints and the environment (Laseau, 2001). Significantly, Paul and Elder (2009) stated that generative power (creativity) and judiciousness (criticality) function as one in the thinking process, and are only separated artificially. Critical and creative thinking are actions of the mind, which need knowledge as a natural source and skill to deal with the processes in the mind. These actions of the mind are involved with problem solving, and are intensively driven by analysis, synthesis, and evaluation (Lawson, 2006) (Figure 3.1). Creative and critical thinking need to be understood and analysed in order to explore ways to assist design.

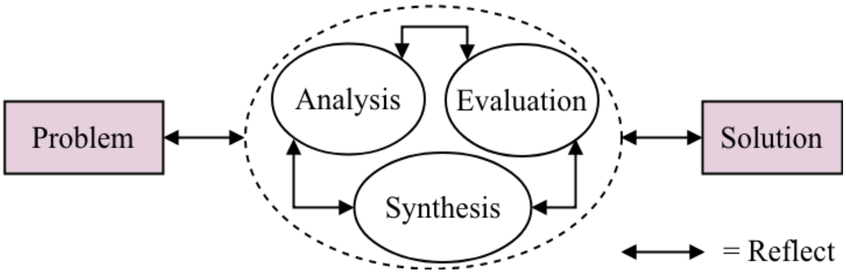


Figure 3.1 Lawson's Problem Solving
(Source: Modified from Lawson, 2006)

Creative thinking is regarded as thinking that is artistic and free, imaginative and spontaneous, original and intuitive. When an individual thinks creatively, they produce something novel; an aesthetic object, a new approach to an ethical issue, a reasoned argument, or an experiment (Oxman-Michelli, 1992). Okpara (2007) echoes the definition of Oxman-Michelli (1992), that the art of problem solving is generated through imagination and rational thinking, which is an activity of the mind enabling the exploration and discovery of solutions (Okpara, 2007). To see or do in a novel way helps designers to explore their thoughts, and can lead to the discovery and generation of solutions. This is highlighted in Ellis Paul Torrance's four components of thinking, addressed in the *Glossary of Thinking-Skills Terms* (Alvino,1990, cited by Cotton, 1991) and illustrated in Figure 3.2.

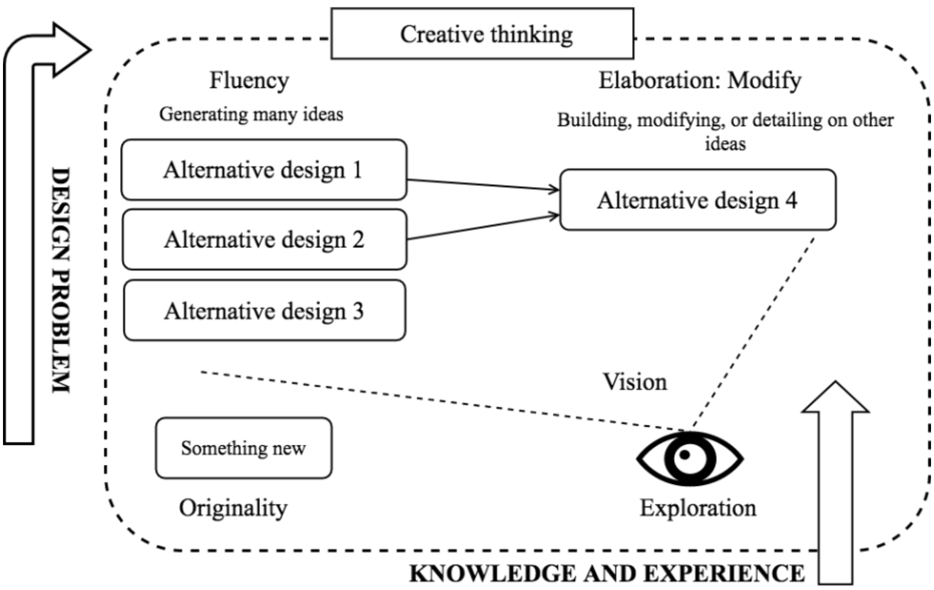


Figure 3.2 Ellis Paul Torrance's Components of Thinking
(Source: Summarised from Alvino,1990 Cited by Cotton, 1991)

1. FLUENCY - generating many ideas.
2. FLEXIBILITY - shifting perspective easily.
3. ORIGINALITY - conceiving of something new.
4. ELABORATION - building, modifying, or detailing on other ideas.

Williams addressed all of these components are also addressed in terms of the cognitive factor for creativity; he refined the cognitive factor in his Cognitive Affective Interaction Model that consisted of fluency, flexibility, originality and elaboration (Hsiao, Wong, Wang, Yu, Chang, & Sung, 2006). Hsiao et al. (2006, p.411) stated that flexibility is "a variety in the directions and categories of thinking related to questions, responses, etc.". In this research, flexibility is identified as a map of creative design ideas, which enable the designer to explore a change of direction. Ellis Paul Torrance's four components is one kind of creative thinking tool.

The three components of fluency, originality, and elaboration become the main components in generating ideas from internal representation to external representation. Flexibility, the fourth component, can assist in exploring other ideas from external representation. Knowledge is important as a natural resource for creative thinking. Technical ability represents the skill of putting existing ideas together in new combinations (Okpara, 2007). These creative thinking models can be condensed so that creative thinking emphasises the activity of the mind. In addition, the exploration of solutions must be original and appropriate in order to create something novel.

In terms of critical thinking, the adjective 'critical' denotes its evaluative possibility, referring to a meaningful and constructive interpretation of information (Lizarraga, Baquedano, & Villanueva, 2012). Critical thinking directly relates to logic, analysis, and judgment, and is applied when evaluating information from experience, knowledge, and principles (Oxman-Michelli, 1992). It is the linear process of adopting information, conscious logic and rational thinking to form knowledge and understanding, or reach a decision (Sofo, Colapinto, Sofo, & Ammirato, 2013). Similarly, Olivares, Saiz, and Rivas (2013) stated that a solution is generated between reason and decision, both of which depend on skill and a desirable knowledge of reality or greater wisdom. Critical thinking can be defined as an action to attempt to solve problems through the analysis of information and an evaluation of principles and knowledge, or wisdom based on rational thought and decision. An external representative can help to address analysis and evaluation, which is recognised diagrammatically as a tool for critical thinking. The diagrams are generally abstract and made of symbols; they do not have a scale and do not relate to pictorial representations (Parthenios, 2005).

In summary, creative and critical thinking are actions of the mind, which need knowledge as a natural source and skill for processing in the brain. Although Paul and Elder (2004) stated that creative and critical thinking comprise one process, the solution becomes the output of both, which varies depending on the thinking characteristics (Paul & Elder, 2004). Critical thinking adopts a linear dimension that needs to start with the analysis of information, and the evaluation of analysed information through reason and decision. In the contrast, creative thinking is not a linear dimension and is thus more complex to explore. Resource and knowledge are required to find an appropriate solution in synthesising novel ideas.

According to the meaning of concept design, designers progressively develop creative ideas from abstract to concrete. Collaboration among multidisciplinary designers offers opportunities to closely work together in the concept design stage. Multidisciplinary designers come from different backgrounds and can possess varied skills and thinking approaches. To develop a digital tool, this research needs to consider support for creative and critical thinking in order to address both the internal and external representation of participants' minds. The features underpinning creative thinking include: fluency, originality, elaboration, ideas generation, and flexibility in supporting the exploration of other ideas. Critical thinking requires a capacity for describing information in order to facilitate reasoning, for example, measuring the dimension and area of objects.

3.2.2 Visual Thinking

Tools used in the concept design stage enable crucial communication between multidisciplinary professionals. Over previous decades to the present day, visual thinking has played an important role in assisting these professionals to produce concepts and communicate collaboratively in the concept design stage of the AEC industry. Goldschmidt (2014, p.445) defines 'visual thinking' as:

> A preferred cognitive strategy in design because it is useful to work with visual representations when endeavouring to arrive at the creation of a tangible entity that must by definition have distinct spatial/visual properties.

The process of visual thinking is also described by Ware (2010) as a kind of movement stimulated from the environment, with some information stored internally, and some externally. It is an internal-external dance of cognition that leads to a greater understanding of how design information can be gained and its meaning (Ware, 2010). Visual thinking uses internal and external images, to act as important triggers in influencing professionals, such as architects, engineers, and designers; this aids the design process by enabling the integration of complex information. Internal images are formed when mental visual imagery temporarily makes pathways in the brain. These internal representations can be subjected to diverse transformations or deleted to clear the memory in a short-lived cycle. Enormous energy must be invested to continually refresh internal representations or to prevent them from fading away. External representations are created in the physical world and are important for two reasons. Firstly, they enable explorative thinking, and secondly, they can be loaded into memory. Design information is often complex and needs significant memory capacity to process. Thus, external memory becomes a necessary tool to enable immediate access to information and to extend capacity. This helps to reduce the cognitive load associated with attempts to retrieve and maintain these items within the long and short-term memory (Goldschmidt, 2014).

In terms of visual thinking, both traditional and digital tools are classed as external. These tools will be explored through the concept design stage, which consists of three main sub-sections: sketching, model-making, and digital tools. These sections each have particular characteristics and functions for developing representations and for use as thinking aids.

3.3 Analogue tools in design

Throughout history, different types of traditional tool have been used extensively to assist designers in understanding what they create, and for communicating with other designers and the wider multidisciplinary team. In the initial development of concept design, sketching and model making become the main analogue tools used within the construction industry, and have also been applied in the field of education. However, due to the widespread introduction of digital tools, analogue tools, such as sketching and model making, have declined in use in professional offices. Despite this, it remains necessary to explore and discuss the traditional tools of sketching and model making, and to identify their utilisation and weaknesses.

3.3.1 Sketching in the Initial Design Stage

In Europe, paper of sufficient quality existed from the end of the Fifteenth Century, which enable designers' sketches. Since then, designers have used sketching to transform and develop their thinking to solve design problems. Although it is used throughout the design process and is versatile, sketching is likely to be influenced by the designer's objectives in the concept design. Fish and Scrivener (1990, cited in Schubert et al., 2014) stated that the essential qualities of sketching within the design process are that it contains selective and fragmentary information, intentional or accidental indeterminacies, and the ability to gain three-dimensional experiences from two-dimensional representations. These attributes demonstrate why sketching is considered to be an appropriate tool for the initial stage of the design process.

The first important attribute of sketching is that selective and fragmentary information gathered by designers can be easily seen on paper. Designers use mental visual imagery to explore or attempt to solve design problems; however the brain has a limited capacity and cannot store all the images generated (Fish, 2004). These mental pictures need to be stored temporarily elsewhere to await other fragmentary information. Transferring ideas to paper enables all of these pieces of information to be gathered leading to evaluation and creation of ways to develop design solutions.

Secondly, it is stated that intentional or accidental indeterminacies become an important function that are used when designers sketch from vague and incomplete design information. This makes sketching an ideal tool for a gradual design development. Vagueness is described as the reason needed to preserve alternative ideas among complex design information. Designers can be stimulated to create more design alternatives from rough sketches, and multiple interpretations of items, such as incomplete contours, wobbly lines or symbols (Tseng, 2007; Tseng & Bell, 2010). This vagueness helps designers to translate thoughts that emerge in their mental visual imaginary before they disappear from the temporary memory.

The final attribute of sketching is that it encourages the translation between diverse modes of visual representation, moving from two-dimensional to three-dimensional space. The representation of three-dimensional information in a two-dimensional form is an essential attribute of the visual thinking process, and supports the designer's creative work in perceiving and translating complex ideas which are then refined to simplified design information in the thinking process. As external images are two-dimensional forms in sketches, these can be loaded into the memory and immediately encourage explorative thinking, thereby supporting the designer to maintain their spatially depictive imagery (Schubert et al., 2014).

Similarly, other functions of sketching noted by Fish (2004) include the recording and communication of ideas, including hypothetical functions, and the amplification of a designer's visual thoughts and inventions. Fish noted that hypothetical functions connect to each other and support sketching as tool in design cognition; they enable the translation of representational type, the retrieval of perceptual memory, and the superimposition of mental imaginary. Firstly, sketching is positioned between depictive (picture-like) and descriptive (language-like) representations, which are independent components, and need to interact efficiently within working memory. Secondly, the attributes of a sketch exploit the unconscious process, which can be inventively or accidently stimulated, and provide fast access into long-term memory for human perception and object recognition processes. Thirdly, sketches are percept-memory hybrids, which stimulate a percept that invites the completion from memory and the imagination of incomplete design information. Such properties support the generation of temporary mental images that are transformed and spatially superimposed on an internal representation of the sketch after a matching process. Fish (2004) concludes that the translation of representational type is the main hypothetical function, which is served by perceptual memory retrieval and superimposed on mental imaginary functions through a medium, such as the sketch (Fish, 2004).

The creation of representational and feedback loops is enabled by this tool in relation to both external and internal representations, and in terms of the designer's visual thinking. Sketching provides a fast and cognitively cost-free representation that encourages the use of a cyclic 'dialogue' between the mind and hand; the hand is the operator for sketching and the eyes provide the visual perception of the design information captured on the paper to instigate feedback to the designer. In the same manner as Laseau (2001), the communication loop comprises four parts; the eyes, brain, hand, and sketch. Laseau (2001) explained that the eye, assisted by perception, can identify an important point or area in which selective information exists and other design information is excluded. The hand and sketch are also important within the process, creating an image sketched onto paper for insertion into the dialogue cycle. Theoretically, more often the design information is circulated around the loop, providing more opportunities for the designer to change or develop their ideas.

One of the advantages of sketching is that it allows the fast representation of design ideas, which exploits the designer's tolerance for inaccuracy, incompletion and a lack of scale in favour of the main advantages, which are the ease and speed of sketching (Goldschmidt, 2014). Thus, sketching tends not to require the accuracy associated with detailed drawing. The sketched design information can be created as incomplete elements, which can then be stored in the mind; the elements not represented on the paper may be already present as components in the imagination, due to the cognitive integration of internal and external representations. Similarly, neither scale nor accuracy present obstacles for designers who use this method to deal with design problems. Their mental imagery can deal with anomalies in the absence of scale and accuracy by using their own perception of proportion and estimation.

A common traditional technique of sketching enables designers to modify elements in a design by employing an eraser on paper (Goldschmidt, 2003). Alternatively, transparent paper laid on the top of the sketch allows for the exploration of alternative solutions by tracing; this is often a preferable method to address a design problem. It allows the designer to re-sketch on new layers and to transform objects without losing the original concept. This can allow for alternative designs by tracing on new layers or new, overlapping papers (Goldschmidt, 2014). Although designers have been trained to practise in orthogonal projections in order to create space in their sketches, they have also created space from the use of sections and plans in order to broaden their understanding of the design. This technique is still frequently used in the initial design process.

According to a survey by Parthenios (2005) that gathered data from 242 architects on the tools they used for concept design, it was discovered that sketches proved to be extremely productive as a starting point for conceptual design. In his research, sketches can be categorised into two informational components - geometrical and non-geometrical (see Figure 3.3).

Non-geometrical information can be classified as both text and diagram; diagrams are generally made of symbols and are abstract; they do not have a scale and do not necessarily relate to pictorial representations. The text may contain the required project information, ideas for solutions, thoughts, questions and feedback from other designers. Geometrical information can be divided into three areas, consisting of representative, abstract and symbolic sketches. Representative sketches detail spaces and forms at a recognised scale; they can be realistic or fully detailed. Abstract sketches enable designers to capture the notion of the form or space, provide a perception of contextual relationships, or convey a loose concept in which these sketches allow for interpretation through a level of abstraction (Parthenios, 2005). Symbolic sketches are made of symbols to show a concept; moreover, they retain some spatial characteristics and relationships without literalness.

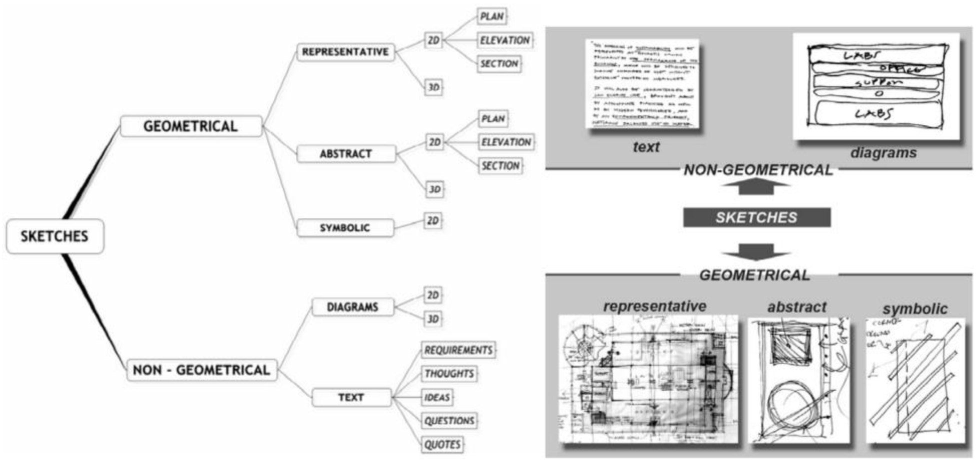


Figure 3.3 Categorisation of Sketches
(Source: Parthenios, 2005, pp.136 -137)

Thus, the use of this medium is encouraged amongst designers as it supports the immediate communication of their ideas and a cost-free cognition that does not obstruct their thought process. Indeed, the internal memory of the brain is limited in its ability to store complex design information for an extended period of time. Although designers will not use any external tools to deal with the imagination, they will invest enormous energy in the preservation of their design information (Bilda & Gero, 2007). Therefore, sketching is currently appreciated as a useful traditional tool, both for use in the design process and for communication.

3.3.2 Model-Making in concept design

By the late 1800s, designers, such as Antonio Gaudi, had begun to use models to explore structural ideas and to aid development in the concept design process (Smith, 2007). Model making became recognised as a design tool to supplement the limitations of sketching's orthographic and perspective-based drawing methods in the communication of the design intent. In the 1920s and 1930s, its usage increased, and it became an integral component of architectural education and practice. Until modern times, it has been a powerful tool for exploration and has been only been challenged by the development of digital tools.

Kvan and Thilakaratne (2003) explained that models are used in architectural and engineering design for several purposes at the early stage of a design cycle; these include exploration, experimentation, and presentation purposes. These models are made as abstract representations, and not the replication of realities; thus, their scale, accuracy, and material can be altered depending on the specific objective for which they have been created. Therefore, architectural models do not represent the properties of materials, true colours, or textures (Kvan & Thilakaratne, 2003). For designers, a physical model is as important as other media, as illustrated in Figures 3.4 and 3.5. Dunn (2014) states that the physical model is important because it supports design in an experimental and precise manner; indeed, other elements of the project may not appear to make much sense until these models are visualised in three dimensions (Dunn, 2014). These models are miniaturised which makes them easier to manoeuvre and manipulate in order to study and observe their design elements, such as proportion, space, or mass, and to show the relationship of form, scale, and environment (Dunn, 2014), as illustrated in Figures 3.4 and 3.5.

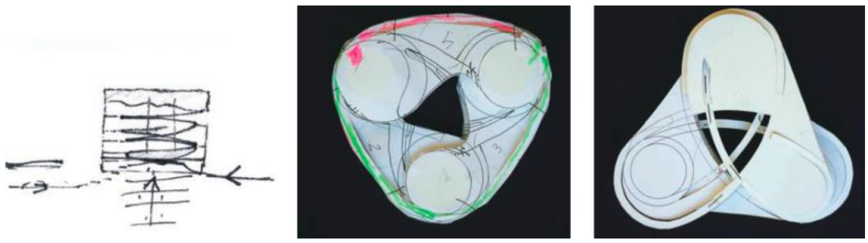


Figure 3.4 Developing Sketching into Model-Making.
(Source: Dunn, 2014)

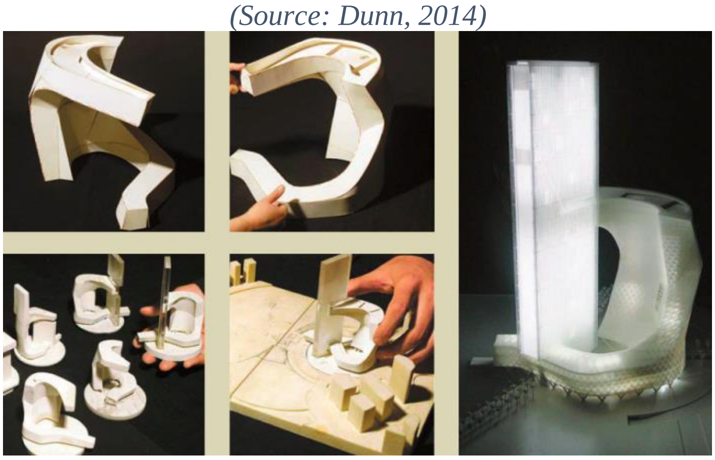


Figure 3.5 The Relationship of Form, Scale, and Environment.
(Source: Adapted from Dunn,2014)

In the initial stage of the design process, study models are created to examine particular aspects of design ideas, which are transferred by sketching from the designer's imagination. These rough models encourage the designer to better consider their ideas and make informed decisions in the design process. Model-making does not only assist visual thinking, giving a clearer perception of three-dimensional imagery, but also encourages designers to explore different forms and to understand the relative scales of a project within the surrounding environment (Kvan & Thilakaratne, 2003; Zaman, Ozkar & Cagda, 2011). These rough models are not just created as one single type; they can be classified depending on their intended objectives, which include sketch, diagrammatical, concept, massing, and solid/void models (Mills, 2011). Massing and solid/void models, as illustrated in Figures 3.6 and 3.7, are frequently found at this stage of the design; they are used to explore the building's volume and its relationship between the open and closed areas. This enables the consideration of environmental constraints, and the form and function of the building, including the mass and space of the concept.

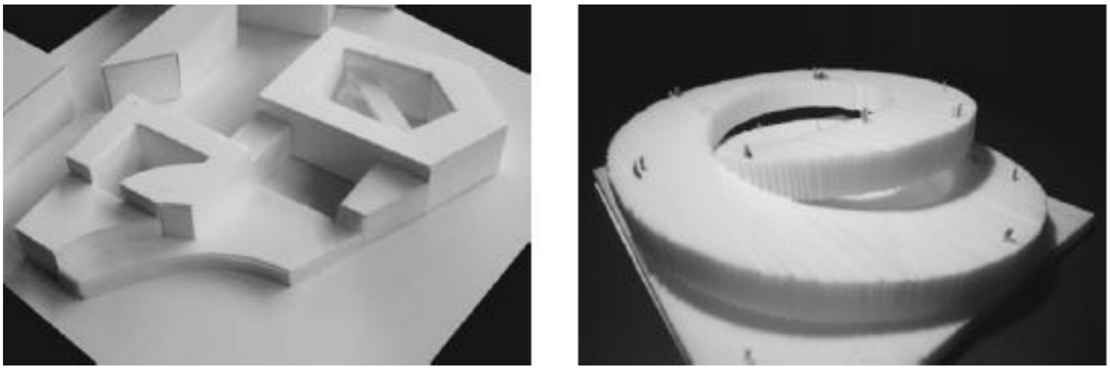


Figure 3.6 Massing Models in Concept Design
(Source: Mills, 2011, p.7)

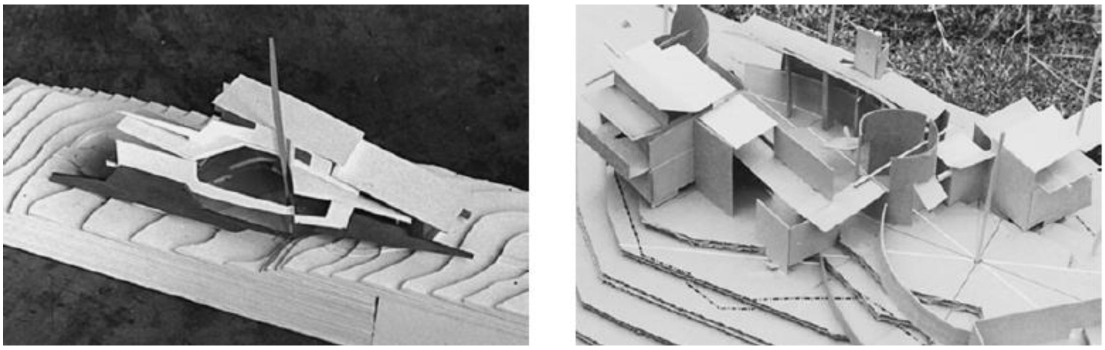


Figure 3.7 Solid/Void Models in Concept Design.
(Source: Mills, 2011, p.8)

Before this point, it was claimed that physical models had been difficult to make in ways that represent certain architectural forms. Thus, 2D and 3D Computer Aided Design tools - Computer Aided Manufacturing (CAD-CAM) - are now progressing their capabilities to enable designers to share files from digital tools, such as Non-uniform rational basis spline (NURBS) modellers or traditional polygon software, and to print out physical three-dimensional models from digital models (Barrow, 2006). These advanced software programs are entering the creative design process and are increasingly enhancing the designer's ability to explore and design their own creativity.

The traditional tools, which are the focus of this part of the literature review, are sketching and model-making; both of these are used for exploration in design creativity at the concept design stage. Sketching is still a powerful tool to enhance the designer's ability to use and simplify complex information, and to represent the relationship between two-dimensional and three-dimensional forms. Similarly, physical models support sketching in the communication process between individuals who are involved in the design process. They create collaborative working methods and a three-dimensional reality in the physical world.

3.3.3 Disadvantages of Traditional Tools used in the Early Design Stages

Traditional tools, such as the sketch and physical models, are used in the concept design stage, which is the early stage of the process in the AEC sector. Although many advantages are known, there are also several disadvantages to their use. For example, the physical model consumes significant amounts of time to build or to add fenestration. Sketching on paper in either pen or pencil also has its drawbacks, such as a lack of modification capability, design memory, and interaction between the designer and the paper-based design (Landay & Myers, 1995). Four key limitations are discussed in more detail in this section.

Firstly, paper-based sketching has limited options for modifications due to its physical constraints where the original intent is lost once a change is made on the paper. Designers preserve their thoughts and design details by immediately sketching on paper before they disappear from their temporary memory; as such, they must frequently redraw to retain the design (Landay & Myers, 1995). Similarly, Rahimian, Ibrahim, and Jaafar (2008) also point out that sketch as a tool is limited by its fragility in term of editing and review. The designer is unable to easily change or resolve the design alternatives.

Secondly, a sketch has no capability for interaction between designers, and paper-based design also has limited physical attributes (Landay & Myers, 1995), which prevents users' physical interactions and control (such as through zooming or panning, as is the case with computer software). Landay and Myers (1995) stated that designers have to manipulate several sheets of paper and/or models to understand what they actually see. In addition, Rahimian et al. (2008) state that this medium has a low degree of capability for visualising design alternatives. It does not support the activity of designers in enabling shifts and alternations between micro and macro levels, and designers face this weakness through the frequently changing scale of representation (Rahimian et al, 2008).

Thirdly, design sketches are understood to represent knowledge, which should be managed and recorded (Herbsleb & Kuwana, 1993). A lot of design sketches can serve as a diary of the design process and often prove more valuable to both the client and designers when these design sketches are annotated to indicate the reasons why particular decisions are made. However, it is not easy to go back and search for evidence; this problem highlights a lack of support for the 'design memory' (Landay & Myers, 1995). Moreover, finding this evidence means it becomes difficult to maintain design ideas between the design process and the transfer of these design sketches, which have to be used at other design stages (Rahimian et al., 2008).

Finally, a crucial limitation of the paper-based sketch is that its characteristic medium, namely paper, does not support a shared physical space, thus impeding collaboration among designers (David, Eoff, & Hammond, 2010). Nevertheless, sketches based on paper are advantageous in that they enhance collaborative activities by providing an external representation through interaction with team members. Thus, they establish collaboration in order to focus attention on design groups and this eases communication (Craft & Cairns, 2009). According to an experiment by David, Eoff, and Hammond (2010) on how the paper interface affects the ability to collaborate, participants implied that they were obstructed by the paper interface due to its lack of shared physical space. User feedback confirmed worries regarding the physical constraints of other hands being able to draw on the same spot. It is, in fact, generally recognised that each team member requires a personal area, and that this is limited by the paper dimensions and the need to sketch on a shared paper interface. At the same time, it is almost impossible to facilitate collaboration amongst team members. Thus, Zhu, Dorta, and De Paoli (2007) point out that sketches create difficulty in the communication of ideas between designers and other specialists using the traditional design method.

In considering the aforementioned drawbacks, the following points can be summarised:

1. Physical models are time-consuming to build and cannot be easily modified when designers need to alter and improve their ideas.
2. Sketch is a rigid 2D tool and its physical limitations means that it lacks the characteristics to enable interaction between the designer and the paper-based design. In addition, there is no capability to manage the visualisation of design alternatives, to reform alternative designs, and to modify the objects drawn.
3. Sketches are knowledge resources, but they are unable to support design memory.

4. Paper-based sketches have a low capability to communicate for collaboration, and to facilitate designers in working together with partners at the same time and on the same 'spot'.

Therefore, in terms of the traditional tool, this study has identified that, although the sketch is an intuitive tool to support the streaming of a designer's creative thinking, there are problems, such as the physical limitations of paper and the limited interaction with users, a lack of support for design memory, and the low capability for collaborative communication. These limitations could be improved with the development of a digital sketch tool to enhance the ability of designers to access these resources of design memory and collaborative communication.

3.4 Digital technology

The utility of BIM tools in the UK and USA has been driven to integrate activity within the concept design stage. In Thailand, BIM has similarly been promoted and the Architecture Council of Thailand and Council of Engineers (Thailand) have supported the development of knowledge using BIM tools in the design process. Naturally, the concept design stage is complex and deals with several digital tools, whether CAD or BIM based. The exploration of these tools can enable an understanding of how current paradigms at the initial design stage tend to use these digital tools and what causes the drawbacks that appear in digital tools.

3.4.1 CAD Software Computer in Concept Design

The CAD system was built and has been continuously developed since the 1970s; its use has been supported among stakeholders in the AEC industry. Egan (1994) recommended the adaptation of new technology in the UK AEC industry in order to provide better products and with the goal of improving productivity through lower design costs and shorter design project completion times. Later, the CAD system became part of AEC organisations, which invested in the purchase and installation of CAD tools in their workplaces. Narayan, Rao, and Sarcar (2008) claimed that there were several reasons for the implementation of CAD, as follows:

1. To increase the productivity of designers, which was the most important reason;
2. To take advantage of the tool to improve design quality;
3. To improve communication through documentation; and
4. To create a manufacturing database (Narayan et al., 2008).

Narayan et al. (2008) explained that the CAD system helps designers to visualise, synthesise, and analyse design products and alternative designs, which increase productivity in terms of cost and time. In addition, design errors are reduced leading to improvements in design quality and accuracy due to the high degree of capability amongst CAD tools. CAD tools encourage more efficient drawing and greater standardisation, which improves the quality of the design information exchange and improves communication and collaboration among the stakeholders. Moreover, the product design documentation, such as the bill of materials or digital files, are also managed and collected in the database (Narayan et al, 2008). Lawson (2005) pointed out that, in order to narrow CAD implementation, normal usage CAD can be efficiently implemented in design, planning and construction to assist in drafting and documentation. However, it is difficult for the designer to use high memory resources to develop design solutions and to thus keep many things in mind at the same time for rapid decision-making when using a computer tool (Lawson, 2005)

Currently, CAD tools aid the designer in the design process within the AEC industry. This includes several types which are categorised (Parthenios, 2005) into five groups; draft tools, modelling tools, BIM, concept design tools, and others, which are listed as follows:

1. Draft tools: generic CAD programs such as AutoCAD;
2. Modelling tools: including 3D modelling applications such as 3ds Max, FormZ, Bonzai3d, Rhino, and Maya;
3. BIM tools: classified independently by 2D and 3D modellers, such as Autodesk BIM, Bentley Architecture, ArchiCAD, MicroStation, and Vectorworks;
4. Concept design tools: including stand-alone software and plug-in software, such as Fromit360, Grasshopper, Rhinoceros, Bonzai3d®, and SketchUp®; and
5. Other groups: tools used for calculating or graphic representation, such as Excel, Illustrator, or Photoshop.

The sketch is still a dominant tool used to produce creative ideas in the concept design process, which needs swift design exploration and low cognitive demand in order to accommodate a designer's knowledge and intuition. However, there are also acceptable lightweight CAD tools, such as SketchUp, Rhinoceros, and Bonzai3d; these can facilitate the designer's need to explore and conceive ideas during this process (Eastman, Eastman, Teicholz, & Sacks, 2011). As these lightweight tools have the characteristics of a 3D modelling tool, Eastman et al. (2011) stated that they have an intuitive user interface, which enables easy operation to create the forms of models without the behaviour type of objects, and with the reduced complexity of graphical user interfaces.

These lightweight tools have the capability of providing a user-friendly interface to create a 3D model based on the polygon model type, such as SketchUp and NURBS (Non-Uniform Rational B-Splines), including Rhinoceros, and Bonzai3d. A crucial advantage is that they can support the import and export of other file formats, such as AutoCAD DXF and DWG, 3DS, IFC, and BIM models. They have an enhanced capability for file-sharing to connect with other software and BIM tools, such as AutoCAD, 3ds Max, Revit, and ArchiCAD. In addition, these software tools can also facilitate design teams' communication with each other with regard to spatial and visual considerations (Eastman et al., 2011). Other software tools support the concept design stage, such as spatial programming, energy usage or financial feasibility; these are provided and integrated as plug-ins with the BIM tools from software companies. However, Eastman et al. (2011) admitted that the experience of building creative ideas is still difficult from the perspective of conceptual design. This is due to its complexity and cognitive load, which includes a steep learning curve. The weakness of the somewhat unfriendly user interface then becomes the main factor in restricting 'creative exploration'.

To summarise, CAD tools used in the concept design process are currently all developed by commercial software providers who still need to consider the potential for more intuitive and creative thinking software. According to the literature, lightweight tools are more readily available when creating 3D modelling although digital tools with greater capabilities in the concept design process are needed. These would enable designers to explore and further develop their ideas from abstract to concrete levels with 2D rather than accurate 3D models for spatial and visual considerations. Nevertheless, none of the CAD tools can be appropriately used to support all features of concept design (Eastman et al., 2011). Thus, CAD and BIM tools are useful for designers when adopting a design product to enable them to reach high levels of productivity in terms of quality, cost and time. On the other hand, to support the building of creative ideas using CAD and BIM tools, there has been an overall lack of improvement since the 1970s.

3.4.2 BIM tools and Information Sharing in the UK

It is widely accepted that BIM tools can assist teamwork between professionals in the AEC industry and it is claimed to provide a collaborative system for information sharing to reduce errors and increase efficiency in the design process. To better understand this tool, it is important to start with its definition. BIM (Building Information Model) is defined by the Construction Project Information Committee (CPIC) as a:

> ... digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition (Snook, 2011).

The emphasis of BIM is not on what software vendors are providing (Revit, Bentley, or ArchiCAD) to support the AEC industry, but on its ability as a tool to re-use and co-ordinate information, and its function as a shared knowledge resource, which should be considered at the beginning of the process. Many activities can be summarised and illustrated by the model diagram of the BIM evolution ramp in the AEC industry (Bew & Richards, 2008). This provides a guide to the levels of BIM adoption, from manual drafting to a fully integrated and interoperable BIM. The BIM Evolution Ramp (Bew & Richards, 2008) illustrated in Figure 3.8, includes steps, which can be enhanced within the process to achieve seamless working and efficient data and process management, with the potential to remove error and reduce waste at levels 1 and 2. The system can increase profit through a collaborative process, when design information and processes are fully integrated and interoperated within the BIM file format, Industry Foundation Class (IFC) at level 3 (Bew & Richards, 2008). This diagram is widely referred to in the UK industry as the UK Government's phased implementation programme is based on these levels (Sinclair, 2012). Following the phased implementation, the UK government required fully collaborative BIM Level 2 (with all information shared) by 2016 on all public projects (Cabinet Office, 2011).

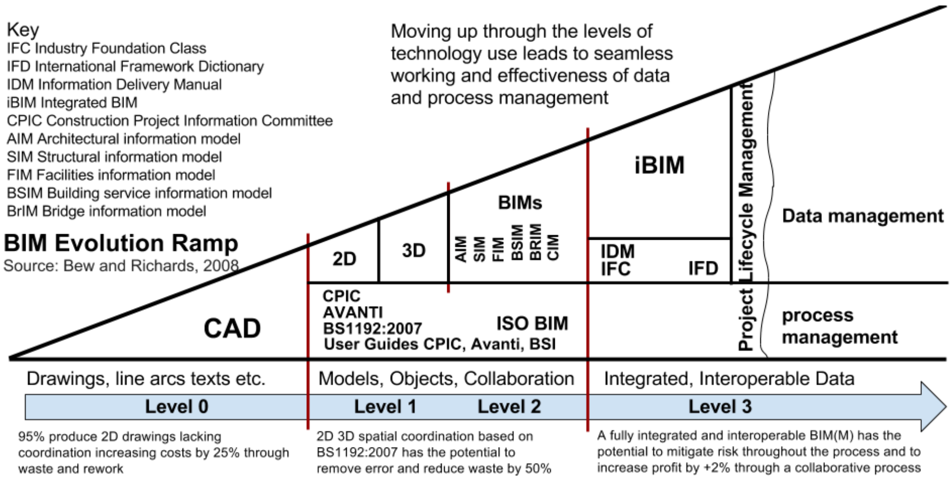


Figure 3.8 BIM Evolution Ramp
(Source: Modified from Bew & Richards, 2008)

The whole process of the AEC industry is characterised by chaotic communication patterns due to the widespread and temporary nature of projects, and the discipline-specific teams. These teams involve people who are engaged in an intense collaborative process requiring sophisticated software tools (Charalambous, Thorpe, Demian, Yeomans, Doughty, & Peters, 2013). The strength of BIM is in its virtual pre-assembly, error checking, on-site construction coordination, building maintenance, and interoperability. Since 2011, the BIM adoption target of 2016 has been mandated by the UK Government, which is considered one of the leaders in developing an innovative strategy to push forward social change with the aim of enhancing interoperability throughout the whole AEC industry.

Sinclair (2012) recommended that BIM should be used in the design work plan at the concept design stage. Its important steps are as follows:

1. Pre-start meeting for BIM usage.
2. Creating concept level parametric objects: all objects in architecture, such as functions or circulations, will be made as parametric objects.
3. Enabling design team access to BIM data.

The architecture team can run a pilot to fulfil their responsibility to consider the scope of their activities and to set up all items within the BIM model as mass or parametric objects. Then, other design teams will start the interoperability and gain access to the collaborative BIM environment. All design teams can use BIM to work with their outline architectural design, including structural engineers and mechanical building services. In addition, it is recommended that BIM data is used for the environmental analyses and appraisals with these parametric objects. However, this is the first recommended step for BIM usage, and the most strategic point to use the tool in the early detailed and construction design stage. Leon and Laing (2013) pointed out that the current paradigm for the early conceptual design stage still tends to use an analogue approach for communication among designers. In the next section, the digital tools are explored to better understand their disadvantages.

3.4.3 Disadvantages of Modern Tools used in the Early Design Stages

Currently, CAD usage is common amongst stakeholders and construction offices in the AEC industry and throughout which almost all stages of construction projects, which are driven and supported by these modern digital tools. Whilst CAD efficiently supports conceptual design in terms of drawing, presenting, simulating, energy analysis, and financial feasibility, there are still some drawbacks that do not fully support designers at this stage. However, with significant usage in computing, these tools should be able to help users to deal with reasonable, complex objects and to provide quick feedback allowing for intuitive visual evaluations in the design process (Eastman et al., 2011).

Eastman et al. (2011) positively reported that these commercial tools used in concept design empower the quality of decision-making and do not present problems for users while working with the designer's through process. They also state that these tools enhance the designer's ability to assess proposals at the sketch level of the concept design stage. In particular, these technical terms represent an opportunity to articulate energy, costs, and some aspects of function. Lightweight tools, such as SketchUp, Rhinoceros, and Bonzai3d, are accepted as concept design tools by a few architectural designers, who are familiar with them, suggesting that they provide 'almost real-time' feedback (Eastman et al., 2011). However, these tools do not address the creative and communicative roles of designers, who are required to work together remotely or co-located, to enhance the design process (Reffat, 2005). Henceforth, BIM is becoming a useful tool in almost all processes including some parts of concept design. Eastman et al. (2011) stated that BIM design applications have too steep a learning curve, are a complex method due to many state-dependent operations, and almost prohibit creative exploration because of their operations and user interfaces. However, the crucial weaknesses of CAD tools emerge through their difficult user interfaces, laborious use of input/output devices, the removal of suitable features akin to traditional design processes, and the rarely featured communication for collaboration. These issues are further outlined as follows.

Firstly, vagueness in traditional design thinking is a useful feature, which is removed from modern digital tools in the concept design phase. CAD tools need more precise information to create models or drawings; however, in concept design, the designer's thinking process needs to interpret vague information from their experience and knowledge (Zhu, Dorta, & De Paoli, 2007). Both CAD and BIM systems are drawn upon to create concrete objects of accurate models and drawings; this consumes memory resources and takes more time to model than creating abstract objects to solve design problems which lead to sub-optimal outcomes (Shapir, Goldschmidt, & Yezioro, 2007; Denzer & Gardzelewski, 2011; Ibrahim & Rahimian, 2010). Ibrahim and Rahimian (2010) demonstrated that the lightweight tool, SketchUp, enables designers to overcome its weak points through additional work; thus, the two-dimensional user interface is insufficient for the manipulation of three-dimensional objects when time could be better spent concentrating on architectural design decisions (Ibrahim & Rahimian, 2010).

Although several researchers have admired SketchUp for its ability to support creative design thinking due to its friendly graphical user interface, there are some queries regarding the limitation of design ideas. For example, Elkær (2009) argues that ideas quickly created from SketchUp tend to generate designs that look very 'boxy'. In addition, when observing users designing with SketchUp they found that they spent more time initially creating the model than generating alternative ideas, and they encountered limitations when considering complex designs (Pietsch, Shannon, & McCarthy, 2006).

Secondly, the complex user interface of CAD and BIM tools impede the thinking process when designers are dealing with the visual process. Creative ideas appear so rapidly that the designer is unable to capture their visual thinking or cognitive modelling before it evolves (Akalin & Sezal, 2009). The creative idea is generated internally as a mental visual image within the human brain and alternates between internal and external representations (Ware, 2010). To accommodate the dual tasking involved in cognitive modelling whilst navigating a difficult user interface, more resources are required to cope with the continual switching of working memory resources instigated by the movement between tasks. Thus, limited resources are engaged in completing the CAD or BIM commands, which leads to the inability to successfully capture visual imagery, and a significant decrease in the capacity for creative thinking. Consequently, these views highlight how the unfriendly user interfaces of CAD and BIM tools and their obstructiveness to the mental workflow and cognitive load of designers, in addition to the consumption of memory and time resources whilst attempting to deal with visual process.

Furthermore, designers frequently struggle with attempts to solve simple design problems due to a lack of support from input/output (I/O) devices. Although CAD tools provide sketch commands for designers, they still struggle with this feature. In terms of their weaknesses of digital I/O devices and compatibilities with existing CAD tools, it has been argued that, due to their lack of intuitiveness, these I/O devices are inadequate for designers at the concept design stage (Ibrahim & Rahimian, 2010). Ibrahim and Rahimian (2010) also imply that the mouse device and command interface of current CAD software do not sufficiently support the designer's graphical tasks as these are intuitive characteristics of the concept design process. A 32-week study by Kim et al. (2015) comparing the use of a mouse and a digital pen demonstrated that a digital pen has a significantly higher performance than a mouse with regard to controllability and accuracy. Similarly, Schubert et al. (2014) supported these findings, stating that the mouse and keyboard are no longer sufficiently intuitive, with designers struggling to use these devices at the concept design stage. Therefore, the research suggests that I/O devices are developing beyond the capabilities of current CAD tools, which now no longer meet the requirements of an efficient user interface and thus support creative thinking at this design stage.

Finally, CAD tools rarely possess a feature of communication that allows collaboration within concept design. Holzer (2007) stated that existing digital tools support high-resolution design solutions more rapidly than a communication framework allows, and this leads to an imbalance between collaboration and communication. Almost all CAD tools are specifically designed for tasks, such as three-dimensional modelling or two-dimensional drawing, and are not supportive of communication for collaboration although they have the ability to share files in the same format. BIM and some CAD tools, such as AutoCAD, have a central server system feature, with email as the medium for communication and collaboration. However, it has been found that e-mail is restrictive for collaboration (Sharif, Matthews & Lockley, 2012). Sharif et al. (2012) demonstrated that large volumes of e-mail cause confusion and distraction amongst users because they cannot identify or prioritise the merit of their content. It has been argued that communication via "e-mail is the wrong medium" for collaboration and communication (Sharief et al., 2012, p.7).

In summary, the general disadvantages of digital tools in the early stages of the design process are:

1. The lack of synchronous and asynchronous tools supporting creative design thinking for collaboration and communication in concept design.
2. The abandonment of suitable features for intuitive tools derived from the traditional thinking process of design.
3. A lack of support for creative thinking due to the complex user interface of digital tools.
    a. The mental workflow is obstructed by complex information and a complex user interface, which consumes the memory load of users.
    b. The cognitive load leads to the decreased efficiency of creative design and diminished design quality.
4. The impediment of the mental workflow and intuitive operations for building creative ideas, which, as a result, mean inadequate input/output devices.

This literature review highlights the efficiency of modern digital tools in supporting designers to enhance productivity, but recognises that there is a gap in capability between efficiency and ease of use. To support collaborative design activities and enhance efficiency in the concept design stage, a new modern digital tool needs to be designed with an intuitive interface that addresses the concerns of the designers and remains user-friendly. Moreover, a digital tool in concept design should not only be concerned with reduction of complexity in the user interface, but also with the support of new devices, such as the tablet and digital pen. This will provide additional support to designers, and mean they no longer need to rely on traditional input/output devices, such as a keyboard and mouse.

3.5 Communication technology

Design team communication can be defined as interactions between senders and receivers, via information communication technology. Communication media exists to ensure the flow and to understand the meaning of communication. Two main types of communication media exist, namely synchronous and asynchronous interactions, and both provide different functions (Tseng & Abdalla, 2004). Synchronous and asynchronous interactions have developed with existing technology through the Internet, and affect collaborative design within different organisations and amongst diverse professionals. An exploration of these types of interactions highlights their differences, pros and cons.

Both synchronous and asynchronous interactions within communication media provide significant benefits to users, enabling communication and collaboration between all professionals in a team. Synchronous interactions occur in the 'same-time-different place' and confer the functional advantages of immediately facilitating the engagement of people, simultaneously and irrespective of distance. The drawbacks include the high cost requirement of bandwidth for an efficient outcome, and the difficulty in co-ordinating conflicting schedules to achieve 'same-time' interactions. Asynchronous interactions support communication and collaboration over an interrupted timeframe, through a 'different time and place' mode. These interactions possess the advantage of collecting knowledge that is easy to share, and contributes to the interaction of team members working at different times. The disadvantages are highlighted within groups of people who are no longer familiar with technology as 'login' and who are afraid to lose 'the sense of privacy'.

There are six technical tools in existence within communication media which facilitate collaboration among design professionals. Applications for asynchronous interactions are conducted via e-mail and bulletin/message boards. Other shared application tools include instant messaging, and online conferencing, which allow for synchronous interactions in real time (Tseng & Abdalla, 2004). Social media applications provide both synchronous and asynchronous interactions (Kask & Wood, 2009). These tools and their features are summarised in Table 3.1.

Table 3.1 Summary of the features of all communication media tools.
(Source: Modified from Tseng & Abdalla, 2004)

	Technical tool	Type	Feature
1	Sharing applications	Synchronous	Use of a 3D viewer to assist users, without CAD software.
2	Online conferencing	Synchronous	Convergence of video, audio and real-time collaborative environments that support real-time communication.
3	Instant messaging	Synchronous	Information immediately received on the user's computer, with an accompanying beep sound and pop-up window to alert the user; for example, Line, or Messenger.
4	Social applications	Asynchronous and synchronous	Web 2.0 technology encourages social participation and is free to users; for example, Facebook.
5	E-mail	Asynchronous	Automatic e-mail notification and automatic saving of e-mail data.
6	Bulletin board Message board	Asynchronous	Allowing users to post, read, update, or respond to messages.

To evolve, collaborative-driven communication technology within the design process has incrementally changed from synchronous to de-synchronous collaboration. In the traditional design process, a meeting among specialists would take place around the conference table to exchange design information, deliver a presentation, agree common ground, and discuss issues, which may sometimes mean the creation of a schematic design to elaborate details after the meeting (Gross, Do, McCall, Citrin, Hamil, Warmack, & Kuczun, 1998). Gross et al. (1998) state that exchanging design information via technology was thought to create a meeting space for synchronous collaboration through video teleconferencing, faxes, live boards, and the desktop computer.

At present, design collaboration is almost the same, but more difficult to achieve than in the past. Namely, the design process is characterised by specialists' delocation or different workplaces. This is exacerbated by a now globalised society that is supported by ICT tools and in particular requires desynchronous or asynchronous information exchanges in which both delocation and desynchronisation pose more complex problems in 'communication' and in 'interpreting and understanding the contents of complex information'. This resuls in misunderstanding and conflict (Carrara, 2012). In addition, there is still concern regarding the loss of information between designers during the collaborative design process, which requires amendments (Du, Jing, & Liu, 2012).

Moreover, problems in collaboration occur naturally as several specialists have unique experiences. Moreover, Carrara (2012), Sun et al. (2015) and Poole (2011) state that the main problems arise with communication, interpretation, and understanding. Problems with communication are, in part, caused by social problems or cultural boundaries that lead to issues with information exchange. This can be due to misinformation and the misunderstanding of messages and can result in conflict (Carrara, 2012; Poole, 2011 cited in Sun, Mollaoglu, Miller, & Manata, 2015). Sun et al. (2015) demonstrate that specialists with different experiences create difficulties in the interpretation and understanding of collaborative design. Similarly, Carrara (2012) points out that, the different worldviews of specialists require a greater understanding of the language and conventions in each discipline, whilst Leon and Laing (2013a) agree that the various glossaries utilised by different AEC professionals need to be communicated to develop a common ground for sharing and understanding.

Moreover, both the misunderstanding and misinterpretation of information are problems described by Carrara (2012), who explained that professionals involved in collaboration processes use different methods and notational forms to communicate their work, such as different kinds of drawings, numbers, and shorthand references for standard materials. Naturally, one professional discipline is not knowledgeable about another discipline's representations; however, this creates difficulty when communicating and can perpetuate a lack of understanding which leads to misunderstandings and errors. However, this can be solved by 'simplifying communication', which means that the design representation of each professional must be included by other professionals during the information exchange (Carrara, 2012). Sun et al. (2015) agree with Dossick and Neff (2011) who propose the use of ‘messy talk’ and informal communication to overcome the problem of communication among different professions; this can further contribute to project success by optimising complex-problem solving (Sun et al., 2015).

Du et al. (2012) raised the issue of lost information between professionals due to the collaborative nature of the design process; they argued that these professionals can usually exchange design information through video conferencing, audio talking, online chatting and e-mail. However, the information shared through these means can be disorganised, out of sequence, and full of digression. Email is a kind of text communication, which can confuse and distract users from their normal and automatic emails (Sharif, Matthews, & Lockley, 2012).

Therefore, there is a variety of channels of communication which can be used to work collaboratively. The contents of communication and collaboration are an important source of evidence and knowledge, which should be preserved and stored for future retrieval. Usually, design professionals use meetings as the main channel of communication, with instant messaging and social media applications adopted for only basic communication due to the complexity of design images and content. For in Thailand, multidisciplinary professionals use a variety of communication channels similarly appear in the findings of this research (see section 5.4.1.3).

3.6 The Research Gap

Collaborative approaches to the design process have been developed from the traditional approach to Integrated Project Delivery (IPD) in the USA, and from the previous versions of the RIBA Plan of Work 2013 in the UK. This collaboration is supported by technology in the form of both BIM and CAD tools, and is driven by the sharing strategy of BIM. However, collaboration is not always effective with this technology. In Thailand, the approach to the design process is similar to the traditional approach in the USA. Problems arising in the construction phase originate from the concept and schematic design phases, leading to iterative design because of incomplete images and poor communication (Makulsawatudom et al., 2004; Charoenpornpattana, 2015).

Although BIM and CAD tools are used to share information among relevant stakeholders, ineffective collaboration and communication still exists in Thailand. The weaknesses of these modern tools in enabling concept design are due to the complex information involved and the difficult user interfaces. The combination of these challenges obstruct the mental workflow (Bueno & Turkienicz, 2013; Ibrahim & Rahimian, 2010; Still & Dark, 2013; Coates, Arayici, Koskela, Kagioglou, Usher, & Reilly, 2010), results in a steep learning curve (Denzer & Gardzelewski, 2011; Eastman el al., 2011), and is ineffective for, or not supportive of, communication (Holzer, 2007).

Two explicit problems were addressed in this section. The first was the visual thinking of the designer, and the second was the current nature of collaboration. Through a critical review of these problems within the current literature, the research gap will be identified. Firstly, according to the literature review, concept design involves the development of creative ideas from the abstract to the concrete level. Creative ideas emerge from the capture of visual thinking or cognitive modelling, and appear so fast that it is difficult to promptly seize or capture them before they disappear (Akalin & Sezal, 2009). The human brain is a limited resource (Fish, 2004), which has to switch between internal and external representations (Ware, 2010). Visual thinking is vital in producing creative ideas (Goldschmidt, 2014), but must not be restricted by the cognitive load that results from processing information from multiple sources and is directly affected by the designer's tools.

Secondly, the nature of collaboration involves the adaptation of mental structures, called schemata, from the building of knowledge, and to share experiences and information from other disciplines (Gautier, Bassanino, Fernando, & Kubaski, 2009). Participants need to build and sustain their knowledge to enable them to predict others' behaviour and to better understand whatever is shared within the team. Egan (2011) suggested that one of the key requirements for collaboration among team members is to learn from experience. In addition, the complex nature of globalisation presents problems for collaborative design communication, which requires both synchronous and de-synchronous information exchange (Carrara, 2012). Although there are similar characteristics amongst communication media, such as e-mail and instant messages, they are not appropriate to serve the needs of collaboration (Ashley, 2003; Lauron, 2008; Sharif, Matthews & Lockley,2012). In addition, social differences and/or cultural boundaries can lead to misinformation, and the misunderstanding of messages and information exchange, which results in conflict (Carrara, 2012; Poole, 2011 cited in Sun, Mollaoglu, Miller, & Manata, 2015). It can be concluded that, currently, the multiple disciplines involved in collaborative design are also affected by globalisation and influence the integration of actors/specialists within other disciplines and result in social problems, "…those that are rooted in the psyche of the participants" (Carrara, 2012, p.125).

Therefore, the research gap can be identified as the lack of digital tools that facilitate collaborative conceptual design, as the case study in Thailand suggests. The gaps identified in the empirical research can be addressed as follows:

1. What is the situation for collaborative conceptual design teams in Thailand?
2. What is the archetype of a digital tool for collaborative conceptual design teams?
3. What are the results when professionals evaluate the prototype tool for real-time collaboration and communication?
4. How do professionals recommend the adoption of digital prototypes for collaborative conceptual design teams?

3.7 Summary

The human brain is complex and comprises multiple functions which communicate and work together, including analysis, synthesis, and evaluation. In concept design, designers employ creative and critical thinking to intuitively generate design ideas which alternate from representative tools, hands and eyes, to the brain, via visual thinking and other functions. Representative tools are important in the development of design ideas, from abstract to concrete, and include traditional tools, such as sketch or model-making, and digital tools. This chapter has explored the available literature concerning the thinking process in design, analogue tools, digital tools, and communication technology. One tool alone cannot be used for all of these processes because of various limitations that depend on the design level and situation. The employment of tools in design was investigated within the case study that was based in Thailand. The study concluded that Thai professionals use both traditional and digital tools for conceptual design, and share their designs among relevant disciplines via communication tools, such as email, instant messaging, and social media. Complex designs requires professionals to work together using existing design tools and communication technology, although barriers were also raised within this chapter. Further research is required to identify the archetype of a digital tool for collaborative conceptual design.

CHAPTER 4:
RESEARCH METHODOLOGY

4.1 Introduction

This research is a qualitative study which analyses users' requirements of a digital prototype and evaluates the digital prototype developed for collaborative design. Data is collected from professionals in Thailand, who are involved in concept design within the Architecture, Engineering, and Construction industry.

The research methodology is a crucial part of research practice, in that it enables a researcher to conduct the study in an appropriate and efficient way. Easterby-Smith (1997, cited in Crossan, 2003, p.47) identified three reasons that support the definition of a research methodology. He stated that:

> Firstly, it can assist to refine and specify the used research methods in a study ... to clarify the overall research strategy to be used.
>
> Secondly, knowledge of research philosophy will enable and assist the researcher to evaluate different methodologies and methods and avoid inappropriate use and unnecessary work by identifying the limitations of particular approaches at an early stage.
>
> Thirdly, it may help the researcher to support to be creative and innovative in either selection or adaptation of methods... (Easterby-Smith, 1997, p.48).

A research methodology constitutes several interrelated elements, which will be explained in this chapter. The first section focuses on the research philosophy and discusses the underpinning philosophical assumptions; this specifically relates to ontology, epistemology, and the appropriate research methods. The second section identifies the most appropriate research approach to develop the theory, whilst the third section describes and justifies the methodological choice. The strategies adopted for this study are discussed in the fourth section, whilst the time horizon is explained in the fifth section. The sixth section explains the techniques and procedures adopted in terms of the data collection and the workflow of these procedures. Finally, the key points of this chapter are outlined in the summary.

4.2 The Research in Context

Between 2007 and 2016, Saunders, Lewis, and Thornhill (2007, 2016) developed their widely known and applied model, called the 'Research Onion'. This comprises several interrelated elements of research methodology, which are arranged in layers from the external to the innermost layer. Moreover, each layer contains a range of available research choices (see Figure 4.1). The onion helps to explain and develop an understanding of the elements of the research methodology. It can also clarify the choices when designing a research methodology. The diagram consists of six layers, comprising: 1) Research Philosophy, 2) Research Approaches, 3) Research Strategies, 4) Research Choices, 5) Time Horizons, and 6) Techniques and Procedures.

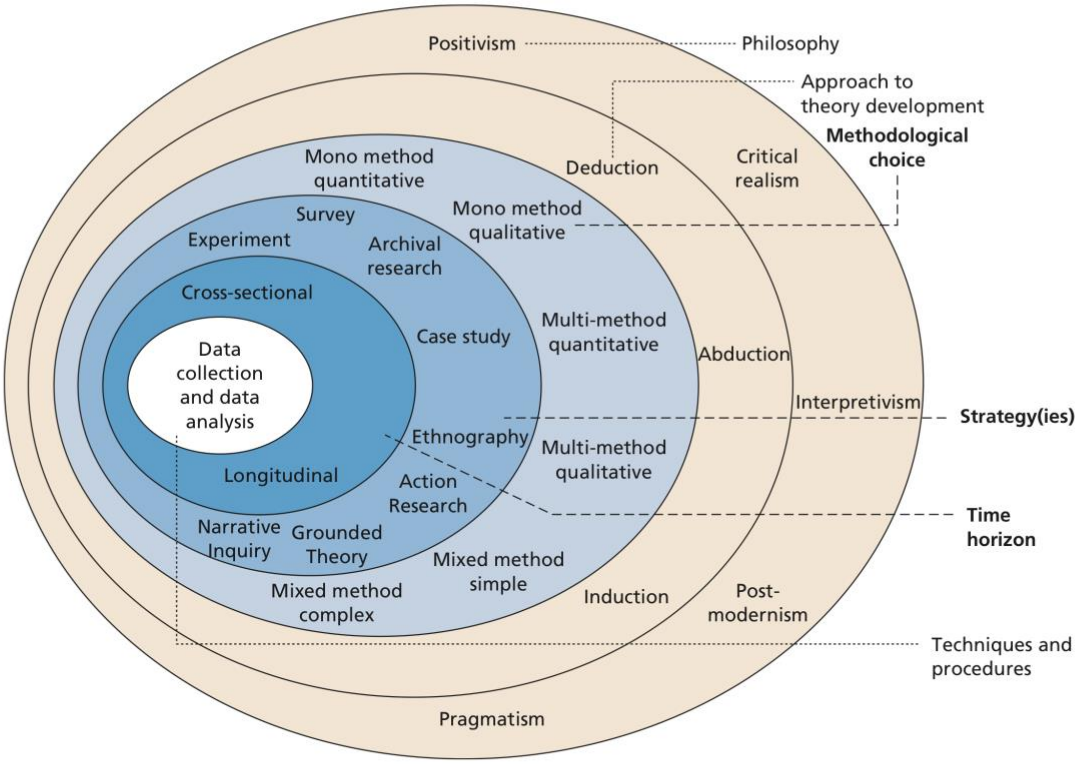


Figure 4.1 The research onion
(Source: Saunders, Lewis, & Thornhill, 2016)

By considering each layer, from the external to the innermost, the research onion enabled the development of a methodological framework for this study, as shown in Figure 4.2. This framework adopts a pragmatic research philosophy, which is associated with theory development by abduction. The framework adopts multi-method qualitative methodological choices, which consists of two strategies, namely survey and case study, in a cross-sectional study. Finally, in this framework, the data collection method consists of a literature review, qualitative questionnaire, participant observations (performance measure), and a focus group. The framework of this research will provide a guideline to discuss the methodological decisions of this study.

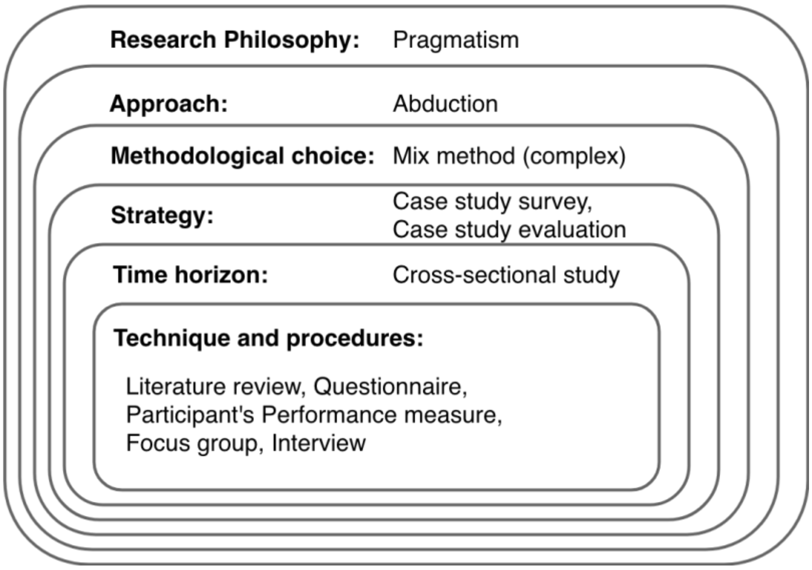


Figure 4.2 Research approach layers for this Ph.D. research (Adapted from Saunders, Lewis, and Thornhill, 2016)

4.3 Research philosophy

The research philosophy is a significant foundation for any research and directs the researcher as to the most appropriate decisions to develop new knowledge. Saunders and Tosey (2012) described the research philosophy as shaping assumptions about human knowledge and the nature of the reality. These will be encountered through a range of research views in order to understand the associated design that influences the specific methodological choices and strategies taken to collect significant and useful data. An awareness of philosophical assumptions can increase the quality of the research and contribute to the creativity of the researcher (Easterby-Smith, Thorpe, & Jackson, 2012). Particular epistemological, ontological, and axiological bases underpin these assumptions; these relate to human knowledge (epistemological assumptions), reality (ontological assumptions) (Proctor, 1998, cited in Crossan, 2003), and value in the research process (axiological assumptions). In turn, these bases are underpinned by the methodological choice, research strategy, data collection techniques, and analysis procedures (Saunders et al., 2016). As the research philosophy is based on ontology, epistemology, and axiology, this prompts four questions, which are:

1) ‘What can we know?’ This represents the ontological question concerning the nature and form of reality;
2) ‘How can we know?’ This indicates the epistemological question;
3) ‘What approach should be used?’ This provides the methodological question, and;
4) ‘What specific tools should be used?’ This concerns the data collection and analysis methods (Wright, O'Brien, Nimmon, Law, & Mylopoulos, 2016).

Thus, the next sections will explain the research methodology through the ontology, epistemology and axiology for this study.

4.3.1 Ontology

Ontology is the philosophical assumptions about the nature of reality (Easterby-Smith et al., 2012) when studying subjects and the nature of being (Hassani, 2017). Ontological assumptions represent the reality required to create questions that help to describe ‘what is’. It is concerned with ‘how things really are’ and ‘how things really work’ in the specific context under consideration (Saunders et al., 2012; Scotland, 2012). Ontology is the study of the nature of the context itself and everything within that context. These are analysed through two aspects, namely objectivism and subjectivism.

Objectivism: The principle of objectivism in ontology is a reality ‘in itself’, which exists independently of the human mind (Wiebe, Durepos, & Mills, 2010). Objectivism incorporates assumptions of research that describe, predict, and understand natural phenomena. The phenomena include social entities that exist in an external reality and are independent of social actors (Saunders et al., 2016). It is based on empirical evidence from observation and experimentation.

Subjectivism: Subjectivism refers to the human mind, which involves individual experience, perception, and interpretations of the world; this includes the material conditions and social relations that mould a person’s vision (Wiebe et al., 2010). Subjectivism is used to understand situations, interactions between people, phenomena and processes, the influence of phenomena, and the reasons for such influence (Saunders et al., 2016).

The researcher adopted two types of ontology to understand users’ requirements of a digital tool and their evaluation of a prototype developed; this focused on addressing collaborative design in concept design. Subjective reality was observed by investigating users’ experiences of professional collaborative practice by using tools and eliciting their requirements of a digital prototype for collaborative design, and by collecting users' evaluations of a prototype. Objective reality was discerned by observing the statistical reality that captured the experiences of using the digital prototype designed and developed for the investigation. As a result, the epistemological basis considered both objectivism and subjectivism.

4.3.2 Epistemology

Epistemology is a set of assumptions about the nature of the world (Easterby-Smith et al., 2012) and refers to the theory of the formation of knowledge (Hassani, 2017). Epistemological assumptions are concerned with 'what it means to know'; it considers the knowledge involved, which can be created, acquired from chosen research methods, and communicated to others (Scotland, 2012). Epistemology is the philosophical study of scientifically distinguishable ways of forming knowledge (Wiebe et al., 2010). This research considers the three main types of philosophical study, which are:

1. **Positivism**: Positivism is based on assumptions of an objective reality and a truth that can be discovered from observing and predicting outcomes, which are concerned with a law-like generalisation of cause and effect (Saunders & Tosey, 2012). The positivist purpose emphasises: the understanding of complex phenomena; the discovery of how things are; the justifications offered; and the measurements that determine why such phenomena are a particular way (Vaishnavi & Kuechler, 2007; 2015). These all inform that which is accepted as fact in the 'real world' around us (Walliman, 2011).
2. **Interpretivism**: Interpretivism collects rich insights into subjective meanings, which focus on conducting research from people rather than upon objects. Interpretivim aims to understand the social world and to interpret the given meaning from the viewpoints of the people involved (Saunders & Tosey, 2012). Besides understanding and describing on human beings, its purpose also includes reflecting on human beings and human actions (Vaishnavi & Kuechler, 2007; 2015)
3. **Pragmatism**: Pragmatism integrates both objectivism and subjectivism and is a multiple reality (Creswell, 2013; Saunders at el., 2016). The philosophy significantly focuses on the practical consequences of research findings; it tends to start with a problem and aims to contribute to practical solutions that inform future practice (Saunders at el., 2016). Vaishnavi and Kuechler (2007; 2015) pointed out that the purpose of pragmatism is to design and modify existing situations to achieve better solutions.

Research has been explained as systematic investigation (Burn, 1997, cited in Mackenzie &Knipe, 2006) whereby data is collected, analysed and interpreted in some ways to understand, describe, predict, or control a phenomenon (Mertens, 2005, cited in Mackenzie & Knipe, 2006). This philosophy considers the difference between positivism and interpretivism, evaluating their merits, assumptions, and appropriate methodologies (Hammersley, 1992, Oakley, 1999, and Gage, 1989 cited in Bryman, 2008) that Bryman (2008) explained that:

> …The paradigm wars in this sense centre on the contrasting epistemological and ontological positions that characterize quantitative and qualitative research and their various synonyms…

At the level of epistemology, desirability becomes the contrast leading to a battle between positivist and interpretivist philosophical principles; this battle is based on specific theoretical and methodological stances (Brayman, 2008). Positivists argue that, "the world exists externally and that its properties should be measured through objective measures rather than being inferred subjectively through sensation, reflection or intuition" (Easterby-Smith, Thorpe, & Lowe, 2002, cited in Kulatunga, Amaratunga, & Haigh, 2006, p.28). Conversely according to interpretivists, reality is determined by people rather than by objective and exterior factors (Easterby-Smith et al, 2002, cited in cited in Kulatunga, Amaratunga, & Haigh, 2006). Although positivism contrasts philosophically with interpretivism, both are based on the basic epistemic attitude of 'what-is', which builds knowledge about the world as it already exists (Goldkuhl, 2011).

In comparison, pragmatism avoids engaging in the contested truth and reality paradigm was between positivism and interpretivism (Saunders et al., 2007; Tashakkori & Teddlie, 1998 cited in Tadayon, 2018). It is not only concerned with 'what-is' when describing the existing world as a pattern of cause and effect, but with the orientation of knowledge to the world ('to-be') in which it is used in a constructive way to contribute to change and improvement (Goldkuhl, 2011). Thus, pragmatism advocates stepping into future with purpose to build the better world, or to build practical solutions that inform future practice (Saunders et al., 2016).

Pragmatism is the most appropriate epistemological basis for this research. It considers the question: 'how can we know the reality'. Thus, this research starts by identifying a digital tool for collaborative design in concept design. It tests assumptions and collects recommendations from users. This study has multiple philosophical positions, and the first aspect of the research relates to positivism (namely, the performance measure and the Software Usability Scale questionnaire); the second aspect relates to interpretivism (namely, users' requirements).

4.3.3 Axiology

Saunders et al. (2016) state that axiology is a branch of philosophy that studies judgements about the role of values and ethics, determining between value-free and value-laden entities at each step of the research process. Value-free is defined as having no value for research participants while collecting data; this could be due to a lack of participation with the researcher. On the other hand, value-laden is defined as having value for respondents through personal interaction with the researcher while collecting data. Researchers are thus concerned with values from the incorporated questions in their study. Therefore, to produce credible results, it is important to consider how values are dealt with - both the researcher's and those of their participants - at all stages of the research process (Saunders et al., 2016).

This research adopts pragmatism as a philosophical approach, while its ontology integrates both objectivism and subjectivism. The research is both value-laden and value-free in terms of the data collection. Subjectivism is value-laden as it considers the personal interactions between the researcher and research participants when collecting data about their experiences and attitudes. The study incorporates subjectivism in the interview on the prototype evaluation process. However, in the first data collection phase, the questionnaire is value-free, as this step did not require any participation and personal interaction with the research participants. In addition, objectivism forms a value-free basis and was adopted by collecting data from the Software Usability Scale (SUS) questionnaire and performance measure. Thus, credible research is gathered from personal interaction between the researcher and research participants by collecting data on their experiences and attitudes in connection with the study focus.

4.4 Research approach

Within the research approach layer, there are three types of theory development - deduction, induction, and abduction. These approaches are based on inferences that differ within each approach to logic. Firstly, deduction states that, when the assumptions are true, the conclusion must be true; this logic flows from the general to the specific. Secondly, induction uses assumptions to generate untested conclusions; this logic flows from the specific to the general. Finally, for abduction, known assumptions are used to generate testable conclusions, which are generated by the interaction between deduction and induction (Saunders et al., 2016). These approaches are described as follows:

1. **Deduction**: Saunders et al. (2016) concluded that deduction infers from the general to the particular, which involves 'moving from theory to data'. They described its characteristics in the following series of steps: 1) A search is conducted to explain causal relationships between concepts and variables; 2) After reading the academic literature a number of hypotheses are developed; 3) To test these hypotheses, data are collected. Thus, the data collection is used to evaluate propositions or hypotheses that are related to an existing theory for verification.
2. **Induction**: Induction involves 'moving from data to theory' (Saunders et al., 2016). Saunders et al. outlined a series of steps to induction, as follows; 1) This represents an alternative approach to developing theory that starts with the qualitative data collection and requires a small sample of subjects; 2) The purpose is to 'get a feel of what is going on', so as to better understand the nature of the problem; 3) The analysis results inform the formulation of theory, which is often expressed as a conceptual framework. In this approach, a phenomenon is explored from the data collection, which enables the identification of themes and patterns from which the conceptual framework is created to generate or build the theory.
3. **Abduction**: Wiebe et al. (2010, p. 48) explained that,

> Abduction must occur in recursive interplay with deduction and induction in order to arrive at plausible theoretical insights. Ideas have to be articulated and worked out in relation to one's generated data and what one already knows.

Suddaby (2006, cited in Saunders et al., 2016, p.148) concluded that an abductive approach moves back and forth, combining deduction and induction. Saunders et al. (2016) explained the sequential steps of abduction: 1) Data is collected to explore the phenomenon; 2) The data is identified and explained themes and patterns; 3) These explanations are integrated into an overall conceptual framework, and then, to build up a theory; 4) The conceptual framework or theory is tested by existing data and new data and revised as necessary. In this approach, a phenomenon is explored from the data collection to identify themes and patterns, build a conceptual framework, and then test this through a subsequent data collection, and so forth. This approach aims to build new theory or modify existing theory.

As this research used abduction, it: 1) built a characteristic model of a digital tool for collaborative design in concept design, which was developed through the qualitative data; 2) tested a digital prototype developed from the built model, which was collected through the performance measures and recommendations from focus group participants in the prototype evaluation; 3) analysed the prototype evaluation process through interviews. All data were analysed and explained to follow the research aim and objectives.

4.5 Methodological choice

A methodology identifies and selects the most appropriate research methodological approaches for the data collection. This is represented by two main methodological choices; mono-method, and multiple methods. These methods can either be quantitative or qualitative, and are defined as follows:

1) A quantitative method is often used to collect numeric data to measure a phenomenon with numbers. It therefore uses statistical techniques to analyse the data and usually adopts a deductive approach to test an existing model or theory (Saunders et al., 2016).
2) A qualitative method is used to collect non-numeric data, such as words, images, video clips, and other similar material. It can be used to investigate behaviour, attitudes, or experiences through such methods as interviews or focus groups. It attempts to get an in-depth opinion from participants (Dawson, 2009). It tends to adopt an inductive approach in order to build or develop a model or theory (Saunders et al., 2016).

Saunders et al. (2016) explained that a mono-method adopts a single research method that may be quantitative or qualitative. In comparison, multiple methods adopt two sub-methods - multi and mixed-methods. If a study uses quantitative or qualitative methods in a methodology without mixing them, it is considered multi-method. Meanwhile, a mixed-method study adopts both quantitative and qualitative methods, which can be simple or complex. The simple mixed-method only uses two different methods, namely quantitative and qualitative; in comparison, the complex mixed-method approach will adopt more than two types of these methods.

During the data collection, one methodology can be embedded within another in a linear approach to the gathering of data. In comparison, in a sequential multi-phase is when one method needs completing before another method is started (Saunders et al., 2016). Saunders et al. suggest that single-phase research may be designed to concurrently use both quantitative and qualitative methods, but these are collected separately, and one will be analysed to support the other.

Qualitative methods constitute the main data collection initiatives in this research, which integrate quantitative methods to support an abductive approach. Qualitative research is important in developing a greater understanding; Ormston, Spencer, Barnard, and Snape (2014) identified the following common characteristics:

1. Qualitative research methods support the aims and objectives, in order to provide an in-depth and interpreted understanding of research participants' contexts. This is achieved by learning about the sense they make of their social and material circumstances, including their experiences, perspectives and histories.
2. A non-standardised, flexible method of data generation can be adapted for each participant to allow for the exploration of emergent issues, such as observational methods, semi-structured and in-depth interviews, and focus groups.
3. Data are detailed, rich and complex (again, the precise depth and complexity of data may vary between studies).
4. In terms of the qualitative data analysis, it retains its complexity and nuances, and respects the uniqueness of each participant or case as well as the recurrent, cross-cutting themes.
5. There is openness to emergent categories and theories at the analysis and interpretation stage.
6. Outputs include detailed descriptions of the phenomena researched; these are grounded in the perspectives and accounts of participants.
7. It represents a reflexive approach, where the role and perspective of the researcher is acknowledged. For some researchers, reflexivity also means reporting their personal experiences of the field (Ormston et al., 2014).

Thus, this study adopts a multiple and mixed-method (complex) data collection technique. However, in the mixed-method (complex) approach, there are two main methods to consider:

1. The qualitative method: this is used to collect data from participants following which the data is analysed to build a prototype model based on explanation of its requirements.
2. A sequential multi-phase embedded design for the prototype evaluation, for which there are three sub methods:
    - 2.1. A quantitative method is used to collect users' performances measurements in terms of the prototype usability; this supports other methods in this research,
    - 2.2. A second qualitative method is adopted to collect users' experiences and recommendations when using a digital prototype,

2.3. A third qualitative method is used to collect users' recommendations on the prototype evaluation process.

4.6 Research strategy

According to the previous layers of the 'research onion', the philosophy was identified as pragmatic, adopting an abductive approach and methodological choice. The goal of this research is formed from the research philosophy and approach. To achieve the goal, the study required a plan of action (Maxwell, 2008; Saunders et al., 2016), which is addressed by the research strategy.

4.6.1 Purpose of research design

Research is usually designed to fulfill the purpose of the researcher by arranging methods and strategies to achieve the research goal. The purpose can be exploratory, descriptive, explanatory, or an evaluatory; alternatively, it can be a combination of these (Saunders et al., 2016; Yin, 2017). Each purpose is described in more detail to explain the most appropriate strategies for this study. Saunders et al. (2016) described these purposes as follows:

1. **Exploratory:** An exploratory study uses open questions to discover what is happening and to gain insights into a topic of interest. Exploratory questions are likely to begin with 'what' or 'how', which are asked during the data collection stage to explore an issue, problem or phenomenon. Exploratory research is flexible and adaptable to change, which are its advantages.
2. **Descriptive:** The purpose of descriptive research is to collect an accurate profile of an event, person, or situations. Descriptive questions used during the data collection are likely to begin with 'who', 'what', 'where', 'when', or 'how'. Descriptive research can be integrated with exploratory research. A clear picture of the phenomenon is important before starting the data collection.
3. **Explanatory:** An explanatory study establishes causal relationships between variables. Questions seeking explanatory answers during the data collection are likely to begin with 'why' or 'how'. This emphasises the study of a situation or problem in order to explain the relationships between variables.
4. **Evaluative:** The purpose of evaluative research is to find out how well something works. Questions are likely to begin with 'How', 'What', or 'To what extent'.

5. **Combined:** A research study can combine more than one of the above purposes, such as descripto-explanatory studies. In addition, a combined study can be adopted to choose a research method type in order to form an action plan for the research strategy. Both multiple and single method research can use a combined study scope to facilitate more than one purpose (Saunders et al., 2016).

According to the previous method choices, this study adopts two main methods: qualitative and a sequential multi-phase. These methods are developed from the research purposes and identified by the research strategy.

Firstly, the purpose of first method is to combine exportation, explanation, and description as it aims to collect professionals' experiences of collaboration and their requirements of a collaborative design tool in concept design. This enables the development of a prototype design model. The first method can adopt a 'case study survey' strategy, which fits the purpose of combined research. Thus, the main purpose is exploratory research.

Secondly, a sequential multi-phase choice is designed to support the main purpose of the evaluation research, which aims to determine how well the prototype works. This comprises three research methods that: measure how it works, collect research participants' recommendations in terms of the prototype, and collect research participants' recommendations on the process. The second method uses a case study strategy, which is appropriate for the purpose of evaluation research.

4.6.2 Sampling

A sampling technique is necessary for most research methodologies whether quantitative, qualitative, mixed or multiple research method to define the selected sample from target population which is a subset of population. This helps to define the selected sample from the target population, which is a subset of population. This sample focuses on the requirement of the research inquiry in order to manage time, and cost, and effort by collecting and analysing data from very specific cases within an entire population. There are two types of sampling techniques in social and behavioural sciences - probability and non-probability (see Figure 4.3).

Firstly, probability-sampling techniques are primarily adopted in quantitative research and based on the specific purposes of answering a research inquiry. It selects a relatively large number of cases from a population, or from specific subgroups of a population, in a random manner (Teddlie & Yu, 2007). It is most commonly associated with survey research strategies where the research makes inferences from the sample about a population. Thus, the researcher needs to: identify a suitable sampling frame; select the most appropriate sampling techniques; identify the sample; check that the sample is representative of the target population; and to meet the objectives and research questions (Saunders et al., 2016)

Another type of sampling technique is non-probability or purposeful sampling, which is primarily adopted in qualitatively research. This technique is based on a specific purpose and/or unique cases rather than a random selection of a certain sample that either represents a broader group of cases as closely as possible or sets up comparisons among different types of cases (Teddlie & Yu, 2007). Non-probability sampling may be called non-random sampling, and may be the most practical technique. This type is adopted to answer the research inquiry, meet the research' objectives, and gain theoretical insights from undertaking an in-depth study that focuses on a small number of cases chosen for a particular purpose (Saunders et al., 2016).

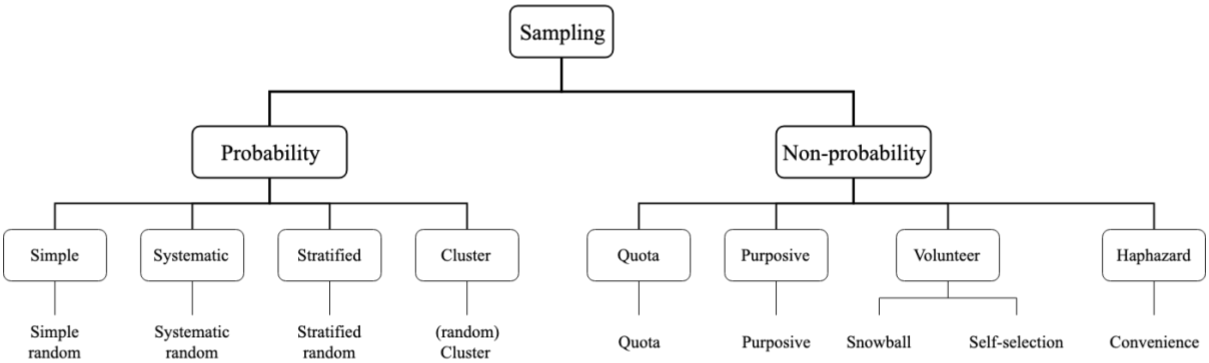


Figure 4.3 Sampling technique
(Source: Modified from Saunders et al., 2016)

This research adopts a non-probability sampling technique and selects a volunteer and snowball sampling techniques. Snowball sampling is commonly used when it is difficult to identify research participants amongst the desired population (Saunders et al., 2016). Saunders et al. (2016) noted that the main problem in making initial contact with the sample and defining new cases. Thus, the researcher makes contact with the initial cases in the population, who in trun identify further cases.

The sample focused on professionals who have been closely involved in collaboratively design the concept and schematic design processes of small, medium, or large projects. These are professionals, including architects and engineers with professional (ACT and EIT) licenses, who are representative of the Thai AEC industry. Snowball sampling is the most appropriate technique in which the first and second data collections are conducted. Thus, purposive sampling is applied for the first round of contract with professionals, after which the snowball sampling technique is used to ask for recommendations from other professionals who would qualify to provide data for the study. In the next section, the research strategy and the sampling size are described.

4.6.3 Case study

Case study research involves the exploration of a real-life, contemporarily bounded system (a case) or a multiple bounded system (cases) over time to collect data from multiple sources of information (such as observations, interview, audio-visual material, and documents and reports), and then to report a case description and case themes (Creswell, 2013). The 'case' in may refer to a person, group, organisation, association, change process, event, or other types of subject that refer to the interactions between the subject and its context (Saunders et al., 2016).

Saunders et al. (2016) and Yin (2017) state that a single case is usually required to prepare a sub-unit in a studied context. A single case is often adopted to study a critical case, or an extreme or unique case because it typically allows for the observation and analysis of a phenomenon that few have studied (Yin, 2017). Significantly, for a single case study, the research requires a number of logical sub-units within the context (Yin, 2017). Thus, this study focuses on a single case to collect data from groups of professionals who are involved in collaborative design at the concept design stage; this includes architects, interior designers, and engineers. Qualitative research was conducted to collect data as a first step, whilst the second step invited other groups of professionals invited to test the prototype. In addition, this study provides a ‘design and development’ phase to fill the gap between the first and second methods and to create the prototype, or built model, from the outcome of the first method. Therefore, the prototype was incorporated within the second method to test the concept.

The action plan of this study adopts a case study as a research strategy. This is the main strategy, which is characterised by a sequential multi-phase. The research strategy comprises the following three phases:

1. Phase 1: Case study survey
2. Phase 2: Design and development
3. Phase 3: Case study evaluation

4.6.4 Phase 1: Case study survey

Case study survey research can use a survey strategy to gather the data within a specific case. The case can either be a small sample or an entire population that describes an aspect or character of the sample (Chmiliar, 2010). The sample can be questioned about their opinions, behaviours, abilities, beliefs, or knowledge. Chmiliar (2010) stated that the purpose of a case study survey is to identify the characteristics of the sample connected to a particular issue. Although survey research allows for the collection of data from a large number of people, the whole population is generally not studied. A case study survey allows for a smaller sample than the larger number typically associated with survey research. Significantly, a sample is carefully selected from which to gather data in order to examine characteristics and thus identify and describe trends in the population. This enables learning about the sample. In terms of the application, the case study survey is a one-time-only method. Thus, a cross-sectional survey design is used in this study to collect data for a case at one point in time. Moreover, this case study survey uses a qualitative questionnaire to collect data, where the questions can be closed or open (Chmiliar, 2010).

Case study survey research is designed to integrate the case study and survey to collect data in a particular way. A case study strategy is a useful tool for the preliminary, exploratory stage of a research project (Rowley, 2002); moreover, it can be appropriately used for exploratory research. In addition, its particular characteristics mean a focus on a particular case, with a small sample size that is advantageous in better enabling a definition of the case. Moreover, a smaller size helps to adhere to the purpose of exploratory research.

This research is based on qualitative methods and its main purpose is exploratory; thus, the size of the sample is important in this case study survey. Usually, a sample size needs at least 30 research participants; however, exploratory studies might only have a sample of 30 research participants (Guthrie, 2010). For qualitative methods, the adequacy of the sample size means judging that it is not too small or too large for its intended purpose. Moreover, Sandelowski (1995) recommended a sample size of around over 50 for qualitative studies. In addition, Teddlie and Yu (2007) recommended a sample size of around 30 participants or less for non-probability techniques, and at least 50 the participants in probability techniques (Teddlie & Yu, 2007).

Thus, the case study survey further enables the exploratory purpose of this study, by integrating descriptive and explanatory research. This is adopted for use in the qualitative questionnaire following the literature review in order to define the prototype model from the data offered by the research participants. Questions used to collect data from research participants are: 'who', 'what', 'where', 'when', or 'how' for a descriptive study; 'why' or 'how' for an exploratory study; and ‘what’ or ‘how’ for an exploratory study. The participants in this case study survey are AEC professionals who are involved in design and collaboration at the concept design stage in Thailand. In this case study survey, the required sample size for qualitative research is around 30-50 research participants.

4.6.5 Phase 2: Design and development

The design and development phase takes place between the case study survey and the case study. Its purpose is to use the outcome of the case study survey to develop a prototype, which becomes a representative model for testing the case study. In software engineering, the Software Development Life Cycle (SDLC) concept is grounded in many development methodologies (Hu, 2013). These methodologies form a framework to build the digital tool for this research, which is explained in Chapter 6 (see Figure 4.4).

The SDLC model consists of five parts, which comprises the following requirements: analysis, design, implementation or coding, testing, and evolution. The model is adopted in the design, coding and testing, and described as follows:

1. **Requirement analysis**: The model forms the case study survey and analysed for its validity and potential for system development.
2. **Design**: The system or software was prepared from the requirement specification studied in the requirement analysis. The system design specifies the hardware and system requirements and helps in the definition of the overall system architecture (see Chapter 6).
3. **Coding**: The system design detail was used to develop the coding or implementation. The entire system code was written and built by the researcher.
4. **Testing**: The product from the coding phase was conducted to examine the functional testing (unit testing), integration testing, and system testing. The evaluation was based on the collection of data within Chapter 7.

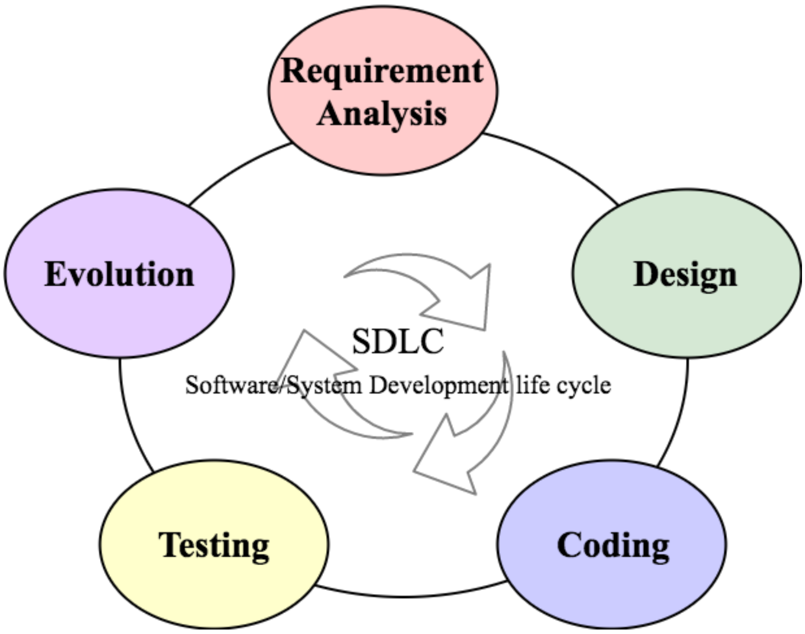


Figure 4.4 Model of the Systems Development Life Cycle (Modified)
(Source: Hu, 2013)

4.6.6 Phase 3: Case study evaluation

Keen and Packwood (1995) defined the case study evaluation or intrinsic case study (Stake, 1995, cited in Creswell, 2013). One or multiple methods are designed to comprise quantitative, qualitative, or mixed methods, to investigate a complex circumstance. This type of case study evaluation is not used for the experimental approach; instead, the main purpose is for assessment (Keen & Packwood, 1995), which focuses on the case itself, such as evaluating a program, or studying a student (Stake, 1995, cited in Creswell, 2013). The particular question used within the research strategy aims to collect practice and policy data that impinge on the professional lives of users; such questions involve ‘how’ or ‘why’ in the case study evaluation (Keen & Packwood, 1995).

Keen and Packwood’s (1995) case study evaluation strategy, fits the sequential multi-phase methodological choice of this study. This supports the multiple methods in the case study strategy and the purpose of the evaluation. The sample for this case study evaluation focuses on professionals, and data are collected on the use of the prototype. This includes participants’ recommendations following their use of the prototype, and the process assessment of this research. This process requires the following samples: 15 research participants or three participants per group (Nielsen, 2012). The sequent multi-phase research comprises three methods: a usability test, a group evaluation, and a process evaluation.

1. **Usability test:** This is used to collect data via a quantitative method. A usability test is the process for testing software and assesses the usefulness of the prototype when it is a part of a software development cycle. The usability test was proposed by Nielsen (1994), McClelland (1995), and Rubin & Chisnell (2008) to measure the performance (use) of a prototype, and it is measured in terms of numeric data from research participants (see the usability test, p.125 and p.239). Moreover, these participants are required to complete a questionnaire to collect data on their level of satisfaction (Rubin & Chisnell, 2008).
2. **Group evaluation:** This is used to collect data via a qualitative method. Each group tests the digital prototype in terms of collaboration. There are three terms of collaboration: co-location, different workplace location (delocation), and a mix of both. Each group participated in a focus group to collect data on their experiences and recommendations after using the prototype (see the six thinking hats technique, p.125 and p.241).
3. **Process assessment:** This is used to collect data via a qualitative method. Five research participants were invited to interview in order to collect their recommendations in terms of the process in which they had participated (see the interview technique, p.127).

4.6.7 Summary of the Research Strategy

The research strategy for this study is integrated into three phases. Principally, this research adopts case study research to focus on AEC professionals in Thailand involved with collaborative design in concept design. The first phase adopted a case study survey strategy to collect users' views (via a qualitative method) in order to determine their needs from a digital tool, or model for collaborative design, in concept design. The second phase applied the System Development Life Cycle (SDLC) model as the strategy for the prototype design and development. Finally, the third phase comprised three sub-sections, which were: usability and an evaluation group, and a process assessment. The usability test comprises the measurement of the prototype use, and an applied a quantitative method. Next, was the evaluation group adopted a qualitative method to evaluate the prototype, whilst the process assessment used a qualitative method to collect participants' recommendations from the evaluation process.

4.7 Time horizon

This study adopted a cross-sectional time horizon to: firstly, investigate a specific phenomenon in a particular period in order to form a characteristic model of a digital tool for collaborative design; and secondly, test the development. The study collected data and tested the prototype from the perspectives of AEC professionals involved in design collaboration within concept design.

4.8 Techniques and procedure

This section comprises three parts: firstly, the data collection methods and procedures are explained; secondly, the development of the PhD research methodology is outlined; and finally, the ethical considerations are justified. Data collection methods and procedures are described in order to provide an understanding of what these methods are and how they were implemented. Next, an overview of the research methodology development is explained throughout the research. The overview concludes all processes in this research addressed in the chapter, from the philosophy to the techniques and procedures. Finally, ethical considerations are explained including the protocols followed with all participants in this research.

4.8.1 Data collection methods and procedures

The primary data collected for this research were quantitative (numerical) and qualitative. Five data collection methods were used, which were deemed appropriate for this study: literature review, questionnaires, focus groups, a usability test, interviews data analysis, and trustworthiness. In addition, the design was synthesized from the literature review to assist the researcher when designing a digital prototype. From this, a model of development was adapted to guide the researcher when developing the digital prototype in this research. These data collection methods and procedures were as follows:

4.8.1.1 Literature review

The literature review gathers a range of documentary sources for the data collection; documents can include textual data, photographs, images, audio, or digital files. A key concern is to assess their credibility to determine their authenticity, correctness, and whether they are free from bias and error (Johannesson & Perjons, 2014). The main advantages of this method are that data sources from documents can be collected in a short period of time; it is relatively inexpensive; and does not pose usually ethical problems. On other hand, a disadvantage of a literature review is its credibility as some documents may not be acceptable (Johannesson & Perjons, 2014). Nevertheless, a literature review was a crucial method to investigate and review research findings before the questionnaire design; explained and provided further resource for other methods in this research.

4.8.1.2 Questionnaire

Colin (2010) explained that a questionnaire is a data-gathering technique that is used to collect either qualitative or quantitative information from an individual unit. This is identified in the research sample through written self-reports regarding the unit's knowledge, beliefs, opinions, or attitudes about or toward a phenomenon. In a case study, there are two ways to adopt research questionnaires, namely: 1) the questionnaire can be the primary technique of a research strategy for data collection, or 2) the questionnaire can be used in combination with other case study techniques, such as interviews (Colin, 2010).

In this study, questionnaires were used in two ways; firstly, they were delivered to research participants for them to complete by themselves over the Internet. A qualitative questionnaire was adopted (see Appendix 4) that employed both closed-ended and open-ended questions to collect the data. This is particularly appropriate for descriptive, explanatory, and exploratory studies. These answers were analysed as a qualitative method using coding and themes, which helped to build a final model for the data collection and analysis. Secondly, a questionnaire was used while research participants completed the performance measurement of the usability test. Participants completed the Software Usability Scale (SUS) questionnaire; these results were calculated and analysed to score the usability. The satisfaction score was defined in terms of its usability.

4.8.1.3 Design

After understanding users' requirements, the prototype architecture was built as a master plan of the prototype design and development. It was used to develop a digital prototype based on the model of Creative and Critical Thinking in Problem Solving for Design (CCTPSD) and a tool for Problem Solving. These were modified in this research for the concept and system design in this research. The CCTPSD model integrates components of design, Lawson's idea creation model of thinking (2006), and Torrance's creative thinking (Alvino, 1990, cited by Cotton, 1991) (see p.77) in order to address creative and critical thinking in the design process. The CCTPSD model helped the researcher to build user-interface and system design diagrams and to develop a graphic user interface for the prototype in order to follow the architecture, as illustrated in Figure 4.5.

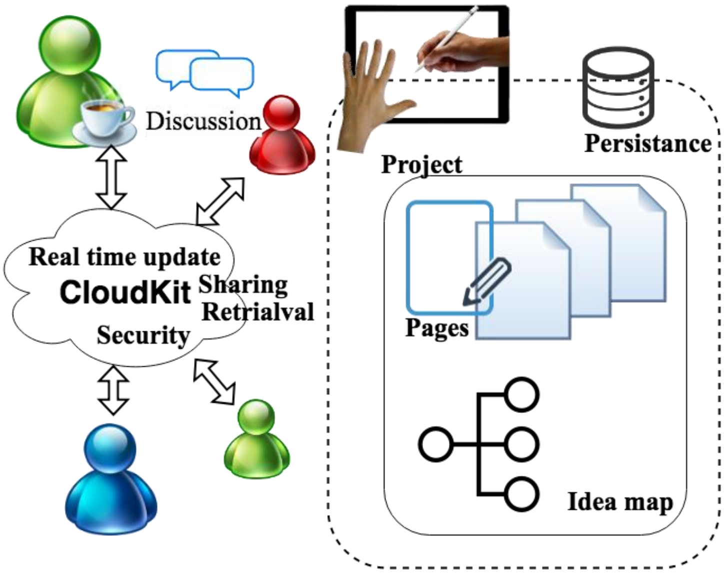


Figure 4.5 Architectural model of prototype
(Source: Researcher's own)

In this research procedure, the specification requirement was defined for the architectural model (Figure 4.5). Thus, the researcher implemented the specification requirements to build a digital tool for a portable device. A portable device platform was chosen, which uses a CloudKit framework to manage the data among the target users, who are AEC professionals involved in co-designing within concept design. From this, the researcher adopted the strategy addressed in the CCTPSD model. The user interface and system designs were first developed as diagrams by the researcher at the first. Then, the prototype's graphic user interface was designed and developed. In the concept and system design process, it is necessary to consider prototype's environment, requirement, and operation system whilst the diagrammatic and graphic user interface are designed in the individual process.

4.8.1.4 Development

After developing the user interface and system designs, a development method was used to help the researcher simultaneously develop the coding and testing in order to build the prototype through the appropriately modified software development approach (see p.210). This stage was possible because the researcher is a software developer. The modified approach was developed from the prototyping model (Davis, 1992) and integrated the incremental process so that the prototype could be developed in stage, from a small to a complete prototype (see, p.217).

Coding is a process of computer programming, and was undertaken by the researcher. The prototyping was divided and incrementally developed to complete each part within three to four weeks. Each part was iteratively improved and developed for new additional features and was then tested. The researcher ensured that the coding was tested, both in terms of its functions and via an integration test, which was conducted before research participants undertook the evaluation.

4.8.1.5 Usability test

A usability test assesses how software works after it is developed or before it is released as user software. Nielsen (1994) and McClelland (1995) explained the process steps required to set the instruments in place for the user test. The following outlines how this was conducted, which comprised two sub-procedures:

The first sub-procedure was a measure performance, where each user tested the prototype tasks. The time performance of each task was captured and compared with an expert undertaking the same tasks; this helped to calculate the efficiency and learnability values. This part of the study used a quantitative method to collect numeric data, which complemented the results generated from other methods. Nielsen (2012) advised a sample size of three to five participants or three to five participants per group. The user performance is almost always measured by inviting a group of test users to perform a predefined set of test tasks while collecting time and error data. The goal of the user performance measures is to collect usability attributes: learnability, efficiency, memorability, errors, and satisfaction. Thus “With 5 users, you almost always get close to user testing's maximum benefit-cost ratio” (Nielsen, 2012). The second sub procedure was the Software Usability Scale (SUS) Questionnaire, which was used to support the data collected from the other methods.

In this research, the performance measurement and the SUS Questionnaire were adopted to collect data from participant groups; the sample size of each group was three participants. Participants’ activities were recorded, and this was used for the performance measurement when using the prototype. After that, the SUS questionnaire was handed out to collect the participants’ satisfaction levels (see the SUS questionnaire form, p. 341).

4.8.1.6 Group evaluation and focus group

This procedure gathered three groups to test the prototype in terms of collaborative design. In particular, it focused on: 1) colocation, 2) different locations or delocation, and 3) a mix of both conditions.

- Firstly, all participants were assigned to use the prototype on the same table to replicate the condition of colocation.
- The next condition was different location, when all participants were separated and assigned to work together through the Internet and a WIFI connection.
- The final condition was a mix of both, when two participants worked together, and another was separated but could work with other participants through the Internet and a WIFI connection.

Each collaborative design term was used in the group evaluations, and this method gathered three participants per group to use the prototype with each other. The purpose of this procedure was to prepare each group of participants to gain experience of the prototype in order to enable a discussion in the focus group on collaborative design.

Focus group

A focus group can be conducted using semi-structured and in-depth interviews that concentrate on enabling and recording an interactive discussion between participants on clear and precise topics (Saunders et al., 2016). A focus group emphasises participant interactions, which is a key feature in enabling an interactive discussion and thus obtaining views or attitudes about a product. The purpose of the focus group is to construct shared meanings through participant interactions, including their sense-making of a topic. The number of participants depends on the complexity of the topics; thus, for more complex topics, a smaller group of interviewees is recommended, such as two, four, or ten participants (Saunders et al., 2016). Barlow (2010) advised that three to five groups of participants could help to verify the data and determine whether these are influenced by particular group dynamics. In addition, a session length of 90 minutes is generally sufficient, although participants are usually asked to attend for around two hours (Barlow, 2010).

In this research, a focus group was used in the evaluation process to collect data from at least three groups of research participants. After completing the group evaluation and gathering participant experiences of the prototype, all groups were arranged into focus groups. Each group spent 60-90 minutes in the group discussion, and the Six Thinking Hats technique (De Bono, 2017) was adopted, which is explained further in Chapter 7.

4.8.1.7 Interview

Interviews are widely used to collect data when conducing a systematic inquiry; they are defined as 'conversations with purpose and direction' that seek knowledge and understanding (Barlow, 2010). The interview adopted in this research was semi-structured, which lies between a structured and unstructured format, and explores a number of predetermined topic areas with some flexibility. The purpose of the interview can follow that of the research, namely, it can be exploratory, descriptive, explanatory, or conduct an evaluation.

The semi-structured interview aimed to conduct a process of evaluation and required several participants in a face-to-face method. Nielsen (1994) advised that five participants for an interview method is usually appropriate. These participants were invited to attend an interview after participating in the focus group. The length of the interview ranged from 30-45 minutes in length (see Appendix 13 For the interview questions p.354).

4.8.1.8 Data analysis

Analysis was conducted for both the qualitative and quantitative data. This research adopted an abductive approach and chose a multiple phase methodology using a mix method (complex) approach. Therefore, quantitative (numeric) data were collected from performance measurements, which gave participants' levels of satisfaction in the usability test (see p.121 and p.239).

Building coding and themes were used for the qualitative data analysis; this helped to describe the phenomenon in depth (Braun & Clarke, 2006, Braun, Clarke, Hayfield, & Terry, 2018, and Yin, 2011). Yin (2011) proposed qualitative data analysis through a cycle of 'Five Analytic Phases', whilst Braun and Clarke (2006) provided a linear 'Theme Analysis' process comprising six phases; these were similar to the code building and theme analysis on the interaction among phases (see Figure 4.6). Yin (2011) and Braun et al. (2018) advocate the gradual digestion of complex contents collected from qualitative methods. They suggest: 1) identifying the keywords or themes and, 2) assembling these keywords or themes into, an appropriate category through interpretation. Building coding, themes, and categories are adopted to analyse data in the qualitative methods of this research.

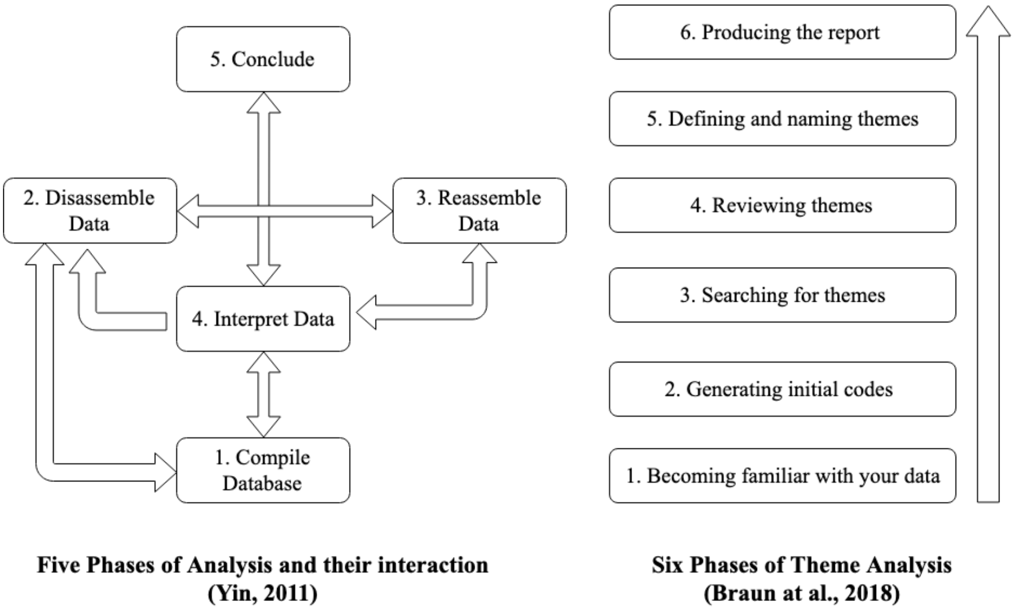


Figure 4.6 Five Analytic Phases and Theme Analysis
(Source: Modified from Yin, 2011 and Braun et al. 2018)

The abductive approach in this study combined both induction and deduction to explore the phenomenon; this help to build and test the concept framework. Furthermore, this research conducted a two-step data collection (see the research approach, p.111 and methodological choice, p.112) as follows:

1) The first data collection was inductive: it continued the research process from through addressing the objectives and questions. This was achieved by collecting and analysing data from the sample. The qualitative data analysis helped to generate codes, define themes and build relationships. The themes were assembled into appropriate categories to further analyse the phenomenon. Triangulation was used to support the findings and to explain the coding and themes from multiple sources, for example the literature review and another data collection methods (Yin, 2014). These categories helped to build model of the prototype and to transfer the model and explain the prototype specification.
2) The second data collection was deductive and similarly, continued the research process by addressing the objectives and questions. This phase involved the selection of research methods, and the analysis of quantitative and qualitative data. The quantitative data from the usability test were analysed to measure and describe participants' use of the prototype. In comparison, the qualitative data analysis involved the participation of subjects in the focus group, who engaged with the Six Thinking Hats technique to

evaluate the prototype. After analysing both qualitative and quantitative data, these results were explained to evaluate the prototype and the process.

The abductive approach is adopted and based on a combination study, which integrated exploration and evaluation. Furthermore, the data analysis for this study needed to: 1) explain 'what' or 'how' is the model, and 2) evaluate the 'how' and 'what' in relation to the prototype's function. These need to follow the aim and objectives of this research and offer recommendations for improving design team collaboration.

4.8.1.9 Trustworthiness

Trustworthiness is necessary to assure the quality of a study and relates to the degree of confidence in the data, interpretation, and methods used (Pilot & Beck, 2014, cited in Connelly, 2016). Guba (1981) stated that the criteria for trustworthiness in qualitative methods include: credibility, transferability, dependability, and 'confirmability'. These criteria are required for both quantitative and qualitative methods, and are considered as follows:

1) Truth value: Credibility-Validity (internal validity),
2) Application: Transferability-Generalisability (external validity),
3) Consistency: Dependability-Reliability, and
4) Neutrality: Confirmability-Objectivity (Guba, 1981).

Guba (1981) described credibility as referring to the confidence in an accurate account or the truth of the findings carried out in a particular context; these are analogous to validity in the quantitative method. Application refers to the relevance of the data findings to a different setting; in the quantitative method, transferability is linked to generalisability or external validity. Furthermore, Connelly (2016) noted that transferability is required to provide a rich, detailed description of the context, location, and sample; this includes transparency about the analysis and trustworthiness. The term dependability is a similar concept to reliability in quantitative method and refers to the stability of the data over time and throughout the study conditions (Polit & Beck, 2014, cited in Connelly, 2016). Finally, neutrality refers to 'confirmability', which is similar to objectivity in the quantitative method. This concept demands the removal of the investigator and subjects' biases (Guba, 1981).

Table 4.1 presents the keys and strategies of trustworthiness, which were adopted in this research. The first column details the keys whilst the second column lists the strategies used by the researcher. These strategies were carried out in this research, as detailed in the Procedure column:

Table 4.1 Trustworthiness strategies used in this research

Trustworthiness	Strategy	Procedure
Credibility	• Varied field experience	• Researcher is a professional architect with 21 years of experience
	• Triangulation	• The results from the first data collection were triangulated by comparing them to the existing literature and the second data collection
	• Member checking	• Participants checked their evaluated information in the focus group • Participants invited into the interview checked their information
	• Validity: Usability test	• Groups of participants evaluated the prototype with performance measure
Transferability	• Snowball sampling and Purposeful sampling	• The samples chosen for the first and second data collections are representative of professionals who design together in concept design
	• Detailed description of sample, location, and context	• Participants' information was presented in the overview • Context was presented a vivid picture in literature in terms of collaboration in Thailand. • This research is conducted in Thailand
	• Data saturation	• Participants' answers were included in the data analysis

Trustworthiness	Strategy	Procedure
	• Generalisability: Usability test	• It is useful to understand the prototype tested by professionals and its result can generalise the finding to the wider population
Dependability	• Triangulation	• The results from the first data collection were triangulated by comparing them to the existing literature and the second data collection
	• Peer review	• Peer review by academic researcher and team
	• Reliability: Usability test	• Performance measure was the evaluation tool; the study adopted the usability test which can be used in other evaluations the same test should produce the same results
Confirmability	• Triangulation	• Methodological triangulation adopted to compare data between primary data collection methods and the literature review
	• Peer review	• Peer review given by academic researcher and team
	• Member checking	• Participants checked their evaluated information in the focus group

4.8.2 PhD research methodology development

By addressing all the layers of the 'research onion', these methods were arranged to fit together, and are illustrated in Figure 4.7, which is a diagram of the research methodology. The methodology for this study was informed by pragmatism, and its position was underpinned by the adoption of both positivism and interpretivism within an abductive approach. The study therefore: 1) identified the methodology and issues for this research; 2) explored information from Thai professionals to gain an understanding of users' requirements of a digital tool for collaborative design in concept design; and 3) evaluated professionals' perceptions of a developed digital tool model.

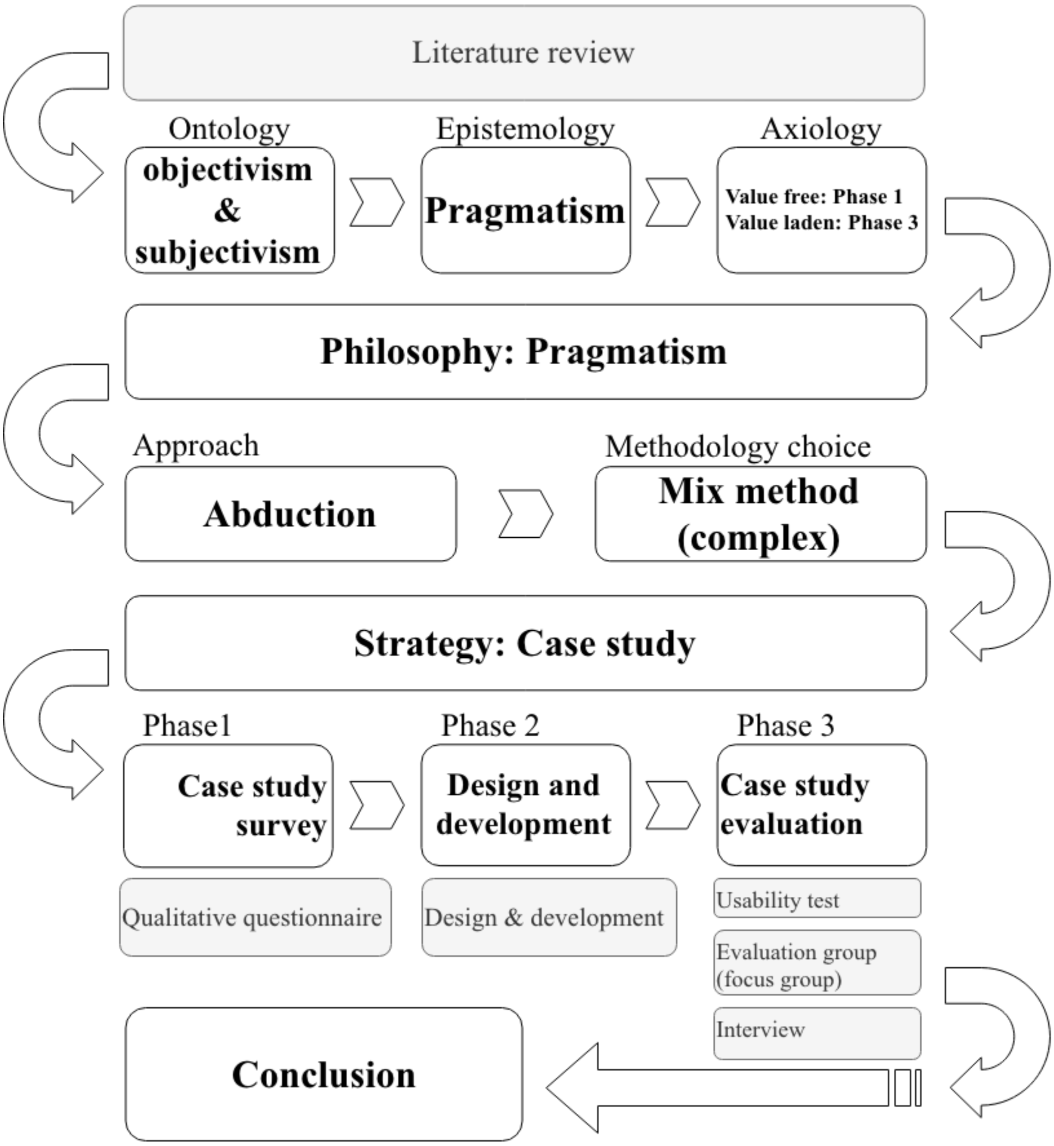


Figure 4.7 Diagram of the Research Methodology
(Source: Researcher's own)

4.8.3 Ethical considerations

This research undertook two data collection phases that highlighted ethical concerns in relation to the research participants. They received information for all aspects of the research, concept, and influences that could affect their participation. For the first data collection, the invitation letter and all information were attached to an emailed invitation that was to professionals participating in the qualitative data collection. After they responded, the Internet questionnaire, along with the informed consent form, was sent to participants.

For the second data collection, the invitation letter and all information were sent to participants by email. The information provided a full explanation of all the processes that would be carried out as part of the research. Moreover, information was provided about the devices that would be used during the evaluation process. These were explained to ensure a full understanding of the process. Informed consent was collected on the day of the evaluation process.

In terms of data security, all collected data were kept as digital files on Cloud storage and were not published. Moreover, no personal information, responses and opinions were released to protect and respect participants' privacy. Furthermore, all the collected data was kept secure. Participant names, personal information, responses and opinions were not published in order to protect and respect participants' privacy.

4.9 Summary

This chapter identified the research philosophy that informed the research approach and methodology carried out for this research. A pragmatic philosophy was identified, which was underpinned by an abductive approach. The chosen strategy was a case study, which was adapted to the data collection methods conducted in Thailand. These aimed to: 1) collect data to define a model for the required digital tool; and 2) evaluate the developed digital tool. Finally, both trustworthiness and ethical considerations were considered to demonstrate how these informed the conduct of the study.

CHAPTER 5:
DEFINING REQUIREMENTS FOR A TOOL FOR COLLABORATIVE CONCEPT DESIGN

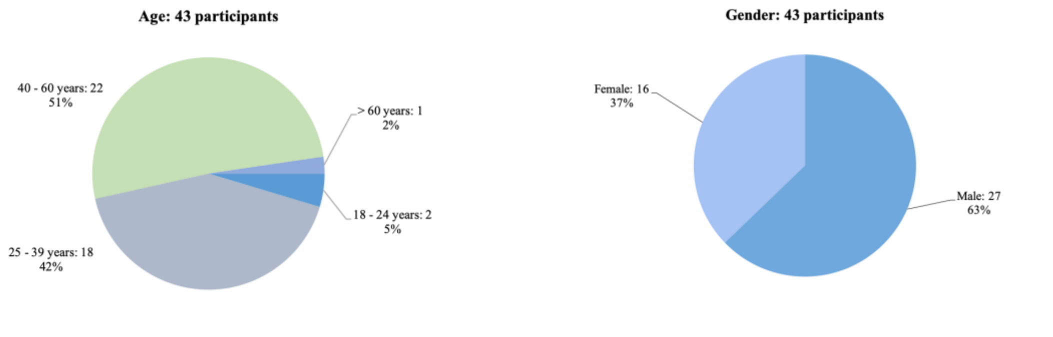
5.1 Introduction

This chapter details the findings from the first data collection of the study. The case study survey adopts a qualitative questionnaire that gathers participant information and views; thus, this chapter presents the data analysis results and findings from the questionnaire. The participant information (section 5.2) shows demographic and other information regarding the sample. Section 5.3 presents the descriptive data analysis; this is coded to enable the interpretation of the data in a way that follows the objectives of the survey (see Appendix 5). It includes a general summary of the data from the coding technique and frequencies, which are sorted and grouped to understand the phenomenon. After that the section focuses on findings from the data analysis and considers the objectives for the first data collection by describing the problems experienced by practitioners. This leads to a summary of the findings that details the designers' requirements of a tool for collaboration in concept design.

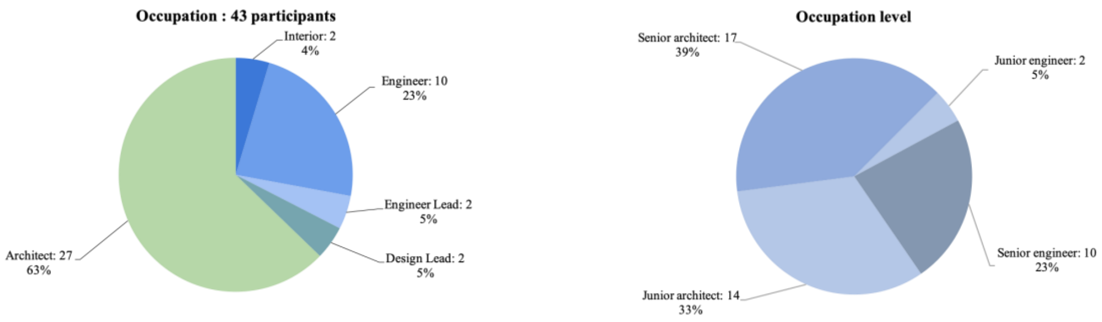
5.2 Participant information

Research participants include architects and engineers with professional licenses from either the ATC or the EIT, which indicates that they are representatives of the Thai AEC industry. They were invited to participate in this phase of the study through applying a purposive sampling technique. This enabled the researcher to select participants who had gained a license for professional practice and designed within the concept and schematic design stages. Then, a snowball technique was adopted to invite other professionals to participate in the data collection. The collection of the survey results started in November 2017 and was finalised in July 2018. The qualitative questionnaire was built in Google Form and sent to 347 professionals, comprising 189 architects and 158 engineers from the AEC industry of Thailand. In total, 43 complete responses were collected from 31 architects and 12 engineers.

Both junior and senior architects replied to the survey, seventeen were senior architects and two transferred to interior design. All 12 participating engineers indicated experience in a design team at the schematic design stage. They comprised two building service engineers, eight civil engineers (structure and construction), and two leading civil engineers (both structure and construction). Amongst the ten civil engineers, was a senior engineer whilst the remaining two engineers were civil engineers. A range of respondent information is presented as key demographics, which includes age, gender, occupation, and level of occupation. Participant information was presented to understand the groups of professionals who responded to the survey and whose views informed the development of the prototype (Figures 5.1).



1. Age range of participants 2. Gender of participants



3. Occupation of participants 4. Levels of occupation

Figure 5.1 Particular Demographics
(Source: Researcher own)

The age and occupation levels are key to the categorisation of professionals in Table 5.1. The 43 research participants for this data collection comprised architects and engineers. Amongst the sample were 16 junior professionals, 14 architects and two engineers, who are under 40 years of age. Of the 27 senior professionals, 13 architects and ten engineers comprise the 40-60 and over 61 years age categories whilst four senior architects are included in the less than 40 years category (see Table 5.1).

Table 5.1 Category of professionals by age, and occupation level

Age	Level	Architect	Engineer	No. of professionals
24	Junior	1	1	2
25-39		13	1	14
	Senior and over	4	0	4
40-60		12	10	22
61 and over		1	0	1
Total		31	12	43

5.3 Qualitative Data Analysis Results

This section focuses on the description of the data and aimed to identify patterns and extract meaning from participants' answers. Data on collaboration and the problems encountered, the use of tools, and professional requirements were collected from the field in Thailand. These data were analysed and described as follows. The results are presented to follow the seven objectives of this data collection (see Appendix 5).

5.3.1 Collaboration in concept and schematic design

According to collaboration in Thai project delivery approaches addressed in Chapter 2, design projects are usually handled by an architect and architectural design team at the concept and schematic design stage and then other professionals, such as engineers, are brought into the process from the design and development stage. This process is guided by the documents produced by ACT (2015). In this section, the circumstances of collaboration in Thailand were explored; participants provided responses on the patterns of collaboration, their recommendations for collaboration, the types of disciplines involved, and the range of designs generated at the concept and schematic design phases.

Firstly, participants were asked to describe the rationale for collaboration among professionals in the concept and schematic design stages in Thailand. Almost all participants (90.70%) agreed on the need to increase opportunities for collaboration in the concept and schematic design stages. This is significant as the literature demonstrated that collaboration among professionals is required within concept and schematic design in order address any problems, especially within complex or specific building designs.

Caption 5.3.1.1 A Participant's Rationales for Collaboration within Concept and Schematic Design

Architect: "*The building design has to use knowledge from several professionals to achieve the goal and objectives. These professionals are important to assist each other and share specific information so that the design will be achieved without any problems.*" (Q4.P044)

Architect: "*I think building design needs knowledge of relevant multi-disciplines. Architect deals with the owner to create a concept design idea, which is an abstract idea and does not cover the design of other professionals, such as structure or building service. If there is not the chance to talk or plan at the beginning, the incomplete design will present problems and perhaps cause conflicts amongst these professionals.*" (Q4.P011)

Architect: "*The collaborative design process is to work together to consider possibility and other issues, so that the project will have less problems.*" (Q4.P025)

Architect: *"Some types of building are complex and specific. I think it is important to encourage all designers to work together among disciplines."* (Q4.P026)

Engineer: "*The process can assist all designers to produce ideas and solve problems to get the best idea or solution."* (Q4.P037)

Engineer: "*I found that many problems appear in the construction phase although a construction drawing was designed by designers, architect and other professionals. To solve these problems in the construction phase is too late. It's difficult to improve the design, and it wastes cost and time as the design may be changed in some cases."* (Q4.P041)

However, some architects (9.3%) disagreed with increasing collaboration within concept and schematic design. They indicated that they initially need to use traditional processes, and that design should first be completed within the schematic design stage. They agree that collaboration is necessary to deliver the design to other professional at the design and development stage.

Caption 5.3.1.2 Some Disagreements from Participants

Architect: *"I disagree, I think that each part of the design should have specific borders for each discipline."* (Q4.P022)

Architect: *"I disagree. When the design idea is finished by the architect, other professionals can be brought to collaborate and design other systems in the design and development phase."* (Q4.P050)

Architect: *"I disagree. Concept and schematic design should be created by the expert designer. Then, the design is delivered to each relevant professional to consider the performance in the next step."* (Q4.P043)

Architect: *"I disagree. This should be only an architectural designer's responsibility."* (Q4.P042)

The question allowed participants to identify the most important reasons for increasing collaboration among professionals in concept and schematic design; for this question, they could select from a list (see Table 5.2). This helped the researcher to understand the problems that are important when working together among multidisciplinary and multifunctional teams. Efficient collaboration was thus expected to reduce the process steps, cost and time. Notably, both architectural and engineering participants indicated that collecting information and generating ideas were important to enhance efficient collaboration. This helps to enable understanding and decision-making in order to solve problems. Some participants (both architects and engineers) pointed out that collaborative design can reduce conflict when encouraged among design team from the beginning.

Caption 5.3.1.3 The Reasons Given for Increasing Opportunities of Collaborative Design

Architect: "*To create a concept design requires information that's analysed from many parties. The collaboration among relevant multi-disciplines can help to entirely collect ideas to cover project elements. This is efficient in creating a good design.*" (Q4.P019)

Architect: "*To create concept design together will help us to know the possibility of the design, which can be built to follow the essentials.*" (Q4.P030)

Engineer: "*This needs to be agreed with ideas from all parties who have responsibility together at all times.*" (Q4.P035)

Engineer: "*…the collaborative design process can reduce conflict problems in design.*" (Q4.P040)

Architect: "*…If there is no talk or planning at the beginning, an incomplete design will become a problem and perhaps cause conflicts among these professionals.*" (Q4.P011)

Table 5.2 Rationale for Collaboration in Concept and Schematic Design

Reasons	No. of code addressed	Category	Frequency
Understanding in the same direction	9(9A, 0E)	Understanding	18
Decisions and conclusions	2(1A, 1E)		
Collecting ideas and information	7(4A, 3E)		
Efficiency	5(4A, 0E)	Efficiency	12
Cost	1(0A, 1E)		
Time saving	4(1A, 3E)		
Reducing process steps	2(0A, 2E)		
Solving problems	8(5A, 3E)	Problem solving	17
Reducing problems	6(3A, 3E)		
Preventing conflict	3(2A, 1E)		

Secondly, when working with other disciplines in concept design, participants described general information in terms of their discipline and the collaboration process. The data was analysed and is presented in Table 5.3. A small design project involves a minimum of two to three designers, which generally includes the architect, and/or structural engineer, or the building service engineer. In comparison larger-scale projects require more professionals. Thus, the number and type of disciplines involved depend on the project type and delivery approach, as guided by the ATC (2015). Furthermore, some projects require other disciplines; for example, participants recommended landscaping, interior designer, or other specific experts. In addition, financial managers or marketing managers can be included within collaboration for concept and schematic design if the design requires this.

Significantly, conceptual design ideas are created and developed into two or three prototypes; the architect (and/or design team) creates these, from which the chosen design is confirmed by the owner and delivered to other professionals so that the architect can consult on specific issues/solve problems. This sometimes becomes an iterative design process as all designers work together after receiving the chosen design when they often note the problems. Meanwhile, professionals try to integrate their discipline into the design (see Table 5.3).

Caption 5.3.1.4 Participants' Descriptions of the Process of Collaboration

Architect: "*I firstly design my idea and work with my architect team who assist me to draw and make a model to clarify and solve problems on my idea. When I complete my conceptual and schematic designs, the design will be delivered to engineers to design its structure and building service system. The design may be improved through re-design if there are some errors or other, better choices/solutions.*" (Q5.P.23)

Architect: "*Architects create ideas for the concept design and continue to design from abstract to concrete ideas within the conceptual design. Sometimes, these architects deal with other disciplines, such as the structure engineer, when these developed ideas are finished. Then, they will deal with other relevant professionals in the design and development process.*" (Q5.P027)

Architect: "*An architect defines the main theme of a project, an image of the building, the relationship between the outside and inside of a building. Structure and building service systems are issues to be considered in terms of the limitations so that the design can follow the chosen concept. Then, other disciplines will be brought to work on the design of each part and to improve the design, which may have errors or be incomplete, until the design is finished in the design and development process.*" (Q5.P.024)

Engineer: "*An architect or engineer will start to work with the owner. After the concept design is thought out, the first step of collaboration is to start to meet all team members; architects and engineers.*" (Q5.P036)

Caption 5.3.1.5 Participants' Descriptions of The Process of Collaboration

Architect: "*I think that the architect, interior designer, all engineers, the landscape, cost consultant, and project manager should work together within concept design and schematic design. An interior designer works with the architect team to create space both inside and outside, to relate and harmonize. Next, all engineers, the landscape designer, and architect work to plan the space outside and promote the image of the building. In addition, the building cost is analysed by the cost consultant and the project manager creates a building plan to show the overview of the design.*" (Q6.P.024)

Architect: "*A civil engineer, building service engineers (electrical and air conditioning engineers), interior designer, and architect should work together in concept design and schematic design. This ensures all designers know the dimensions provided by other professionals for all systems that will affect the image of the design.*" (Q6.P.029)

Engineer: "*In the case of a small building type, a design team should have an architect and civil engineer (at least) in the mentioned process. Another case is a large building type, which is complex and large. This type should ensure professionals collaborate in the concept design and schematic design, such as the architect, engineers (structural, electric and mechanical engineers), cost consultant, design lead, and construction lead.*" (Q6.P039)

Engineer: "*All designers are important and I want all relevant professionals to co-design, but it depends on the type of building and size. So I think that it is important to consider choosing who will co-design within the concept design and schematic design.*" (Q6.P041)

Table 5.3 General Information on Collaboration for the Concept and Schematic Design Stages in Thailand

<table>
<tr><th>Project Type</th><th>Current process of collaboration</th><th>Disciplines recommended</th></tr>
<tr><td>Small
No. of Designers in Concept Design is: 2-3</td><td>1. Designs are created: around 2-3 prototypes.
2. The design is chosen when the owner is consulted.
3. And/or the architectural design team help to draw and make the model, which includes problem solving.
(if project requires other professionals, they are also consulted)</td><td rowspan="3">Number of designers depends on the type of project.

At least (2-3): Architect or structural engineer and/or including building service engineer.

General (7): Architect, structural engineer, building service engineer, cost consultant, lead designer project, construction lead

Other disciplines: Interior designer, Landscape, or Law expert

Other relevant people: Marketing, Finance management, Draftsman, technician

Owner and relevant users: owner or user</td></tr>
<tr><td>Medium
No. of Designers in Concept Design is: 4</td><td rowspan="2">1. Designs are created: around 2-3 prototypes.
2. The design is chosen when the owner is consulted.
3. The architectural design team helps to draw and make the model, which includes problem solving.
4. Other professionals meet to consult on specific issues/solve problems.
5. The design may be re-designed if there are errors or other better choices/solutions.</td></tr>
<tr><td>Large
No. of Designers in Concept design is: 7 and/or over</td></tr>
</table>

5.3.2 Current problems in communication and collaboration

Relevant designers working together within concept and schematic design were asked about current collaboration and communication practices. In addition, the survey encouraged participants to propose ways to support collaboration and to solve the problems associated with potential barriers, misunderstanding, misinterpretation, and conflict.

5.3.2.1 Current problems in collaboration

Participants were asked what problems they experience in collaboration and communication. Their answers were analysed and are presented in Table 5.4. The literature review on collaboration (in Chapter 2) indicates that professionals face problems in terms of the silos, communication process, environment, and the designer's capability for collaboration. In the AEC industry, these designers are normally from different disciplines, which reflect different backgrounds and experiences. Eleven participants (24.44%) pointed out that different viewpoints (different interpretations) become the main problem for collaboration in concept design. The difference emerges alongside other problems with collaboration. Thus, six participants (13.95%) noted a lack of collaboration; three participants (6.47%) mentioned problems with self-centredness; five participants (11.62%) acknowledged communication problems through misunderstanding, whilst two participants identified insufficient communication. Moreover, four participants (9.30%) noted missing common goals, stating that they are often vague and not confirmed by other professionals or the owner until other design processes are complete before the construction phase starts.

According to the Thai design process (guided by ACT (2015)), these designers face problems due to the fragmentation of relevant professionals into silos. This can lead to inefficient collaboration and communication throughout the process. Six participants, comprising five architects and an engineer (around 13%) noted a lack of collaboration. Moreover, six participants (around 14%) mentioned communication, whilst three architects and an engineer addressed the lack of common goals. Finally, two architects highlighted insufficient/less communication. In terms of the process, an engineer raised the issue of insufficient time when designs were delivered for them to work on in the concept design process.

Caption 5.3.2.1 A Lack of Collaboration and Communication

Architect: "*The problem is communication when all members work together in concept design and schematic design. Each member acts on own works only and lacks collaboration. As a result, the design is incompatible."* (Q9.P004)

Architect: "*If each party looks only to its own part without looking at the overall project design, and lacks communication with other parties, the design will have errors. For example, when a structure is oversized, it affects the building service system."* (Q9.P024)

Architect: "*There is a lack of good collaborative design. As a result, we cannot see problems or errors in concept design and schematic design….*" (Q9.P016)

Engineer: "*There is a problem in that design in concept design leaves problems for the construction phase due to a lack of collaboration. As a result, the design cannot be built in the construction phase*." (Q9.P037)

Engineer: "*There is less time to work on the concept design. The design process should be extended to create the concept design to more than it was. I think that it will help us see though everything and support everyone to collaborate in the concept design and schematic design process."* (Q9.P035)

Furthermore, seven participants (16.27%) addressed issues with the collaborative design environment. They pointed out that Thai professionals usually work together through a face-to-face channel via co-located collaboration. However, four architects mentioned that a problem arises when members work in different locations, whilst two participants (architects) noted issues with time schedules. Finally, one architect noted the insufficient management of meetings with an inefficient organisation of time. This issue is supported by Carrara (2017) who pointed out that meetings are not always efficient for collaborative design when gathering many professionals at the same time.

Caption 5.3.2.2 A Collaborative Environment

Architect: "*…When many parties in project teams collaborate to comment, spend a long time and cannot identify conclusions*." (Q9.P027)

Architect: "*…difference workplace location of each professional in a design team becomes a part of problems to… and it becomes difficult to manage time. … In addition, it is difficult to work together because each professional is not the same workplace location."* (Q9.P029)

Lawson (2006) pointed out that professionals can characterise self-centredness (Mackinnon, 1976, cited in Lawson, 2006) and hold different attitudes based on their experience and background (Lawson, 2006). Within this study, eight participants (18.6%) noted that different backgrounds and experiences could cause difficulties for collaboration among Thai professionals, whilst three architects and two engineers noted a commitment to their own professional approach, and a further three architects indicated self-centeredness as an influence.

Caption 5.3.2.3 Internal Issue (Problems in Collaboration)

Architect: "*These problems are different viewpoints where each profession sticks to their ideas and the professional principle too much. In addition, it is difficult to bring them to work together..."* (Q9.P005)

Architect: "*The problems are the different aspects and attitudes. For example, the concept design is described in a meeting when we have to spend more time and try hard to make all members of teams (multidisciplinary teams) understand to follow our concept. Because most civil engineers' concerns are strength, security, and budget. But our design will be designed to challenge engineering, we have to deal with the engineer so that structure can be designed to follow architectural design to keep the aesthetic and strength and stay under budget."* (Q9.P011)

Architect: "*I think that problems in collaborative design are too self-centred and not open-minded in concept design and schematic design*." (Q9.P043)

Engineer: "*The attitudes of the architect and engineer come from opposite directions. Most architects need to design the width, height, depth, and number of columns, which is contrary to the principle of engineering, because this character of a design needs to design bigger structures."* (Q9.P033)

Engineer: "*…Each professional has a different individual skill. When all of them are gathered, it creates conflict because there may not be an understanding of each other*." (Q9.P041)

In considering Carrara's collaboration cycle, thirteen participants (32.55%) mentioned the significance of collaboration capabilities. Furthermore, eight participants (or 18.6%) noted the designer's capability issues (and understanding), and five participants (or 11.62%) indicated different backgrounds. In addition, a senior architect stated that architects have insufficient experience. This can reflect the understanding that less experienced architects may not have had opportunities to gain and share knowledge in their practice.

Eight participants (five architects and three engineers) pointed out that they face issue of interpretation when design team members work together. This can lead to conflict, and was attributed to different backgrounds and experiences, such that members cannot clearly understand whatever is shared or discuss the work with each other.

Caption 5.3.2.4 Collaboration Capability (Current problem)

Architect: "*To have a different view leads to misunderstanding and more time spent to improve and adjust these views in the same way.*" (Q9.P014)

Architect: "*…For different experience and background, each professional uses a different method of problem solving and there are different viewpoints of the overall project.*" (Q9.P019)

Engineer: "*The problem is that the imagination of each person is different although it is the same project.*" (Q9.P036)

Engineer: "*There are different viewpoints in each discipline. … it creates conflict because they may not understand each other.*" (Q9.P041)

Five architects pointed out that achieving a common understanding is not easy as it means bringing different professionals to design 'on the same page'. One participant (architect) noted that some architects struggle to make other architects understand their concept design ideas.

Caption 5.3.2.5 Misunderstanding (Current Problem)

Architect: "*There is a misunderstanding and not in the same direction among different professionals.*" (Q9.P016)

Architect: "*…Sometimes, some designers cannot explain concept design ideas to ensure that other collaborators could have a clear understanding.*" (Q9.P019)

In terms of tools, seven architects (16.27%) mentioned that problems arise in using a tool to share, design and communicate. Two participants stated that the data version generated from a digital tool becomes a problem when team members use a different tool/s. In addition, two participants pointed out that communication tools cannot be successfully used in collaborative design to clearly describe a concrete picture; they also suggested that the variety of communication channels can confuse members. Moreover, three participants stated that the current tools used among professionals do not sufficiently support collaborative design to promote knowledge sharing and discussion. Significantly, two participants suggested the need for a new collaborative tool to: 1) assist all design team members to create the same picture in their collaboration in order to reduce conflict and problems in concept design, and 2) aid members to real time design collaboration in meetings.

Caption 5.3.2.6 Tools (Barriers)

Architect: "*Sometimes, collaborators are confused in terms of the latest version of data which they are working/designing with.* *There is a variety of communication channels such as email, letter, line, Facebook, physical notes, or SMS. Some collaborators refuse to use an unfamiliar tool for team communication and struggle to use digital tools for communication. It becomes a problem, leading to not receiving completed data and not updating."* (Q9.P016) **Architect:** "*Current tools have limitations that do not support all professionals in collaborative design in showing their comments to each other and acknowledging colleagues' comments to give a concrete picture* (not only text or sound)*."* (Q9.P039) **Architect:** *"The problem happening between collaborative design is a mismatch. If we have a tool that makes them see a similar picture, it will terminate conflict and error from the different understandings of each person. Besides, there is a problem that arises from the project concept being the issue in construction or other engineering. It needs discussion to develop the concept to a real project at the end. If the problem can be detected faster, it will bring benefits in design development and projects will be efficient, fast, and complete."* (Q9.P023) **Architect:** *"There is no tool that all members can create and modify together in real-time collaboration on co-location or at a physical meeting."* (Q9.P027)

Table 5.4 Current Problems of Collaborative Design in Concept Design

Problems of collaborative design in concept design	**No. of code addressed**	**Category**
A lack of collaboration	6(5A, 1E)	Collaboration
Common goals	4(3A, 1E)	Communication
There is insufficient and less communication among professionals.	2(2A, 0E)	
Process: There is insufficient time to work on the concept design process.	1(0A, 1E)	Design process
Co-location: Meetings consume more time and sometimes cannot complete the objectives.	1(1A, 0E)	Collaborative Environment
Time: Different working time schedules.	2(2A, 0E)	
Workplace: Different workplace locations as a problem for collaboration.	4(4A, 0E)	
Being self-centred	3(3A, 0E)	Internal issue
Different attitudes	5(3A, 2E)	

Problems of collaborative design in concept design	No. of code addressed	Category	
Different viewpoints	8(8A, 3E)	Interpretation	Capability of collaboration
Misunderstanding	5(5A, 0E)	Understanding	
Members of the team have insufficient experience.	1(1A, 0E)	Shared knowledge	
Sharing information is a problem due to different versions; it is difficult to collect and share this with members.	2(2A, 0E)	Medium: Tool	
The variety of communication channels is a problem in collaboration (such as Line, Email, SMS, and Facebook) when users do not like to use Email.	1(1A, 0E)		
Require a communication tool for collaboration	1(1A, 0E)		
Current tools have limitations in supporting collaborative design.	3(3A, 0E)		

5.3.2.2 Barriers and solutions in collaboration

The participants identified the barriers and (where possible) solutions in collaboration (see Table 5.5); some of the problems from the previous Table (5.4) were addressed as barriers by other participants in Table 5.5. These answers could be grouped five categories; Table 5.5 shows that three categories contained a greater number of codes than the remaining two categories. These three categories are: collaborative environment, internal issue, and collaboration capability. They proposed the provision of a mediator for the collaboration process, greater opportunities for communication among design team members, the use of ICT to enhance communication in the process, and the use of graphics in communication to prevent issues arising from the vagueness of language.

Thirteen participants (32.55%) noted issues concerning workplace locations and times; these were noted as key barriers for collaboration in Thailand. This is because a large number of small offices have been the dominant condition cross the Thai construction industry (see the overview of the Thai AEC Sector, in Chapter 2). Six architects and an engineer mentioned the impact of different workplaces, whilst five architects and an engineer mentioned issues concerning time schedule mismatches between professionals. It was pointed out that it is difficult to arrange meetings with all design team members. However, an engineer proposed that both workplace and time schedule conflicts could be reduced by using ICT in collaboration.

Caption 5.3.2.7 Collaborative Environment Issues

Architect: *"… It is difficult to do work schedules due to members' time schedule mismatches and different workplace locations. ..."* (Q11.P016) **Architect:** *"… A time schedule - it is difficult to set time schedule matches which we tried hard to deal with to hold meetings."* (Q11.P029) **Architect:** *"They are not to work at the same workplace location. Now, I solve these problems for collaborative design development and make a schedule for meetings."* (Q11.P031) **Engineer:** "*Barriers that often appear are different workplace locations and scheduling conflicts, it becomes a problem to hold meetings. I think that this problem can be solved by transferring data via the internet."* (Q11.P032)

According to the internal issue (see Chapter 2), professionals come from different backgrounds and with diverse experiences, attitudes, and potential self-centeredness. Social difference and/or cultural boundaries were also mentioned and can lead to other issues, such as misinformation, the misunderstanding of messages, and information exchange problems (Carrara, 2012; Poole, 2011, cited in Sun et al., 2015). Ten participants (23.25%) mentioned that internal issues pose a barrier to collaboration, whilst four architects and two engineers noted different backgrounds and experiences, two architects addressed attitude issues, and two architects pointed out issues with self-centeredness. One architect proposed talking other professionals into working together to prevent the conflict that arises from different backgrounds and experiences. They try to create an atmosphere for collaboration and use strategies to persuade other team members to participate in collaborative design. In addition, an engineer proposed knowledge sharing and the provision of materials, such as experiments, to design team members to assist the building. Another architect proposed the inclusion of mediators or project consultants to prevent/solve potential self-centredness in collaboration.

Caption 5.3.2.8 Internal Issue (Barrier)

Architect: *"… different experience is a barrier in concept design and schematic design. I will persuade and talk to other professionals, such as the structure engineer, to help me design."* (Q11.P020) **Architect:** *"I think that the barrier in the schematic design is that some of these professionals are self-centred. This causes controversy. When some team members design on their jobs, they will not consider other members' designs. A project consultant as a medium is the solution to find conclusions together."* (Q11.P026) **Engineer:** "*There is a difference between experiences and viewpoints. Although all members of a team can see the same problem, they understand it in a different way. This needs to be*

adjusted for all of them, and more reasons offered for clarity. Sometimes, evidence or experiments will be provided or presented to another side to understand and build a sense of togetherness or to accept working together." (Q11.P035)

In addition, interpretation and understanding were mentioned as key issues for collaboration in concept and schematic design (see Chapter 2). Ten participants (23.25%) stated that interpretation, a lack of collaboration skills, and misunderstanding are necessary barriers in collaborative design among professionals. Three participants (an architect and two engineers) pointed out a lack of collaboration skills amongst Thai professionals. One architect proposed that professionals should try to understand the rules of other professionals, and that they should be encouraged to communicate with each other. In addition, two architects and three engineers mentioned that interpretation represents a barrier for collaborative design. Two engineers recommended that relevant professionals should be encouraged to talk each other. One suggested the use of evidence or the results of experiments when communicating with design team members in order to ensure they understand and agree. Moreover, two architects mentioned misunderstanding as a barrier in collaborative design, whilst one architect proposed the passing on of knowledge to prevent misunderstanding.

Caption 5.3.2.9 Collaboration Capability

Architect: *"We should have more communication and try to understand professional rules. I think that professionals should pay attention to talk about what is incomplete in design rather than creating conflicts with each other. Nobody knows everything."* (Q11.P021)

Engineer: *"The main barrier is a different viewpoint in the design of each discipline. So, they need to talk to find out the appropriate point among designers."* (Q11.P033)

Engineer: "*The thought of each is not similar. Because there is difference of ... viewpoint. Although all members of a team can see the same problem, they understand it in a different way. This needs to be adjusted for all of them and more reasons used for clarity. Sometimes, evidence or experiments will be provided or presented to another party for understanding and this will help a sense of togetherness or acceptance at working together."* (Q11.P035)

Engineer: *"Each designer pays attention to just himself and does not try to study the needs of other colleagues."* (Q11.P038)

Engineer: *"Lack of team collaboration skills."* (Q11.P039)

Architect: *"In my opinion, it is mismatch in understanding, or not understanding another party's specific knowledge. This needs understanding or the passing on of knowledge to other collaborators in each discipline."* (Q11.P002)

Two architects mentioned the barriers associated with using tools for collaboration whilst another architect noted communication itself. One of them pointed out the barriers associated with new technology, which some professionals can find difficult to adopt when driven by other Thai AEC representatives. Moreover, another architect mentioned that the barriers are: 1) Complex versions of the data, namely both physical documents and digital files, which can lead to confusion as to the latest version, and; 2) Little to no recording ideas/solutions between collaborators, which can lead to conflict when evidence is not offered.

Gabriel (2000) also confirmed that, without recording or translating verbal messages into text or illustrations in collaboration, information is lost forever. Furthermore, one architect mentioned the inefficient use of communication tools, stating that it becomes a barrier when email does not function for collaborative design (Sharif et al., 2012) and too many communication tool channels can become confusing and/or obstructive, such as social media, SMS, or paper.

Caption 5.3.2.10 Using Tools in collaborative design (Barrier)

Architect: *"Barriers are new technology tools. They have been promoted for use in Thailand's ACE industry, but the tools are not yet used by all professionals."* (Q11.P.012)

Architect: *"…almost all cases involve documents from the owner or other important documents. These documents and lost data, were incomplete, duplicated. Sometimes the versions of shared data cannot be identified, or if it was updated. In addition, improvements between collaborations or meetings but no recording data lead to conflict when there is no evidence to refer to the change."* (Q11.P029)

Architect: *"These barriers are: 1) A tool is an e-mail. It does not have an instant feature to support collaboration in the team. In email, there are a lot of messages. Sometimes, I could not open and read them all. 2) Each member chooses different channels of communication, such as email, social media, Facebook, line, Short Message Service on mobiles, or paper.… 4) Senders and receivers are not on the same page (understanding mismatch)"* (Q11.P016)

Furthermore, language is a barrier due to the various glossaries used by different AEC disciplines; this needs to be considered when developing a common goal (Evans, 2012; Leon & Laing, 2013a). Three architects mentioned language issues; they recommended enhancing communication when language becomes an issue, such as when misunderstanding or misinterpretations arise from the use of jargon. Berardo (2007) pointed out that the language barrier can be solved by frequently checking understanding or allowing for other parties to ask for clarification during conversation. Nevertheless, participants proposed that designers could use tangible graphics to communicate in collaborative work. The tangible graphics generated among professionals include diagrams, sketches, or drawings, which are typically a source of information used in collaboration communication (Scrivener & Clark, 1994, cited in Van der Lugt, 2005).

Caption 5.3.2.11 Language (Barriers)

Architect: *"The barrier is the jargon of each discipline. It is used in communication and collaboration and it leads to misunderstand and mistake."* (Q11.P006)

Architect: *"The barrier is language. I will use graphics in conversations to make sure that others can understand whatever I try to mention."* (Q11.P009)

Architect: *"There are 3 barriers: 1) location, 2) time, 3) and language, in concept design and schematic design. The most cases are found in schematic design in collaborating among professionals."* (Q11.P030)

Architect: *"I think that a barrier is communication. It can be solved by persuading them to talk more."* (Q11.P004)

Table 5.5 Barriers in Collaboration and Solutions

Category	Barriers in collaboration	No. of code addressed	How are the barriers addressed?
Collaborative Environment: Co-location	Different workplace location	7(6A, 1E)	Use ICT technology to enhance collaboration and communication.
	Time schedule mismatch between professionals	6(5A, 1E)	-
Internal Issue	Different backgrounds and experiences	6(4A, 2E)	More communication
	Different attitudes	2(2A, 0E)	-
	Self-centredness	2(2A, 0E)	1. More communication 2. Mediator or project consultant
Collaboration Capability	Lack of collaboration skill	3(1A, 2E)	Integrate his/her self to other
	Different viewpoints (Interpretation)	5(2A, 3E)	More communication and evidence
	Misunderstanding	2(2A, 0E)	Passing on knowledge to colleagues
Medium: Tool	New technology	1(1A, 0E)	-
	Confusion of data version	1(1A, 0E)	-
	No recording ideas/solutions between collaboration		
	Tool for communication due to inefficiencies (email) and the rage of channels (Line, Facebook, email, or SMS)	1(1A, 0E)	-

Category	Barriers in collaboration	No. of code addressed	How are the barriers addressed?
Communication	Language	3(3A, 0E)	Using tangible graphics in communication

5.3.2.3 Resolutions for misinterpretation and misunderstanding

Misunderstanding is a barrier addressed by participants and a problem that designers also face in collaboration (illustrated in Tables 5.4 and 5.5). Misunderstanding can be solved by building knowledge with other colleagues in design teams. According to Carrara (2012), misunderstanding and misinterpretation occur in communication and collaboration among professionals when there is complex information. These are essential collaboration problems, as agreed by all 43 research participants; indeed, they suggested solutions, as shown in Table 5.6. Thus, 11 participants (25.58%) agreed that encouraging more communication, such as discussion, would help, whilst seven participants (16.28%) proposed that bringing professionals together through co-location could reduce the problems associated with misunderstanding and interpretation. In addition, 13 participants (30.23%) recommended the use of tangibles in collaboration and communication, which can help others to understand and correctly interpret a design. Finally, knowledge building is also important in ensuring understanding and avoiding misinterpretation amongst all members of a group.

Misinterpretation directly relates to misunderstanding; as previously discussed, interpretation is the first function in decoding a message and this is sent to the understanding function (Gorse et al., 1999 and Den & Emmitt, 2008, cited in Norouzi et al., 2015). However, diverse backgrounds and experiences relate to different interpretations and understanding in collaborative design (Carrara, 2012; Sun et al., 2015). According to the process of communication and cycle of collaboration (see in Chapter 2), a checking function provides feedback or agrees to respond. To prevent misinterpretation and misunderstanding in communication, a sender receives or requires feedback from the receiver in order to understand the content. Six architects and four engineers suggested the use of discussion to solve misinterpretation and misunderstanding. Two architects suggested talking together, allowing the sender to receive feedback from the receiver and thus check the common goal was communicated in order to solve the issue. For problems associated with a collaborative environment, an environmental barrier (Adu-Oppong & Agyin-Birikorang, 2014) can arise for which ICT tools can be used to increase communication effectiveness. Another engineer suggested the use of technology and communication tools to solve misinterpretation and misunderstanding among professionals.

Caption 5.3.2.12 Communication Suggested to Solve Misunderstanding and Misinterpretation

Architect: *"It can be solved by talking and finding an agreement together."* (Q12.P011)

Architect: *"Problems come up with assembling multi-disciplines with different experiences and backgrounds to work together, but it is necessary. I think that they should talk and explain so that they can collaborate in the same direction."* (Q12.P012)

Engineer: "*Using technology and communication tools support professionals; this will help communication to be better."* (Q12.P041)

Physical meetings involve co-located collaboration and the physical exchange of documents in the same place and at the same time (Germani et al., 2012). Three architects and four engineers proposed close collaboration through physical meetings. One architect described their collaborative process, where meetings can gather relevant team members after the completion of the conceptual design and after which other professionals could contribute to the design so that it can be edited together. One architect described the use of a mediator to avoid conflict from misunderstandings and misinterpretations during meetings. Moreover, when holding meetings, another architect recommended bringing design team members together in a workshop. In addition, one engineer proposed gathering all professionals from the beginning of design process to avoid misunderstanding and misinterpretation, rather than bringing in other professionals from the design and development stage.

Caption 5.3.2.13 Meeting and Co-location Suggested to Solve Misunderstanding and Misinterpretation

Architect: *"I will hold many meetings and workshops.*" (Q12.P024)

Architect: *"We can reduce conflict in collaborative design from holding meetings and using a mediator in negotiation."* (Q12.P006)

Architect: *"I solve problems by improving in meeting. We hold meetings when concepts are finished. If anyone needs to edit some points, we will correct those points in the meeting."* (Q12.P018)

Engineer: *"To avoid misunderstanding and misinterpreting information in the process all participants should join meetings from the beginning of the process."* (Q12.P040)

Tangibles can be referred to as pictures, drawings, sketches, or 3D digital tools, which can be used to increase the effectiveness of communication. A tangible is noted as an external representation of visual thinking, for example a picture can more accurately represent an image than many words and can help participants understand meaning; thus, an image is an extremely rich and valuable source of information (DeLoache & Marzolf, 1992). Eight architects suggested the use of pictures to solve the issues associated with misunderstanding and misinterpretation in communication and collaborative design. Two architects suggested using a picture to promote an easy understanding and to prevent misinterpretation. Another architect mentioned that 3D pictures from 3D software are used to ensure an accurate understanding amongst colleagues and to reduce mistakes in their design. Furthermore, two engineers suggested the use of BIM or a 3D modelling tool to build concrete ideas to solve the problems associated with misunderstanding and misinterpretation.

Caption 5.3.2.14 Tangibles Suggested to Solve Misunderstanding and Misinterpretation

Architect: *"I will solve these problems by talking more clearly and using pictures to promote communication."* (Q12.P016)

Architect: *"It needs to be solved by gathering data from relevant collaborators to help understanding. The data will be clear, easily read, compact which should have pictures to promote easy understanding."* (Q12.P019)

Architect: *"I agree that misunderstanding, due to different experience leading to errors, can be solved by 3D pictures, such as using 3D computer technology, so that we can keep everyone's perception at the same level and minimise more mistakes."* (Q12.P023)

Architect: *"To only talk may encourage misunderstanding and interpreting. So, the problem will be solved by using a drawing to help better understanding in communication."* (Q12.P025)

Engineer: *"This problem can be solved by using a 3d Model or BIM technology in the project." (Q12.P037)*

Engineer: *"I will solve this problem by using a tool that can create concrete ideas in 3 dimensions."* (Q12.P039)

Knowledge was mentioned as helping to solve issues associated with participant misinterpretation and misunderstanding. Moreover, an architect suggested updating their self-knowledge to study other disciplines, whilst another architect suggested sharing knowledge with other design members through collaboration to solve the issue. In addition, an engineer suggested providing training or seminars on collaboration for team members; this would enable development and solve the issue of ineffective collaboration. Carrara (2012) proposed the integration of other disciplines and encouraged the sharing of solutions, suggestions, or knowledge with other members (see Chapter 2).

Caption 5.3.2.15 Knowledge Suggested to Solve Misunderstanding and Misinterpretation

Architect: *"It can be solved by enabling understand or passing on knowledge to other colleagues in each discipline"* (Q12.P002)

Architect: *"We should update knowledge to study other disciplines. Especially, a common ground knowledge of other disciplines should be known. In addition, we have to know the basic information of design project, and that depends on the type of building."* (Q12.P031)

Engineer: *"The problem can be solved by making them understand each other. All members will work together many times to understand where their knowledge is insufficient or unequal. In addition, all different viewpoint members can be brought into the same stage so that they will have an opportunity to understand and to share the same direction. Then, training or seminars may be an appropriate method to increase their knowledge."* (Q12.P035)

Table 5.6 Solving problems of misunderstanding and misinterpretation

Misunderstanding and interpretation can be solved by:	**No. of code addressed**	**Category**
All 43 participants agreed that misunderstanding and interpretation are due to communication problems in collaboration.		
Encouraging more communication	10(6A, 4E)	Communication
Using communication tools	1(0A, 1E)	
Setting up meetings or working in co-located collaboration	7(3A, 4E)	Co-location/Close work
Using pictures in communication	8(8A, 0E)	Tangible
Using 3d digital tools	5(2A, 3E)	
Updating knowledge	2(2A, 0E)	Sharing knowledge
Setting up training or taking courses	1(0A, 1E)	

5.3.2.4 Mediator and Explanation of Solving Conflicts

Conflict has been understood to obstruct team performances and directly affect the performance tasks of team members, producing tension, antagonism, and distraction (De Dreu & Weingart, 2003). Although the negative relationship between conflict, team productivity and satisfaction is widely acknowledged, De Dreu and Weingart (2003) note that it is also healthy to enable low conflict level. This stimulates a team to deal with inefficiencies. It can increase efficiency and enable learning through the adoption of different perspectives, promoting the need to be creative. Unhealthy conflict becomes negative conflict and is usually caused by one or more parties acting defensively (Brown, 2013). Nevertheless, Brown (2013) suggested that conflict is the way to a shared understanding of each decision among a design team in the design process.

All participants agreed that monitoring communication content would help to prevent conflict; they offered opinions on conflict resolution, which are illustrated in Table 5.7. Nine participants mentioned that encouraging all design team members to discuss and explain reasonably could reduce conflict. In addition, setting up meetings or co-locating for collaboration would also reduce conflict when participating in decision-making. Nine participants suggested the use of co-located collaboration to solve conflict. Notably, one participant raised the integration of all designs to detect problems as a way of preventing conflict in collaboration. Moreover, two participants addressed the use of tangibles in co-located collaboration.

Thus, eight architects and an engineer mentioned encouraging design team members to talk and identify solutions to resolve conflict. Three architects suggested that they deal with healthy conflict and encourage reasonable discussion and negotiation amongst team members in order to solve problems so that they can collectively achieve good results. Lovelace, Shapiro, and Weingart (2001) confirmed that healthy conflict increases a team's productivity and efficiency, particularly when the team uses collaborative communication, when messages are shared among the team and can be enhanced by tools to facilitate a shared understanding (Gabriel & Maher, 1999). Thus, less contentious communication arises when expressing disagreement (Lovelace et al., 2001, cited in De Dreu & Weingart, 2003).

Caption 5.3.2.16 Negotiation Encouraged to Solve Conflict

Architect: *"To talk with reason and to find the best conclusion are good for solving any conflict problems, which will be good for all members in the team."* (Q13.P002)

Architect: *"I can solve the conflict problem by talking more. When they have any conflict, they should talk to find a way of solving the problem so that the work can move forwards."* (Q13.P012)

Architect: *"Let them talk to each other on the topic."* (Q13.P028)

In addition, seven architects and two engineers mentioned meetings as important in gathering relevant professionals to resolve conflicts with each other. Usually, Thai professionals follow the design process outlined by the ACT (2015) and work alone within their scope once the design complete and the architect has contributed. Two architects and two engineers suggested that co-decisions are used in meetings. Design team members are encouraged to discuss and/or brainstorm pros and cons by gathering comments, and with the aim of identifying the best way to resolve conflicts in their performance before co-decisions are taken. It is necessary to ensure all relevant professionals mutually agree on a common goal (Brown, 2013). De Dreu and

Weingar (2003) supported that task conflicts return positive impacts, when team members perceive cooperation rather than competition through goal interdependence. In addition, task conflict is healthy when cultivated in an environment that is open and tolerant of diverse viewpoints and that works with cooperative norms, which prevent disagreements from being misinterpreted as personal attacks (De Dreu & Weingar, 2003).

Caption 5.3.2.17 Meetings Explained to Solve Conflict

Architect: *"I will use meetings to support all of them to talk around the table."* (Q13.P015)

Architect: *"The conflict problem can be solved by comments and votes. Before voting, a team will gather the choices of solutions, analyse the pros and cons, and then vote by considering comments."* (Q13.P027)

Engineer: *"If there is a problem, a director can brainstorm comments to find out the best way out."* (Q13.P034)

Engineer: *"If all members of a team have equal experiences, they will use the vote. If all members have unequal experiences, the director will direct the team to decide on the same direction."* (Q13.P041)

For methodological design, an architect suggested a methodology to resolve conflict in concept and schematic design. It integrates the principles of all systems coordination, which should be developed to detect any conflict from the concept and schematic design rather than the design and development.

Caption 5.3.2.18 Integration Suggested to Solve Conflicts

Architect: *"My solution is to bring all design work to overlap each other and look for problems that will appear, and to use the principle of all systems coordination to solve these detected problems."* (Q13.P024)

In addition, tangible graphics were recommended by both an architect and engineer to help design team members resolve conflict.

Caption 5.3.2.19 Using Tangible Graphics to Solve Conflict

Architect: *"All relevant professionals can talk to end the conflict by themselves if the design is concrete enough to show the characteristics, or scale 1:1 on the computer."* (Q13.P023)

Engineer: *"I think that the director should be an architect to monitor all communication contents and can solve project problems through 3d Models or BIM technology."* (Q13.P036)

Table 5.7 Solving Conflicts in Collaboration

Conflict can be solved by:	No. of code addressed	Category
35 of the 43 participants agreed to have a director to deal with any conflict		
Letting them talk and explain/negotiate	9(8A, 1E)	Communication
Letting team members co-decide	4 (2A, 2E)	Co-located collaboration / Meeting
Setting up meetings or working through co-location	5(5A, 0E)	
Integrating all designs and detecting problems	1(1A, 0E)	Integration
Using a 3d digital tool	2(1A, 1E)	Tangible

5.3.2.5 Developing knowledge and understanding

In terms of developing the knowledge and understanding of other disciplines, all participants agreed that this was personally important and enabled collaboration among multiple disciplines with different backgrounds and with diverse experiences (see Table 5.8). Seven participants agreed that communication was still important when building knowledge and mutual understanding. Six participants pointed out that working closely is positive for the development of all members' knowledge and in understanding the importance of information gathering, learning, and information/idea sharing. Moreover, many architects noted that they gather information, share knowledge and information, and learn to develop their knowledge. Egan (2011) suggested that learning from experience is one of the key requirements for collaboration among team members. Knowledge development occurs in the collaboration process, through the offer of proposed and suggested ideas/solutions, and the promotion and enhancement of solutions amongst members through collaborative discussion. As a result, they can use information from proposals, suggestions, and discussions to create or modify their work (Carrara et al., 2017).

Two architects mentioned that they gather information to develop knowledge and understanding from others. One suggested that design team members should be encouraged to easily and rapidly access information so that collaboration will be smooth. In addition, they noted that an appropriate tool for collaborative design could provide a feature to support information gathering; Brown (2013) also supported this function. Alongside the generation of ideas, one of the designer's responsibilities is to generate an ideas document on how the product will look, work, and behave. This document is an important requirement when gathering and sharing the design among design team members.

Caption 5.3.2.20 Gathering Information to Develop Knowledge and Understanding among Team Members

Architect: *"The collaboration will be supported to run smoothly and should be concerned with attitude, tools and workplace. 1) all members will have a positive attitude to work together. 2) appropriate tools will be provided to support collaboration that can gather information. In addition, members can bring the information to use easily and quickly. ..."* (Q14.P029)

Architect: *"I try to gather information from all groups of professionals and share the information amongst all of them."* (Q14.P025)

Learning is part of developing knowledge. Five architects mentioned that they developed knowledge from previous projects and data, and through collaboration. Two of these architects suggested that they could learn and develop knowledge from data sources. Moreover, two other architects stated that they learn from other professionals through sharing knowledge and experience.

Caption 5.3.2.21 Learning to Develop Knowledge and Understanding among Team Members

Architect: *"I support all members to study the data of the project, and others to form an understanding."* (Q14.P006)

Architect: *"I support them to have an experience together, to train or study previous projects."* (Q14.P.021)

Architect: *"Experienced professionals pass on knowledge to younger professionals."* (Q14.P.014)

Architect: *"All relevant parts of a design team need to work in a participatory manner in the design and planning of large projects. They share knowledge and ideas amongst them and learn from other colleagues through collaboration."* (Q14.P027)

Suggestions and discussions enable design team members to develop their knowledge. Three architects and one engineer mentioned that they collected comments during their collaboration in order to develop themselves. Moreover, two architects and one engineer also mentioned that discussions among the design team members help them to build knowledge.

Caption 5.3.2.22 Comments and Talking Encouraged to Develop Knowledge and Understanding among Team Members

Architect: *"Open-minded to get comments and develop a reasonable understanding."* (Q14.P008)

Architect: *"I support the team to study the project and develop an understanding of other systems so that they can ask or talk to each other on unknown or suspect issues."* (Q14.P031)

Engineer: *"It can improve by letting them talk and explain more and often."* (Q14.P034)

For co-located collaboration, three architects and three engineers mentioned that meetings were important in helping to build knowledge. One architect described that they could collect other members' comments in a meeting, and later digest them in order to build their knowledge. Another two engineers described that they needed integration so that problems could be detected and become issues for discussion among design team members; this leads to collective knowledge building.

Caption 5.3.2.23 Co-location to Develop Knowledge and Understanding among Team Members

Architect: *"I support to the holding of meeting with all teams to listen to their comments and conclude the work."* (Q14.P012)

Architect: *"The collaboration will be smoothly supported and should be concerned with attitude, tools, and workplace. 1) all members will have a positive attitude to work together. 2) appropriate tools will be provided to support collaboration that can gather information. In addition, members can bring the information to use easily and quickly. 3) Another is the workplace and time, which will be managed to facilitate all collaborators."* (Q14.P029)

Engineer: *"We need integration to work with each other, which is important to know other disciplines to identify problems and find the appropriate methods to solve problems together."* (Q14.P035)

Engineer: *"If there are any conflicts, they will describe limitations so that all members can easily understand and identify the solution together."* (Q14.P039)

Table 5.8 Developing Knowledge and Understanding of Other Disciplines

Method of team's knowledge Developing	No. of code addressed	Category
Gathering information	2(2A, 0E)	Gathering
Studying previous projects and data	2(2A, 0E)	Learning
Learning from collaboration	3(3A, 0E)	
Getting reasonable comments	4 (3A, 1E)	Communication/Discussion
Talking together	3(2A, 1E)	
Setting up meetings or working in co-location	6(3A, 3E)	Co-location/close working

5.3.3 Experience of using current tools for collaboration in concept design

Currently, many tools, both digital and analogue, are used in concept design. The survey needs to identify how participants experience these tools so that their drawbacks or advantages may be considered when developing a digital prototype for this research. All participants were asked about the tools currently used in their design projects. They were also asked about the drawbacks of such digital tools (namely, CAD and BIM), and the advantages of analogue tools (such as sketch).

Designers use several tools in concept design (Brown, 2013; Denzer & Gardzelewski, 2011). Both Thai architects and engineers typically use several tools in concept and schematic design processes, such as Sketch, 2D AutoCAD, 3D AutoCAD, SketchUp, Revit or ArchiCAD. The survey asked about appropriate tools for concept design, and the results show that all the tools used in conceptual design have similar levels of use (see Table 5.9). Therefore, 3D software comprises 28.39 % while manual sketch represents 27.37%. Furthermore, 2D CAD software comprises 21.31% and BIM software represents 23.02%.

Table 5.9 Appropriate Tools in Concept Design According to Participants' Opinions

Analogue and digital tools	Percentage of participants' comments
Sketch	27.37%
2d CAD Software	21.31%
3d Software	28.30%
BIM Software	23.02%
Total	100%

The proportion of architects and engineers using tools in concept and schematic design is presented in Figure 5.2. The results show that slightly more architects recommend the use of Sketch and 3D CAD than engineers, whilst BIM and 2D CAD were most recommended by engineers for concept and schematic design. Notably, in Figure 5.2, sketch and 3D CAD represent between 25% and 30% for architects, while BIM, 3D CAD, and Sketch represent 25% amongst engineers.

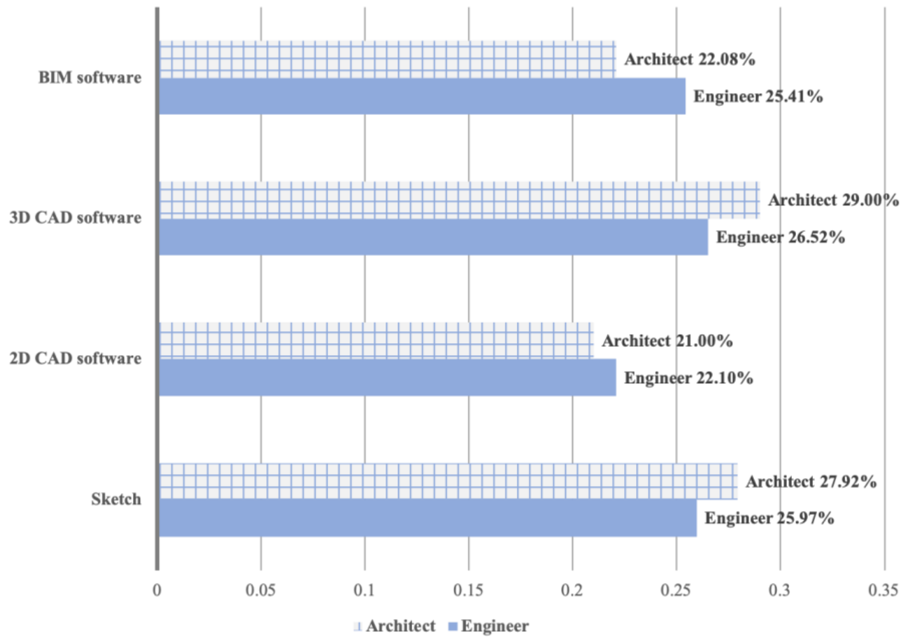


Figure 5.2 Appropriate Tools Used By Architects And Engineers In Concept And Schematic Design (Source: Research own)

5.3.3.1 Problems with using digital tools in concept and schematic design

All participants were asked about current problems with digital tools. Thirty-one participants (83.1%) use both sketch and digital tools while another eight participants (16.9% of all participants, comprising six architects and two engineers) use only sketch and do not use digital tools for concept design. Twelve participants (27.9%) stated that digital tools only assist them to present their ideas and help other relevant persons understand their design. Moreover, eight participants (21%) indicated that a manual sketch is first used to describe their ideas. In terms of real-time collaboration, two participants (4.65%) noted that these digital tools cannot support designers. Moreover, one participant pointed out that sometimes the tool becomes obstructive in the process of developing design ideas and design thinking.

Nine architects and three engineers mentioned that current digital tools are only used to support designers to present their design ideas, namely SketchUp or AutoCAD. Thai architects tend to first create design ideas by freehand sketch and then use digital tools to generate pictures to communicate and create an understanding among design team members in the concept and schematic design phase. Another engineer mentioned that they also use digital tools to show their design ideas in communication and collaboration amongst design team members.

Caption 5.3.3.1 Digital Tools are only used to Display Design Ideas

Architect: *"The computer software can assist us enough because I sketch my ideas on the paper and then bring these ideas to make 3D model so that my colleague can see the picture and understand my idea."* (Q16.P002)

Architect: *"Its capability is enough. ... I use is Sketch Up for making a 3D model. Members of the design team can see the project's picture clearly and it works."* (Q16.P019)

Engineer: *"Its capability is enough, because computer software is the only tool to convey new design ideas for other persons to see and understand."* (Q16.P038)

Moreover, six architects and one engineer felt that the capability of digital tools is insufficient for concept design, whilst another engineer highlighted the steep learning curve of these digital tools. Two architects pointed out that current digital tools are based on a computer desktop and are not used to build conceptual design ideas. Instead, they are only used to create pictures of drawings and 3d models for presentations and to build an understanding amongst team members. Eastman et al. (2011) pointed out the complexity of digital tools and their unfriendly user interface. An engineer also addressed the substantial time needed to learn and practice using the digital tool.

Caption 5.3.3.2 Digital Tools are not used to Capture Ideas in Concept Design

Architect: *"Its capability is not enough. ... computer software is one of the presentation tools that can explain our idea to others to show a picture to follow an architect's concept."* (Q16.P011) **Architect:** *"It is not enough…. because I do a freehand sketch when I am thinking to design and start work as the first step."* (Q16.P022) **Engineer:** *"It is enough, but it is necessary to spend a long time to practice until users can use the computer software. We do not use computer software to create or describe ideas."* (Q16.P041)

In addition, one architect stated that an obstructive issue arises when they use digital tools in concept design, whilst two engineers cited issues associated with real-time collaborative design. Many researchers (e.g. Eastman et al., 2011; Ibrahim & Rahimian, 2010; Schubert et al., 2014; Zhu et al., 2007) mention the obstruction of the creative mental workflow, confirming that neither the graphic user interface nor the input/output (I/O) device support the creative design thinking process. Furthermore, in terms of real-time collaborative design issues, Holzer (2007) pointed out the imbalance between collaboration and communication within digital tools. These existing tools have been developed to support high-resolution design solutions, but a corresponding communication framework has been slow to develop to support collaboration and communication (Holzer, 2007).

Caption 5.3.3.3 Digital Tools are Obstructive and do not Support Real Time Collaboration in Concept Design

Architect: *"I think that computer software is the only tool so that projects can be finished faster and more completely. Sometimes, it can obstruct the ideas of the imagination."* (Q16.P022) **Engineer:** *"It is not enough, because new ideas will sometimes appear after completing designs with computer software. I need to edit or improve the completed design, but it is hard to update relevant teams which are working on it."* (Q16.P032) **Engineer:** *"It is not enough. Sometimes, I have needed to improve some designs, which were passed on from another designer such as an engineer or architect. But the computer tools cannot support collaborative design."* (Q16.P039)

Table 5.10 Participants' Comments in Terms of Digital Tools for Creating Design Ideas in Concept Design

Problems with digital tools in concept design	**No. of code addressed**
Digital tools are only used to display the design ideas in concept design	12 (9A, 3E)
Digital tools do not support designers to capture ideas	9 (7A, 2E)
Current digital tools do not support real-time collaboration	2 (1A, 3E)
A digital tool is sometimes obstructive in the process of design idea thinking	1 (1A, 0E)
81.4% of all participants use digital tools in concept design. Most participants agree that digital tools can sufficiently support designers to aid a presentation.	

5.3.3.2 Rationale for using sketch for concept design thinking

The survey asked all participants about the use of sketch; 31 (72.1%) offered their opinions (see Table 5.9). Furthermore, twenty-six participants (60.5%) confirmed that sketch is the best tool to capture ideas, and five participants (11.62%) pointed out that it is appropriate for communication. Its importance was attributed to speed, as it is able to quickly show ideas. Design thinking is an intuitive process (AIA, 2014) to generate problem-solving through spontaneous imagination and rational thinking (Okpara, 2007) (see Sketching in the Initial Design Stage of Chapter 3); thus sketch is a common traditional technique and an appropriate tool due to its ease and speed (Goldschmidt, 2014). Moreover, sketch is used for informal communication among different professionals. Dossick & Neff (2011) and Sun et al. (2015) encourage the use of sketch as 'messy talk', which supports its use in communication and collaboration.

Twenty-one architects and five engineers mentioned the use of sketch to capture ideas. Two architects described that they could immediately capture ideas before they disappeared. Another engineer mentioned that they need an intuitive interface, like sketch, for concept design. Sketch is therefore considered an intuitive tool and thereby supported for use in concept design (Goldschmidt, 2014).

Caption 5.3.3.4 Sketch is used to Capture Ideas in Concept Design

Architect: *"The hand sketch is the best and fastest tool, because most architects have pictures in their head and can convey their ideas on surfaces such as paper, or an iPad and these ideas are recorded as digital files."* (Q17.P011)

Architect: *"I use the sketch to capture my ideas which crop up at once. I usually sketch on paper before my ideas have gone to make sure that I will not forget them."* (Q17.P016)

Engineer: *"At the concept design, emotion and perception in design concern the use of appropriate tools; computer software does not support designers better than sketching does."* (Q17.P035)

Three architects and two engineers mentioned the use of sketch in their communication and collaboration. One architect described that sketch is used among their design team members. Two engineers pointed out that, although participants are from different disciplines and backgrounds with diverse experiences, they can work together and communicate by using sketches. They therefore support the use of 'messy talk', which is recommended by Dossick & Neff (2011) and Sun et al. (2015).

Caption 5.3.3.5 Sketch is Used in Communication

Architect: *"Using a sketch can help us to work and communicate fast with other members of a design team, who have more experience, such as engineers, specialists."* (Q17.P019) **Engineer:** *"... Noticeably, a person who cannot sketch by hand .... will be able to describe ideas well."* (Q17.P041) **Engineer:** *"Sketching is a tool for describing ideas through rough pictures... that can be used to also communicate ideas."* (Q17.P039)

Table 5.11 Rationale for Using Sketch for Conceptual Design Thinking

Rationale for using sketch for conceptual design thinking	No. of code addressed
Capture ideas	26 (21A, 5E)
Communication	5 (3A, 2E)

5.3.4 Using sketch in Thailand

According to the rationales shown in Table 5.11, the sketch has been used in concept and schematic design to capture ideas and communication among participants. Five categories of sketch were studied by Parthenoios (2005), which are: 1) representative, 2) diagram, 3) symbolic, 4) abstract, and 5) textual categories (see Figures 5.3, 5.4, and 5.5). These categories were shown to Thai participants to check what types they used when creating concept design ideas. Results of sketch types and their proportion used in concept design are shown in Figure 5.3. In addition, results showing the use of sketch by both architects and engineers are shown in Figure 5.4, both in total and proportionally, whilst its use in communication is shown in Figure 5.5.

A qualitative survey of 43 professionals was conducted in Thailand; from the responses, the qualitative research surmised that all types of sketch are used during the concept design phase (Figure 5.3). Thus, 35 responses (28% of the total responses) chose abstract, and 14 responses (11%) indicated symbolic sketches, which are also used to explore the relationship of shape. Finally, 19 respondents (15%) indicated the use of textual descriptions to annotate all types of sketches. The choice of use of symbolic, diagrammatic, abstract, or representative sketches for communication depends on the client's existing knowledge or other professionals and colleagues within the design team.

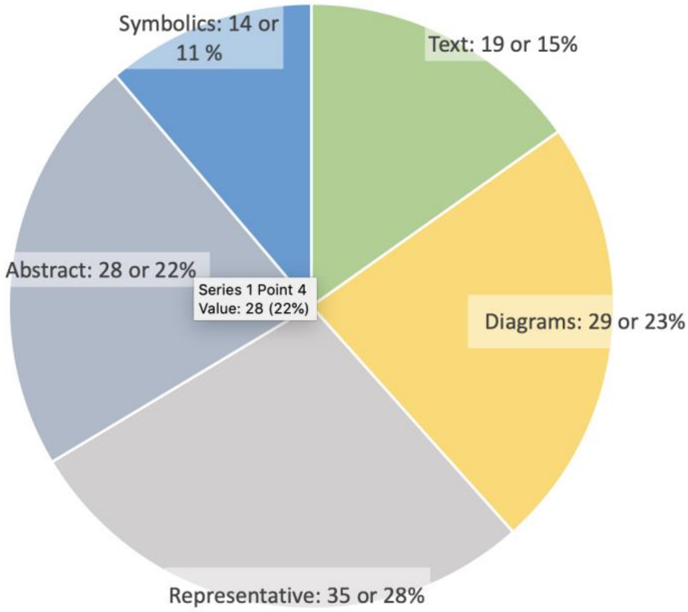


Figure 5.3 Sketch Types and their Proportion used in Concept Design (Source: Researcher's own)

Participants use all categories of sketch to build up concept design ideas. Thirty-five participants (81.40%, comprising 26 architects and 9 engineers) use representative sketches, which are the most commonly adopted in concept design, as they help to explore space. Nearly the same proportion of architects and engineers in the sample use representative sketches. Furthermore, diagrams received 29 responses (67.44%) from 21 architects and eight engineers, although the proportion of participants using diagrams was slightly higher in engineers than in architects. Furthermore, 29 participants (22%, represented by 25 architects and four engineers) use the abstract sketch; thus, in this sample, it is used more by architects than engineers. Moreover, 15 participants use symbolic sketches (34.88%, comprising 13 architects and 2 engineers); these are also used to explore the relationship of shape and are used less by engineers than by architects. Finally, 19 respondents (44.19%, involving 16 architects and three engineers) indicated that they use textual descriptions to annotate all types of sketch. Engineers in this sample use the type less than architects.

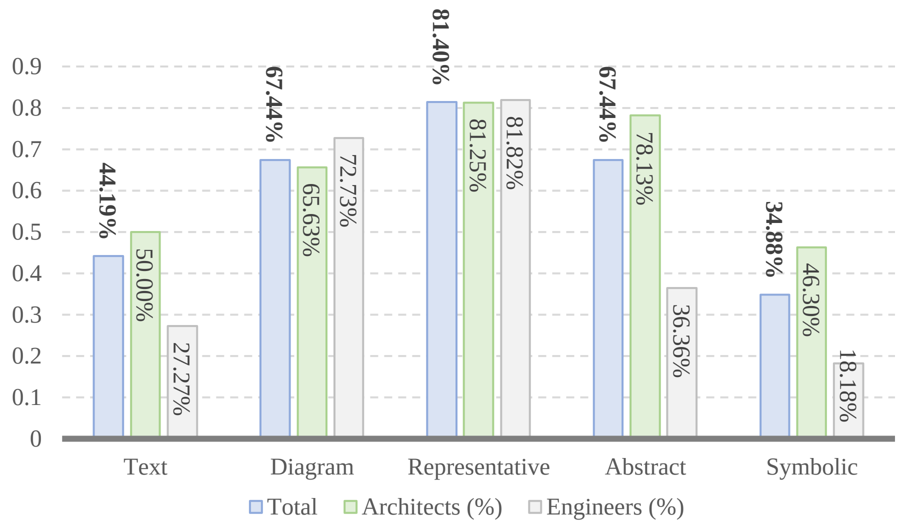


Figure 5.4 Sketch Categories Used by Architect and Engineer in Concept Design (Source: Researcher's own)

In considering the communication or collaboration among design team members, all participants were asked what types of sketch they adopt (see Figure 5.4). Representative sketches were mentioned by thirty-six participants (83.72%), and were the most popular format among the architects and engineers in the sample. Diagram, abstract, and symbolic sketches were used less by eighteen (41.86%), eleven (25.58%), and eight (18.60%) participants, respectively. Moreover, only five participants (11.63%) indicated the use of text in their communication or collaboration among design team members.

In addition, twenty-seven architects and nine engineers selected representative sketch. This is used to detail spaces and form at a defined scale. Four architects described using the right scale in their sketch design so that they can measure its size and distance.

Caption 5.3.4.1 Reasons for Using Representative Sketch

Architect: *"It is the right scale that can measure its size and distance. In addition, it can focus on details when it is considered and designed in terms of the position, possibility, access or zone relationship."* (Q21.P002)

Architect: *"Sketching, being scaled, can show it better overall."* (Q21.P008)

Architect: *"The representative sketch can be used to show in detail and at the right scale."* (Q21.P025)

Architect: *"It is the right scale, which can use to communicate and make other teams understand easily."* (Q21.P027)

Fifteen architects and three engineers indicated the use of diagram sketch in their design. A diagram sketch is used to describe pictorial representations of space and form and, a perception of contextual relationships, such as circulation, or concept, without a scale.

Caption 5.3.4.2 Reasons for Using Diagram Sketch

Architect: *"I start to explain form diagram and continue to lay out functions."* (Q21.P018)

Architect: *"It can be used to show a rough circulation to help all teams understand."* (Q21.P024)

Architect: *"It is easy to make others understand."* (Q21.P028)

Engineer: *"I sketch on a surface of something, which can be picked up to sketch something that needs to be communicated."* (Q21.P041)

Eight architects and three engineers use abstract sketches to explore the form or space, perceptions of contextual relationships, or concepts. Three architects confirmed that they are used to develop their design ideas, from abstract to representative. One of them pointed out that this is adopted in their communication due to its ease of use.

Caption 5.3.4.3 Reasons for Using Abstract Sketch

Architect: *"Abstract is used to start and develop to more detail, to another type, which can better help understanding than other types."* (Q21.P012)

Architect: *"It is used to present the relationships and shape of functions."* (Q21.P024)

Architect: *"I use this to make other members understand and to communicate easily."* (Q21.P026)

Six architects and two engineers in the sample use symbolic sketches in concept design. It is used to show a concept, spatial characteristics, and a relationship without text. An architect described that they also use it in their design ideas and communication because of its ease.

Caption 5.3.4.4 Reasons for Using Symbolic Sketch

Architect: *"I use all of them depending on what I am working on. For this, it is easy for communication"* (Q21.P014)

Architect: *"It will be used to show some character and the relationship of functions."* (Q21.P024)

Finally, text was mentioned by three architects and two engineers. It is used to detail essential or required information. Two architects use it to prevent misunderstanding and misinterpretation.

Caption 5.3.4.5 Reasons for Using Text

Architect: *"It depends on the groups in communication and the level of understanding."* (Q21.P005) **Architect:** *"I use all of the types but, for this, I need to explain in detail to prevent misunderstanding and misinterpreting."* (Q21.P023) **Engineer:** *"I use all of them depending on appropriate use."* (Q21.P039)

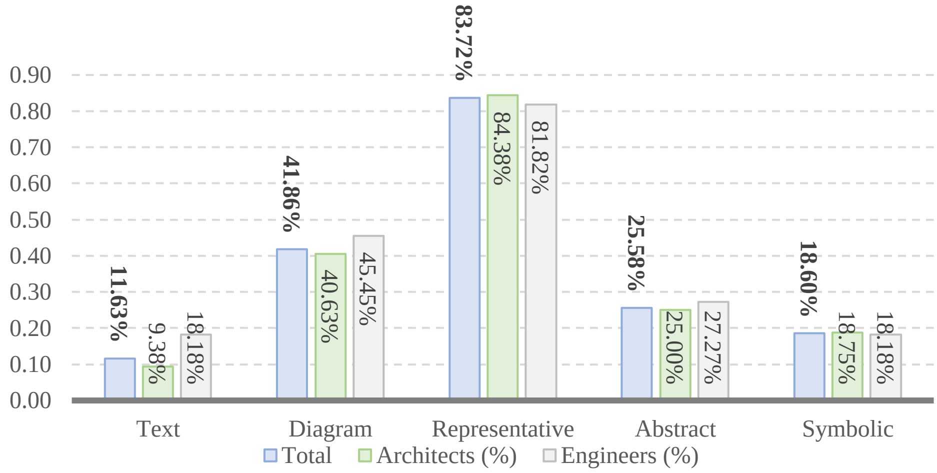


Figure 5.5 Sketch Categories Used by Architect and Engineer for Communication (Source: Researcher's own)

5.3.5 Using Digital Tools in Thailand

In Thailand, digital tools, such as 2D and 3D CAD and BIM, are adopted among architects, engineers, and draft teams who work together in concept design. According to Tables 5.9 and 5.10, 82% of the 43 participants use digital tools in concept design. Usually, they employ a digital tool to present their concept design ideas.

> *The computer software can assist us enough because I sketch my ideas on the paper and then use these ideas to produce a 3D model so that my colleague can see the model and understand in the same interaction. (Q16.P002)*

Participants stated that these tools can support the representation of their concept design ideas; however, some participants indicated that current digital tools should be improved for collaborative concept design.

> *It does not do enough. Because new ideas will sometimes appear after completing designs with the computer software. I need to edit or improve the completed design, but it is hard to update the designs for the relevant teams. (Q16.P032)*
>
> *It is not enough. Sometimes, I need to improve designs, which have been passed on from other designers, such as engineers or architects. But the computer tools cannot support this collaborative design. (Q16.P039)*

Some participants addressed the weaknesses and their requirements of existing the digital tool.

> *CAD can help the designer in concept design, while BIM tools will be difficult and not convenient to use because BIM tools require substantial data input into all objects, but in the concept stage complete data is not available. (Q18.P024)*

> *It should be the tool, which is not complex but encourages users to do their design like they thought. (Q18.P008)*

Therefore, for concept design, digital tools can support designers in presenting their initial ideas. They firstly use sketches to generate their design ideas and then the digital tools are adopted to follow traditional tools. However, the user interfaces of digital tools require improvement to enhance their intuitiveness and collaboration potential among design team members in the concept design phase.

5.3.6 Requirement to Improve the Tools for Concept Design

In order to collect designers' requirements, all participants were asked their opinions on how to improve the current tools (both digital and sketch) used in concept design. Their opinions show their requirements and thus ways to improve digital and sketch tools, particularly in concept design. These opinions will be analysed in categories which become the key to improve tools for collaboration (see Tables 5.12 and 5.13).

5.3.6.1 Ways to improve digital tools for concept design

According to their use of amongst the sample, digital tools are typically employed in concept and schematic design processes to create pictures for distribution among design team members in co-located collaboration. Participants proposed improvements to existing digital tools (BIM and CAD), and their user graphic interfaces.

Two participants noted requirements to improve BIM tools. One participant suggested improving the interface for easier use. Moreover, they advised adding a layer of concept design to encourage designers to adopt the software during this phase. BIM tools require a lot of data for all objects, which, in the concept layer, is problematic as this works on incomplete data. In addition, BIM tools should be improved to support designers in terms of virtual reality to provide a simulation of user's behaviours in daily life, such as walking or running, and to consider functions, namely the use of electricity, heat and air conditioning.

Caption 5.3.6.1 Ways in which BIM Tools should be Improved to support Concept Design

Architect: *"CAD can help the designer in concept design, while BIM tool will be difficult and inconvenient. Because the BIM tool requires a lot of data in all objects, and in the concept layer, it does not have complete data."* (Q18.P024)

Architect: *"It should be improved to better support designers' critical and creative thinking in terms of virtual reality and the simulation of user's behaviours in daily life, such as using electricity, heat, air condition, walking or running in each function."* (Q18.P023)

CAD tools features were proposed to increase its capacity to support designers in concept design. One of the features mentioned by an architect is mass model transferability that can assist a designer to transfer mass paper to 3D digital models. The mass paper model is important and is still used in concept design. The idea is supported by Dunn (2014), Kvan & Thilakaratne (2003), and Zaman et al. (2011) who state that model-making assists visual thinking to give a clearer perception of the designer's imagery. Moreover, digital tools are increasingly required to demonstrate capability in collaboration and communication in the design process (Fischer et al., 2017; Holzer, 2007). Two participants gave their opinions on increasing the capability of digital tools to enhance designers' real-time collaboration. They suggested that digital tools should support the input of different designers and gather data in the design collaboration.

Caption 5.3.6.2 Ways in which the CAD Tool should be Improved for Concept Design

Architect: *"Transfer mass study (paper) to 3D modelling (digital model)."* (Q18.P010)

Architect: *"It can be improved to support the input data feature from groups of multi-disciplines at the same time."* (Q18.P025) *"It should have a feature for gathering data in concept design collaboration."* (Q18.P027)

Intuition is a key concept for software development (McKey, 2013; Oviatt, 2006) and can play a role in concept design by enhancing the design thought process (Eastman et al., 2011). However, current digital tools lack intuitiveness (Ibrahim & Rahimian, 2010). Five architects suggested improvements to the user interface of digital tools, whilst three of these participants advised that they should be easier to use. Such requirements do not need a complex user interface and this simplicity could encourage designers to streamline their thinking.

Caption 5.3.6.3 The Importance of Ease in Improvements to Digital Tools for Concept Design.

Architect: *"I need it to be easier to use than it is"* (Q18.P006)

Architect: *"The tool should not be complex but encourage users to develop their design like they thought."* (Q18.P008)

Architect: *"It should easy to use, and its commands not complex."* (Q18.P029)

In addition, two participants indicated that digital tools should integrate with the sketch interface to support designers. A sketch is an intuitive tool that encourages designers to use critical and creative design; it is the external imagining of the thought process (Fish, 2004).

Caption 5.3.6.4 Integrating a Sketch Interface within Digital Tools

Architect: *"It should provide a feature for hand sketching with a digital pen."* (Q18.P019)

Architect: *"It should support the use of sketching for any shape and form to improve the design."* (Q18.P009)

Table 5.12 Ways to Improve Current Digital Tools for Concept Design

Requirements to improve current digital tools for conceptual design	No. of code addressed	Category	
BIM tools should have a layer of concept design for designers that does not require them to input complete data.	1 (1A, 0E)	BIM Feature	BIM Feature
BIM should be improved to support virtual reality and a simulation of user's behaviours in daily life.	1 (1A, 0E)		
Digital tools should have the capability to transfer mass paper to 3D modelling.	1 (1A, 0E)	Model Feature	CAD Feature
Digital tools should enable designers to collaborate in real time.	1 (1A, 0E)	Collaboration and communication Feature	
Digital tools should have the capability to gather data in concept design.	1 (1A, 0E)		
Digital tools should be improved for easier use.	3 (3A, 0E)	Intuitive interface	Interface
Digital tools should integrate the sketch interface to support designers.	2 (2A, 0E)	Interface	

5.3.6.2 Ways to Improve Analogue Tools

Although sketch is a traditional tool, it is still widely admired and used in the design process. Some participants' responses are listed below from the first data collection in terms of the weaknesses of sketching in concept design:

> *The disadvantage of the traditional type is that it needs a lot of paper and area for storage. In addition, it is difficult to communicate with users in real-time. It is different from computer software, which can copy and send a digital file more conveniently. (Q19.P001)*
>
> *An easy tool should be developed which will make communication more effective. (Q19.P041)*

Some research participants suggested that improvements to the sketch tool are required to enhance designers' abilities in concept design. Features, such as communication and data sharing, need to be addressed to improve traditional tools.

> *The tool should have the capability for working together and sharing data to all relevant people in a group. It needs to inform all of them when there are any changes in design. I think that it can facilitate our work and make us understand each other. (Q24.P031)*
>
> *It should be easily used by everyone because sketches are only ideas or concepts. These objects have no need to be more concrete and should emphasise the presenting of concepts and fast modifications. (Q24.P041)*

Therefore, the sketch is still relevant for use in concept design in capturing and portraying their design ideas. Improvements to the traditional sketch are required for feature communications and the sharing of data; some designers suggested that this is a drawback of the sketch tool.

Sketch is currently being developed through digital sketch, which aims to replace the analogue tool and thereby support designers in concept design. Participants were asked for their perspectives on how to develop a digital sketch and the results are shown in Table 5.13. These results are categorised into four groups: transferability, digital sketch, collaboration and communication features, and portability. These are considered significant in addressing the following disadvantage of existing digital tools: the consumption of resources by CAD and BIM tools due to their use of concrete objects (Denzer & Gardzelewski, 2011; Shapir et al., 2007); impediments to the thinking process (Akalin & Sezal, 2009); and a lack of devices intuitiveness (Ibrahim & Rahimian, 2010). These issues are further addressed as follows.

Firstly, suggestions on transferability (five participants) included the development of the CAD and BIM user interface, and the transferal of sketch from paper to CAD tools (six participants). Participants suggested improving the current digital tool so that the designs sketched on paper can be imported into BIM tools (suggested by one architect) and other digital tools (suggested by three architects and one engineer). Participants recommended improving the user interface for BIM and CAD tools to support hand sketching; thus, these participants require an easy user interface. Another four architects and one engineer suggested the facility to transfer a sketch picture to a digital file. This could help designers to record what they capture on paper.

Caption 5.3.6.5 The Integration of Sketch into BIM and CAD tools and Transferals to Digital Files

Architect: *"I think that sketch can be developed to sketch on screen with a digital pen and to link data to a BIM tool so that the designer can work more easily."* (Q19.P023)

Architect: *"It can link to a 3D model and enable modifications. This includes a feature to build from hand sketches, which will mean more efficiency in design."* (Q19.P027)

Engineer: *"It could be developed to transfer the sketch on paper to a 3D system."* (Q19.P032)

Architect: *"A sketch can be transferred to computer software and modified as a digital file."* (Q19.P004, Q19.P005, Q19.P007, Q19.P013, Q19.P014)

Engineer: *"Sketches on paper can be transferred to software computer."* (Q19.P033)

Seven architects and three engineers recommended developing a digital sketch tool. The main reason was that it would be easy to use in their design thinking process and its data file could be transferred to design team members. Another suggested feature included the development of a vector system (which has a scale and measurement capability feature) rather than a raster system. These participants need to develop their design from an abstract object on a digital sketch to one that uses more resource to create concrete objects (Denzer & Gardzelewski, 2011; Shapir et al., 2007) but does not impede their thinking process (Akalin & Sezal, 2009).

Caption 5.3.6.6 The Need to Develop Sketch as a Digital Sketch Tool

Architect: *"The sketch should be developed into a digital sketch so that it can become a digital file. It will help to efficiently manage and pass on data to other users easily."* (Q19.P019)

Architect: *"It should be developed through computer software and sketches transferred on an accurate scale."* (Q19F.P007)

Architect: *"I think that hand sketching and software should be developed to have the capability to support a designer's thought process."* (Q19.P020)

Engineer: *"A traditional tool, such as sketching, could be transferred to computer software and then the transferred file could be worked on in other software."* (Q19.P033)

Engineer: *"It should be recorded as a digital file"* (Q19.P040)

Another four participants stated that a digital sketch should enable real-time collaboration and have the capability to support discussion among design team members. Two architects mentioned that they need a real-time collaborative tool to increase efficiency and reduce time in their projects. One participant suggested that design team members could integrate images and design on the same correct scale, whilst an engineer similarly stated the need for a tool that enables easy communication and collaboration.

Caption 5.3.6.7 The Development of Sketch to Support Collaborative Design

Architect: "If there is software that transfers sketches and helps to continue work, which is the right scale, and can be passed to other relevant users, it will reduce the time and be more efficient." (Q19.P024)

Architect: "Sketch can be used to collaborate with many users in real time." (Q19.P025)

Engineer: "An easy tool should be developed which will make communication more effective." (Q19.P041)

Moreover, five participants (three architects and two engineers) agreed that sketch should be developed to work on a portable device. A portable device can enable greater freedom from a computer desktop and better support designers to solve problems. However, portable devices lack intuition, which Ibrahim and Rahimian (2010) similarly noted when they stated that a mouse device is not sufficiently intuitive for a sketch and design thinking process (Kim et al., 2015; Schubert et al., 2014).

Caption 5.3.6.8 The Development of Sketch on a Portable Device

Architect: *"Sketch can be developed on a mobile device, such as an iPad."* (Q19.P012)

Architect: *"Sketch can be developed on open platform, such as a computer or mobile, to facilitate work everywhere."* (Q19.P026)

Architect: *"It can be developed for use on an electronic device, which has features to insert pictures and data, and help easy editing, recording, and exporting."* (Q19.P029)

Engineer: *"I think that concept design ideas should be sketched on ... electronic paper and then the ideas transferred and improved with computer software. The traditional tool could be developed on electronic paper - that would be easy."* (Q19.P036)

Table 5.13 Suggestions to Improve Analogue Tools: Sketches on Paper for Conceptual Design

Suggestions to improve analogue tools, such as Sketch on paper, for conceptual design	No. of code addressed	Category	
Sketching could be integrated with BIM tools.	1 (1A, 0E)	Integrate with BIM	Transferability based on current digital tools
Sketching could be developed for a 2D and 3D system.	4 (3A, 1E)	2D & 3D system	
Sketches on paper could be transferred to digital files.	6 (5A, 1E)	Transfer to a digital file	
A digital sketch function could be developed instead of an analogue tool	10 (7A, 3E)	A digital sketch (Easiness)	
A digital sketch function could be developed to support real-time collaboration.	3 (3A, 0E)	Collaboration and communication	
A digital sketch function could be developed to enable communication features.	1 (0A, 1E)		
Sketches could be developed on a portable device to facilitate designers.	3 (3A, 0E)	Portable device Platform	Portable
Sketches could be developed on electronic paper.	2 (0A, 2E)	Electronic paper	

5.3.7 Preserving the Contents of a Collaboration Discussion

Communication is important for collaboration to enable design team members to share their understanding of common ground (Larsson, 2003); moreover, it is an important part of Carrara's cycle of collaboration. Besides enabling a shared understanding, this would help to integrate all the design team to collaboratively build knowledge (Carrara, 2012).

The survey asked participants about the retrieval of discussion content in order to collect their views on the benefits and problems in preserving such content. Significantly, 40 participants confirmed that communication content is important in collaboration. There are many types of communication content in concept design that are gathered in collaboration (such as meetings), or by working together on co-location.

5.3.7.1 Benefits of collecting discussion contents

Participants identify how discussion contents are useful in collaboration within concept design (see Table 5.14). Participants confirmed that it is often necessary to retrieve and reconsider a discussion amongst the design team during their meetings. In collaborative design, evidence, retrieval and knowledge provide a rationale for preserving content, which enables all members' understanding.

Five participants (four architects and one engineer) stated that the content of communication should be preserved and that this is necessary for collaborative design. One architect confirmed that it is necessary to use recorded content so that they can deal with any problems during the process. Similarly, Gabriel (2000) pointed out that, without recording or translating verbal messages into text or illustrations, communication content is potentially lost forever.

Caption 5.3.7.1 The Importance of Recording communication content

> **Architect:** *"It is important … the contents should be preserved so that our thoughts can be a benefit and brought out for use again. In addition, these contents can be checked for errors for when there are problems after that."* (Q22.P043)
>
> **Engineer:** *"These are important and should be recorded."* (Q22.P041)

Thus, this function is useful when reconsidering the content of previous meetings or when involved in co-located collaboration. It helps in recording agreed tasks in meetings and to directly refer to (and reconsider) the content of previous meetings or other activities. Twelve participants recommended that the contents of communication should be preserved for use in collaborative design. Three participants stated that they used recorded content when reconsidering or reviewing and that this helps to prevent conflict or support the identification of appropriate solutions.

Caption 5.3.7.2 The Collection of Contents for Review

Architect: *"Yes, it is important, and it should be saved, because I can return to review the record."* (Q22.P016)

Architect: *"This is important, and the contents of a discussion should be stored to prevent conflict problems. These problems may happen in collaboration and may always change. In addition, the recorded content of previous decisions can be brought out to reconsider and to find an appropriate solution."* (Q22.P029)

Engineer: *"It should be saved so that this discussion content can be explored or used the next time."* (Q22.P035)

Understanding is important in the communication process (Norouzi et al., 2015) as noted in Carrara's (2012) collaboration cycle. Three architects confirmed that recorded discussion contents are important materials that enable an understanding amongst all design team members. The discussion contents are reviewed or used to support the understanding of design team members following a meeting to ensure that they are 'on the same page'.

Caption 5.3.7.3 Using the Collected Content of Communication to Support Understanding

Architect: *"Yes, it is important. The contents should be preserved to share among members of the design team. All members can use the content to…. help an understanding of the contents."* (Q22.P002)

Architect: *"It is important. The contents of a discussion should be concluded after meetings and preserved so that collaborative design can move in the same direction."* (Q22.P004)

Architect: *"It is useful to use the contents so I can explain my ideas to make other people understand."* (Q22.P013)

Thirteen participants (ten architects and three engineers) mentioned that collected communication content could be used to solve problems during meetings (co-located collaboration) alongside individual work. One architect confirmed that it is important to preserve the content of discussions, which provides material for their individual design process following a meeting. Another architect mentioned their use of discussion from previous collaborations, both when developing their design and in current meetings. In addition, an engineer mentioned that, sometimes they cannot understand all information following a co-located collaboration, and therefore need to retrieve and review a recorded discussion in order to develop their understanding. Moreover, it is difficult to maintain design ideas and transfer them within the process (Rahimian et al., 2008). In addition, design sketches could be used to solve problems in a process, as they are seen as knowledge and should thus be managed and stored (Herbsleb & Kuwana, 1993).

Caption 5.3.7.4 The use of Communication Content for Problem Solving in Collaborative Design

Architect: *"Yes, I should preserve the content of a discussion. Because content is collected each time it is used in design."* (Q22.P008)

Architect: *"I think that the discussion is important and can be referred to when we return to consider topics from a previous design at the beginning. It will help to remind us how we have developed from that time until now and will help to develop the design. In addition, it can be evidence to check how we have discussed the topic."* (Q22.P023)

Engineer: *"It is necessary to record because receivers sometimes do not understand whatever the sender wants to communicate at that time. If these records are analysed and investigated afterwards, it will help a better understand."* (Q22.P041)

Two architects stated that all collaborative discussion content represents an important resource, namely knowledge. It is necessary to preserve the content as it represents a resource of knowledge, which can build design team members' knowledge. Carrara (2017) confirmed that a discussion encourages design team members to build knowledge when they adopt these suggestions or proposals in their design. These discussion contents are defined as 'tacit knowledge', which is personal knowledge and experience that is shared and exchanged through collaboration activities (Tiwanna, 2000, cited in Lin, Chang, Chiou, Jan, & Tserng, 2005).

Caption 5.3.7.5 Contents as Knowledge

Architect: *"Yes, it is important. The contents should be preserved to share among members of the design team. All members can use the content to build their knowledge and enable understanding of the content."* (Q22.P002)

Architect: *"The content of communication is important. It should be recorded as a resource of knowledge and evidence in decision-makin,g and if problems arise in future.* (Q22.P015)

For the communication process, agreement is feedback; this signifies to the sender that receivers have understood, or correctly interpreted the information, thus achieving a common goal amongst both parties (Lunenburg, 2010). Three participants mentioned that the contents of communication are reviewed and used to gather feedback to confirm or accept agreements. Two architects and one engineer suggested that the contents should be agreed or confirmed in order to meet the requirements, and provide the principles, of collaborative design.

Caption 5.3.7.6 The Use of Communication Contents for Agreement

Architect: *"It is important, because the content will become the principles for designing together."* (Q22.P001)

Architect: *"It is important. These contents should be recorded and sent to all relevant members to acknowledge and confirm the record."* (Q22.P026)

Engineer: *"It is important. The contents of a discussion in collaboration should be preserved for review (reconsider) so that these contents can be concluded and accepted by all members in the collaboration."* (Q22.P036)

Twelve participants (nine architects and three engineers) confirmed that the recorded contents of a discussion offer important evidence in collaborations. Two of these engineers mentioned that the contents were needed to prevent conflict and confusion after a meeting. In addition, an architect pointed out that most members forget what was discussed, so the contents need to be stored until a project is complete.

Caption 5.3.7.7 The Communication Contents as Evidence

Architect: *"Yes. It is very important, and these contents of discussions should be stored until a project is complete, because most people will forget some of the content discussed previously."* (Q22.P028)

Engineer: *"It should be saved because there are a lot of alternatives which may come back and forth throughout the conversation. A recording can prevent confusion over a decision."* (Q22.P033)

Engineer: *"The contents of a discussion should be recorded as evidence to prevent problems which can appear after a discussion."* (Q22.P037)

Table 5.14 The Benefits of Collecting the Contents of Discussions in Concept Design

Benefits of preserving the contents of discussion in concept design	**No. of code addressed**	**Category**		
Discussion contents are required to be recorded	5(4A, 1E)	Record		
Discussion contents are recorded for reconsideration	12(8A, 4E)	Review		
Discussion contents are used to enable understanding amongst all members.	3(3A, 0E)	Enabling understanding		
Discussion contents are recorded for retrieval	5(3A, 2E)	Problem solving		
Discussion contents are used in design.	8(7A, 1E)	Used for design		
Discussion contents are a resource of knowledge.	2(2A, 0E)	Knowledge		
Discussion contents are used for agreement	3(2A, 1E)	Agreement		
Discussion contents are a source of evidence	12(9A, 3E)	Evidence	Review	Record
Forty participants confirmed that communication contents are important in collaboration				

5.3.7.2 Problems in preserving communication contents

According to the findings, and as shown in Table 5.14, communication content is important for collaborative design amongst Thai professionals. Types of communication content were also analysed, after participants confirmed the type they would recommend storing. In addition, the problems associated with preserving communication content are gathered and analysed to identify the key issues in this area.

These participants still use both physical documents and digital technology to store content in collaborative design (see Table 5.15). Firstly, participants use digital technology to preserve the content of communication. Eleven participants use digital technology in the management of communication content, such as meetings, documents, pictures, notes, and other documents, which include all relevant documents in collaboration. Moreover, two participants record conversations as audio files in collaboration. These digital files are kept on their Smart Phone or computer.

Secondly, participants still use physical documents to record the content of communication. Nine participants manage their communication by gathering the content into meeting documents. The document can include other materials, such as pictures, evidence, or the conclusion of previous meetings. They confirm that these documents are kept in files. Furthermore, thirteen participants use manual methods (by hand) to collect important collaboration content, such as meeting books, or notes, and both use sketches and notes. Ten of the 13 participants use a material (such as paper) that they can pick up to create notes, short notes, and sketches. Some use their portable device to create short notes and sketches.

Table 5.15 Gathering the Content of Communication in Concept Design

Gathering the Content of Communication	No. of code addressed	Category
Digital files, such as notes, pictures or digital documents	11(10A, 1E)	Digital file
Audio recordings	2(2A, 0E)	
Documents (hard copy)	9(8A, 1E)	Physical document
Meeting books	3(3A, 0E)	
Notes	6(5A, 1E)	
Short notes and sketches	4(3A, 1E)	

According to the communication process (see Chapter 2), messages are conveyed by both synchronous and asynchronous media that are passed from the sender to the receiver/s. The media types are traditional communication and computer mediated channels (Lee, 1988;

Lunenburg, 2010). These digital and physical media were presented in Table 5.15; digital files and physical documents are used in communication and collaboration amongst design team members. However, participants note problems when they manage their communication content. These problems are associated with the channel of communication, management issues, retrieval difficulties, and data loss (Table 5.16).

There are many content types used for storage and several media channels, which can pose problems for collaborative design. Two participants stated that there are currently many channels for communication; sometimes it becomes difficult to manage the communication content from meetings, informal discussions, emails, Line, Facebook, and other social media applications. In addition, 11 participants mentioned that they use many methods to gather communication content, including both digital technology and physical documents. One architect pointed out that they use several channels to collect communication content, such as a personal book, computer, paper, and other materials. Moreover, one architect noted that they use devices to collect communication content, such as a computer or mobile device, so that this content is used in their design. However, another architect confirmed that a variety of communication tools can become an issue when managing communication content among design team members.

Caption 5.3.7.8 Problems Associated with the Use of Many Channels when Capturing communication contents

Architect: *"There are many content types of design information, which sometimes I find confusing: 1) I use a book to record data in meetings. 2) My sketches on paper are collected in files and digital sketches are saved on the computer. 3) Construction materials are collected in files categorised by the project."* (Q23.P019)

Architect: *"Most methods of communication are talk or discussion in meetings, and email, which I have not clearly managed in the content of collaborative design. I save design files on my computer, short notes on a mobile device and keep it in folders when I talk or discuss it with other members of the design team. This content is used to design and develop my work."* (Q23.P011)

Architect: *"There are a variety of communication channels, such as emails, letters, Line, Facebook, physical notes, or SMS. Some collaborators refuse to use unfamiliar tools for team communication and struggle to use digital tools for communication. ... Besides the receipt of incomplete or out of date data, it difficult to deal with the content of these channels"* (Q23.P016)

Besides the range of resources and channels, the management of communication content can be difficult for collaborative design team members. The content of communication can be varied; five participants noted that management is difficult but also important. Some stated that problems arise when these contents are not managed. Indeed, issues occur when a lot of documents are not well arranged or categorised, and sometimes, these documents are redundant.

Caption 5.3.7.9 The Content Management of Communication to Support all Members.

Architect: *"I try to memorise and take short notes with sketching, but I sometimes forget where I sketched."* (Q23.P009)
Architect: *"I do not manage design information content well and means I face design problems. The problems will develop and make the design completion late."* (Q23.P023)
Architect: *"Usually, the design information content if stored in files and discarded when the project is complete. The problem is there are a lot of documents, which are not arranged or categorised efficiently. Sometimes, these documents are redundant and many times the important documents are lost."* (Q23.P029)
Architect: *"These contents can be gathered in folders on a computer or on the cloud service. But the problem is, I forget where they are."* (Q23.P043)

Physical resources have a limitation on storage, which can quickly fill, and prompt the need for their conversion to digital files. One architect noted the full storage of physical resources. Moreover, one architect and one engineer noted that it wastes time converting documents to digital files. Both pointed out that converting from hard copy documents to digital files can become a burden for collaboration.

Caption 5.3.7.10 Problems Associated with Content Management: Full Storage and Transferring to Digital File

Architect: *"Sometimes, there is a problem when [a file] is not found, and the storage is full."* (Q23.P004)
Architect: *"I manage the content gathering from meetings by storing it in a file. The problem is that some documents are sometimes on a computer and other documents are on paper. We waste time converting and managing these documents to digital files."* (Q23.P027)
Engineer: *"These contents are gathered in the suspended files; if some of them are important they are scanned as digital files. There is the inconvenient problem of keeping them."* (Q23.P039)

Both digital and physical resources may be inefficiently managed leading to difficulties in retrieval. Three participants (two architects and an engineer) mentioned that content can be difficult to find, whilst another architect confirmed that they are often confused within complex processes despite their use of short notes. Significantly, all relevant members should review the content of communication, which, according to one architect, becomes an issue when facing individual and/or team ignorance. According to the communication process (see Chapter 2), receivers or design team members may not respond to the sender and their lack of feedback leads to inefficient communication among team members. In addition, an engineer stated that the contents of communication are important and can be reused for other projects.

Caption 5.3.7.11 The Retrieval of Communication Contents

Architect: *"Sometimes, there is a problem when it is not found, …."* (Q23.P004)

Architect: *"Yes, there is a problem. I am often confused because designs can sometimes be changed back and forth although I will do short notes."* (Q23.P012)

Architect: *"The content of communication should be written by all relevant members. But the problem is that the relevant teams do not review or bring to review together to make sure that they all understand in the same way."* (Q23.P024)

Architect: *"The contents are stored in both hard copy and electronic data. But the hard copy may have more problems and it is difficult to search for."* (Q23.P026)

Engineer: *"The problem appears when some of the content is not saved and the concept may come back to previous ideas, but members cannot find the records."* (Q23.P038)

Moreover, six participants pointed out that the loss of and incomplete content pose a problem in managing communication content. Sometimes, they cannot collect all information in collaboration and on many occasions, important documents are lost. One architect mentioned that communication content from previous projects is not recorded, and although the information is important, it can be lost forever. 'Tacit knowledge' means embedding the content of communication, which can be useful even after the projects are complete (Lin et al., 2005). However, this is often not collected in the right way or is not recorded at all.

Caption 5.3.7.12 Loss of Communication Contents

Architect: *"I have a problem that some content can be lost."* (Q23.P008)

Architect: *"To gather the content of design information on file becomes a problem when these files are lost, or when some records are not complete."* (Q23.P025)

Architect: *"Usually, the content of design information is stored in files and will be discarded when the project is complete… many times the important documents will be lost."* (Q23.P029)

Engineer: *"The problem appears when some of the content is not saved and the concept may return to a previous idea which cannot be found, and the records are lost."* (Q23.P038)

Engineer: *"Sometimes some comments are not recorded at all and become a problem when analysing the received content at that time. These are already lost."* (Q23.P041)

Table 5.16 Problems in the Management of Communication Contents

Problems in the management of communication contents	No. of code addressed	Category
There are many channels of communication, which are difficult to manage when considering the content of collaborative design. These channels are: discussions, meetings, emails, Line, Facebook, and other social media apps.	2(2A, 0E)	Channels
Without the management of design information contents, (which can help designers to face design problems), issues can develop, in addition, there is a lack of categorisation in design information content.	5(5A, 0E)	Management
Full storage.	1(1A, 0E)	
Time is wasted in transferring hard copy to digital files.	2(1A, 1E)	
The content of a design is difficult to search for. In addition, no team members retrieve and review information/content.	4(3A, 1E)	Retrieval
The design information content can be lost or incomplete.	6(2A, 4E)	Losing

5.3.8 User Requirements of a Digital Tool for Collaborative Conceptual Design

Data concerning user requirements of a new tool for collaborative conceptual design were collected through indirect and direct questions. The survey directly asked all participants to identify what tool would be useful for real-time collaboration in concept design, and how they thought this could work. Indirectly, these participants described their rationale for using ICT to improve collaborative conceptual design. In addition, the survey provided a narrower final question that directly asked about a digital tool to address their particular needs.

5.3.8.1 Rationale for using ICT to improve collaborative concept design

According to the results of this survey, the rationale for using ICT to facilitate collaboration can be categorised into three parts: efficiency, accessing information, and communication and collaboration (see Table 5.17). Thus, 22 participants mentioned using ICT to increase efficiency in collaborative design, whilst five participants indicated they need to use ICT to access relevant discussions, knowledge, resources, and other information. Moreover, 25 participants agreed that current technology helps them to communicate and collaborate.

Firstly, 17 architects and five engineers confirmed that efficiency prompts them to adopt ICT to support collaborative design. Most architects aimed to use ICT to reduce process steps, including travel, time and cost, which increase their efficiency in collaboration. In addition, five engineers noted that they adopt ICT to increase efficiency by reducing time and travel in their practice. Thus, both architects and engineers use ICT to increase efficiency by reducing time and travel during collaboration.

Caption 5.3.8.1 Requirement for the Use of ICT: Increasing Efficiency in Collaborative Design

Architect: *"I agree, because teamwork can solve problems faster and it will be faster when ICT is used to increase the efficiency of collaboration and reduce time."* (Q11.P011)

Engineer: *"I strongly agree. Using ICT can help us to systematically collect pictures, sounds, or text and will support a team to efficiently collaborate. It assists the team to work anytime and anywhere."* (Q11.P035)

Engineer: *"Yes, I agree. It will assist us to reduce time and work processes. In addition, we can easily check and preview each system to reduce mistakes in the design."* (Q11.P031)

Architect: *"I agree. It can help us to feel comfortable at work and save time. In addition, we can reduce the amount of travelling for collaboration or meetings."* (Q11.P019)

Additionally, five participants indicated they need to use technology to retrieve discussions, knowledge, resources, and other information. All participants agreed that ICT supports them to retrieve design information, or communication content. Two architects described that design team members can easily access data through the support of ICT.

Caption 5.3.8.2 Requirement for the Use of ICT: Information Retrieval

Architect: *"I agree. All relevant members should access the project data."* (Q11.P021)

Architect: *"Yes, I strongly agree. With limitless communication, ICT will help us to easily work and equally access data."* (Q11.P026)

Engineer: *"I agree. All collaborators need to use ICT to see the content of discussions and to understand each other."* (Q11.P038)

Moreover, ICT is needed to support communication amongst design team members; it can increase the opportunities to communicate with each other. All participants agreed on the use of ICT in collaboration and communication among design team members. One architect pointed out that it is important because a design needs condensing through collaboration and communication in order to continue to improve until the construction phase.

Caption 5.3.8.3 Requirements for the Use of ICT: communication

Architect: *"I agree. Because both concept and schematic designs still have to be improved a lot. In some case, the completed design still has to be edited in the construction phase. The ICT tool is very necessary to support collaborators to work or communicate with each other quickly."* (Q11.P002)

Architect: *"I agree, because I will be able to communicate with others so that all members can understand in the same direction."* (Q11.P009)

Engineer: *"I agree because the skill of each professional is not the same. Using ICT will help each member to understand other members' thoughts. This will encourage them all to design in an accordant way."* (Q11.P033)

Furthermore, 14 participants agreed that current ICT can be used to help them collaborate when de-located or co-located, and when working at the same or at different times. Significantly, ICT is required when they work individually in their own workplace but still need to connect with relevant professionals to solve problems together. Nevertheless, both architects and engineers confirmed that they require a tool to support de-located and co-located collaboration including when working in different timeframes.

Caption 5.3.8.4 Requirement for the Use of ICT: Environment of Collaborative Design

Architect: *"Yes, I agree. ICT will help us in terms of different locations and times."* (Q11.P025)

Architect: *"I agree that ICT can assist us to work together, both in concept design and schematic design, because we do not need to always work together in meetings. We should use technology to move forwards quickly and efficiently"* (Q11.P043)

Engineer: *"I agree, it helps to reduce travel times and support us when working in both co-located and differently located collaborations."* (Q11.P034)

Engineer: *"I agree. ICT can increase the efficiency of collaborative design both in co-location and de-location."* (Q11.P041)

Table 5.17 Rationale for using Information and Communication Technology for Collaborative Design in Concept Design.

<table>
<tr><th>Rationale for using ICT to improve collaborative design</th><th colspan="2">No. of code addressed</th><th colspan="2">Category</th></tr>
<tr><td>Time saving</td><td>14(12A, 2E)</td><td rowspan="5">22 (17A, 5E)</td><td colspan="2" rowspan="5">Efficiency</td></tr>
<tr><td>Cost saving</td><td>1(1A, 0E)</td></tr>
<tr><td>Efficiency</td><td>4(2A, 2E)</td></tr>
<tr><td>Reducing process steps</td><td>1(1A, 0E)</td></tr>
<tr><td>Reducing travel</td><td>2(1A, 1E)</td></tr>
<tr><td>Accessing or managing information (discussion/knowledge/other information)</td><td colspan="2">5(4A, 1E)</td><td colspan="2">Information retrieval</td></tr>
<tr><td>Discussion, comments, and enabling understanding amongst all members</td><td colspan="2">11(9A, 2E)</td><td colspan="2">Communication</td></tr>
<tr><td>Working together on de-located collaboration</td><td>9(6A, 3E)</td><td rowspan="3">14 (8A, 6E)</td><td>De-location</td><td rowspan="3">Environment of collaboration</td></tr>
<tr><td>Working together on co-located collaboration</td><td>4(1A, 3E)</td><td>Co-location</td></tr>
<tr><td>Working at different times</td><td>1(1A, 0E)</td><td>Different times</td></tr>
<tr><td colspan="5">All participants agreed on the potential for a digital tool that enhances collaboration amongst designers and other specialists whilst working together at a different or the same location and at different times.</td></tr>
</table>

5.3.8.2 Identifying requirements from participants

Finally, the requirements of 47 participants regarding a digital tool for collaboration were collected and are categorised into: external representation, communication, sharing, storage, and platform (Table 5.18). External representation includes ease, the sketch user interface, and other features for which ease is the main criteria to support the design thinking process. Communication is mentioned as connecting and supporting design team members. Moreover, the sketch tool is required to enable sharing, both at the same and at different times, whilst storage is needed to accommodate unlimited size and high security.

Firstly, many participants (11) need a tool that can be easily used by everyone who may be included within collaboration; this includes other specialists and the owner. In addition, two participants recommended keeping the characteristics of a traditional sketch and pointed out that familiarity is necessary. Moreover, five participants advised that this sketch tool should enhance design with features to display both 3D and 2D, insert pictures, and use symbols. These recommendations suggest the use of a sketch tool for concept design, which functions as an external representation to assist the user to explore design thinking and enable loading into the user's memory. Furthermore, these features need to enable users to quickly generate design ideas. The sketch tool does not support the development of a 3D space to help build model; thus, sketch is based on only 2D and reduces memory resources by creating abstract rather than concrete objects or models (Denzer & Gardzelewski, 2011; Ibrahim & Rahimian, 2010; Shapir et al., 2007). Goldschmidt (2014) also states external representation is an important tool to deal with the cognitive load and maintain both long and short-term memory.

Eight architects and three engineers recommended that they need an easy tool for collaborative conceptual design. The engineers stated that all relevant stakeholders should be able to easily use the sketch tool, including the owner. One engineer raised an important argument that the sketch tool does not need to create more concrete objects but rather to facilitate rapid modification.

Caption 5.3.8.5 Ease is Required for a Sketch Tool

Architect: *"I need it to work easily and fast."* (Q24.P009)

Engineer: *"The tool should have scale and be able to include more detail so that receivers will not need to imagine what it is. But it should be easy to use."* (Q24.P030)

Engineer: *"It should be easy to use for everyone in the design team and others."* (Q24.P036)

Engineer: *"It should be easily used by everyone because sketches are only ideas or concepts. These objects do not need to be more concrete and should emphasise presenting the concept and help to modify faster."* (Q24.P041)

In addition, two architects recommended a sketch user interface for this tool. They described its characteristics as providing the best tool for designers who are familiar with generating concept design ideas by hand.

Caption 5.3.8.6 Required Characteristics of the User Interface for a Sketch Tool

Architect: *"This tool should keep the characteristics of the traditional sketch to support user familiarity with sketching and in using a pencil or pen."* (Q24.P028)

Architect: *"I think that hand sketching is the best."* (Q24.P042)

Next, five architects noted the features to increase the capability of this sketch tool. Three architects recommended that this sketch tool should have 3D and 2D features to facilitate users when building a 3D digital model. This feature will not be supported on this sketch tool because 3D modelling requires a designer's memory resource in order to create a concrete object rather than an abstract object; this can obstruct the design thinking process (Denzer & Gardzelewski, 2011; Ibrahim & Rahimian, 2010; Shapir et al., 2007).

Moreover, two architects recommended the use of other features, such as pictures and symbols. One of them noted that this is useful for working together.

Caption 5.3.8.7 Other Features Suggested for the Sketch Tool

Architect: *"It should be modified to have 2D and 3D functions."* (Q24.P003, Q24.P024)

Architect: *"The tool should be 3D so that all users can check the details. It will help all of them to have the same understanding and reduce errors. It will be better if the tool can support the display of pictures in the future."* (Q24.P023)

Architect: *"The sketch tool can provide symbols, which can be used in each group to understanding meanings."* (Q24.P002)

Architect: *"In addition, they should be able to … insert pictures or other data."* (Q24.P029)

Moreover, five participants raised the importance of communication in facilitating collaborative design and stated that a sketch tool should support communication amongst design team members. Although design team members often work together in a meeting, one architect recommended the use of text to communicate. Another architect needed to communicate while working on the same page and across different time zones.

Caption 5.3.8.8 Communication is Required for the Sketch Tool

Architect: *"I do not have any idea about how the tool will be developed. But I think that if each user can input data as text to inform about needs and updates, it will be good. It will not be different from working in a meeting"* (Q24.P018)

Architect: *"The sketch should allow all relevant users to sketch on the same page although they will be in a different time zone. In addition, they should be able to communicate together and insert pictures or other data."* (Q24.P029)

Engineer: *"The tool should have a capability for working together and to share data with all relevant persons in a group. It needs to inform and communicate to all members, so they know when there are any changes to a design. I think that it can facilitate us to work together and help us understand each other."* (A24.P031)

Next, a participant suggested that a sharing feature would be important for collaboration amongst professionals. One architect and one engineer proposed that sharing should be automatic when supporting design team members to work together, as if members are located around the same table. Moreover, both real-time and different-time sharing were mentioned. Five architects and two engineers proposed the use of real-time collaboration. Two architects and one engineer raised different time-sharing, whilst another engineer noted that they are required to spend time thinking in engineering design.

Caption 5.3.8.9 Sharing is Required to for The Sketch Tool

Architect: *"The sketch tool will be developed to support the design team to work together like working around the same table, where all relevant users can share data together."* (Q24.P021)

Engineer: *"It should have the functions of saving and automatically sending to relevant persons."* (Q24.P032)

Architect: *"The tool should allow all relevant users to sketch together like a remote meeting."* (Q24.P022, Q24.P025, Q24.P027)

Engineer: *"The sketch should be used to share ideas in collaborative design in concept and schematic designs like real-time collaboration."* (Q24.P034, Q24.P035)

Engineer: *"Concept and schematic designs need to spend more time thinking and calculating in the field of engineering. It is difficult to be in real time, but real time is appropriate for use in problem-solving."* (Q24.P038)

Furthermore, a few participants noted storage issues, in terms of security, large file sizes, and keeping data on portable devices. One architect recommended that the sketch tool needs to accommodate a large storage size in order gather all data from the design team. One architect also recommended that a high level of security, and the ability to separate and store data in each member's devices.

Caption 5.3.8.10 Storage is Required that Considers Size and a High Level of Security

Architect: "It should have a large storage size to support sharing amongst all relevant members." (Q24.P006)

Architect: "It can be developed to support the team to work together although they will be in another part of world. Data will be stored under high security and separated, to be stored by each member of the design team. In addition, it should be brought to present wherever needed more easily" (Q24.P043)

In addition, participants suggested that the tool has to support multiple-devices, such as portable devices and desktop computers. An architect recommended that this tool should be easy to use on multiple devices and support design team members working anywhere.

Caption 5.3.8.11 A Platform is Required for the Sketch Tool

Architect: "The sketch tool has to be easily used and facilitate users to sketch on multiple devices, such as computer, tablet, or smartphone." (Q24.P019)

Table 5.18 Requirements of a Digital Tool for Real-Time Collaboration.

Requirements of a digital tool for collaboration.	**No. of code addressed**		**Category**	
Everyone should be able to should easily use the tool.	11(8A, 3E)		Ease of use	External representation
It should keep the characteristics of a traditional sketch to support users who are familiar with sketching.	2(2A, 0E)	7 (7A, 0E)	User interface	
A 3D picture display should be supported.	3(3A, 0E)		Other features	
It should have an insert picture feature.	1(1A, 0E)			
It should have a graphic symbol feature.	1(1A, 0E)			
Communication is important in working together.	5(4A, 1E)		Communication	
Sharing is expected.	2(1A, 1E)	12 (8A, 4E)	Sharing	
Different-time sharing	3(2A, 1E)			
Real-time sharing	7(5A, 2E)			
Large data storage size is expected.	1(1A, 0E)	2 (2A, 0E)	Storage	
High security for data storage is required.	1(1A, 0E)			
The ability to store data in a device is expected.				
It can support an open platform (multi-devices) such as a smartphone, computer desktop, or tablet	1(1A, 0E)		Platform	

5.4 The Findings from the First Data Collection

According to the rationale (Table 5.1), the data suggests that collaboration needs to be supported to increase efficiency, understanding, and problem solving among professionals in concept design. Barriers can be noted from the data and suggestions on how to solve problems are reflected and concluded to note participants' requirements of a tool. These are the first findings from the data collection, which consisted of two parts. The first part identified the cause of the problems in collaboration and communication in order to address these as a solution or a set of requirements for a new digital tool. The second part involves problem solving through the development of a digital tool to support relevant professionals to work together and communicate in concept design. Themes emerge from the empirical data that are organised into crucial keys to identify the barriers; this will help to identify the requirements of a tool for collaboration in concept design.

5.4.1 The Cause of the Problems in Collaboration and Communication

The combination of a variety of disciplines is important when designing together and solving problems in a design process. Although technology is brought for use in design practice, professionals face many problems, such as a lack of collaboration and communication, misunderstanding, different workplace locations, or issues with the tools used in communication and collaboration (see Tables 5.4 and 5.5).

The barriers are as follows:

1. Internal issue (personality issues)
2. Collaboration issues
3. Communication issues
4. Tools used in collaboration and communication issues (tool issues)

5.4.1.1 Internal issues

A variety of disciplines work together to design or solve problems in concept design; this is an important issue that can lead to inefficient collaboration due to individual differences. Self-centredness, and different attitudes were addressed as characteristics of professionals in practice and based on different experiences and backgrounds (Lawson, 2006). Thus, internal barriers consisted of different backgrounds and experiences, being self-centred, and having different attitudes (see Internal issue in Table 5.4). These were also mentioned in the focus group by research participants.

1. **Different backgrounds and experience:** Professionals in design teams are from different disciplines; when working together, the different backgrounds and experiences of each professional are not equal and may develop into conflict. In addition, they may have different processes and procedures at work or diverse approaches to problem solving. Participants were encouraged to explain or engage in discussion to facilitate their understanding of the issue and to focus on the design and problem solving.

Caption 5.4.1.1 Internal Issue: Difference Background and Experience

> **Architect:** "*Mainly, there is a problem in making members in another team understand the design of other disciplines. For example, when dealing with the structural engineer, I have to spend more time talking and finding solutions ... because our architectural design may design space and form to affect structure which is difficult when designing the structural engineering. I think that this design is not difficult. I solve this case by talking more and trying to clearly explain what my concept is and how it is necessary."* (Q11.P011)
>
> **Engineer:** "*Each professional has a different individual skill. When all of them are gathered, it can become conflicting because they may not understand each other."* (Q11.P041)

2. **Different professional attitude:** Professionals have different attitudes, which are defined as the way professionals dedicate themselves to the way they practice. However, different attitudes can lead to conflict within collaboration when producing challenging or more complicated design projects. Participants suggested that professionals need to negotiate more and clearly explain in order for other colleagues to understand the reasons behind their design.

Caption 5.4.1.2 Internal Issue: Different Professional Attitudes

> **Engineer:** "*The attitudes of the architect and engineer come from opposite directions. Most architects need to design the width, height, depth, and number of columns which is contrary to the principle of engineering because this character of a design needs to design bigger structures*." (Q9.P033)
>
> **Architect:** "*These problems are different viewpoints where each profession sticks to their ideas and professional principles too much."* (Q9.P005)

3. **Self-centredness:** Self-centredness can become obstructive within collaborative design in concept design. Participants noted that, when some professionals do not consider other members' designs or views, this leads to controversy. In addition, other members may choose not to participate in a collaborative design team but just follow the work process. Participants suggested that all professionals should be encouraged to communicate and/or use a project consultant in collaboration.

Caption 5.4.1.3 Internal Issue: Self-Centredness

Architect: "*I think that problems in collaborative design come from relevant professionals being too self-centred and not open-minded in concept design and schematic design.*" (Q9.P043) **Architect:** *"Some professionals are self-centred which becomes the cause of controversy. When some team members design on the job, they will not consider other members' designs. The solution is to have a project consultant as a medium to find conclusions together."* (Q11.P026)

A few participants in the prototype evaluation process mentioned the internal issue. It is not easy to bring different professionals to work together, and they encountered in their practice.

Caption 5.4.1.4 The Internal Issues mentioned from the Focus Group of the Case Study Evaluation

Engineer: *"The problems in working together and communication in Thailand include three main topics, which are silos, self-centredness, and a senior system in our culture.* *1) The senior system will force consideration of each other. I am your team, or you are my team. 2) It can be too self-centred, egotistical. It is like conducting not like working. 3) When working, it will be in a silo. And when finish working, instead of editing mistakes or asking for help, they will help to pass it or conceal it. They are on the same team.* *When the senior forces consideration, they will have a high level of self-centredness that does not want to see a mistake. It may take some time, but they go back to the silo mode. The work will go back to the same mistakes. There are attitudes from work - like this flag I see from this corner, and you see from another corner. It has to adjust to come together. It still involves the main problems, like I said, self-centredness, silo, and seniority. Where people are afraid to speak or argue. We have to live smarter."* (F.B.4.1.SP.03, SP02, and SP01)

5.4.1.2 Collaboration issues

According to Carrara's collaboration cycle (see Figure 2.21), all research participants, who are 43 professionals of research participants in Thailand, agreed with collaboration in principle. They believed it could enable them to develop their knowledge by understanding other disciplines and to help their colleagues to share and shape knowledge for learning with and from each other through communication and close working (see Table 5.7). Carrara (2017) pointed out that the methodologies and technique based on the face-to-face discussion in meetings are inefficient when a large number of silos have to work together. This is because knowledge and experience can be lost if the discussions are not recorded. Thai silos traditionally work independently and discuss or negotiate in face-to-face meetings; they use traditional methodologies and techniques (see section 5.4.1.2). Although they agree on the principle of Carrara's cycle, there are barriers to their collaboration which prevents collaboration involving successful sharing and shaping of knowledge and experience in their practice. Research participants report collaboration issues due to:

> *"The lack of collaboration and communication are problems that designers face when working alone without collaboration after finishing a meeting. They need other hands to solve problems, as, when there is a mistake on their design it is too late." BQ1.1. B.1.4.SP03, SP04*
>
> *"While members of design teams are meeting or working together in the same place (colocation), all information cannot be recorded, and some records disappear or are lost. When working in different workplaces (delocation), words are not enough to visualise a picture, and are easy to misunderstand." BQ1.1. B.1.2.SP06*
>
> *"Sometimes, each party looks only to its own part without looking at the overall project design, and lacks communication with other parties, the designs have errors. For example, when a structure is oversized which affects the building service system." Q9.P024*

Collaboration issues are barriers, which can obstruct the development of the concept design. Collaboration issues appearing from the data consisted of different workplace locations, time mismatches, and issues with the collaboration method (see Table 5.5).

1. **Different workplace locations:** Physical meetings can be held to discuss issues face to face and this sometimes means working together through co-location. This helps to determine a meeting's conclusion or to solve problems through collaboration. Different workplace locations are difficult in collaborative design, particularly amongst diverse professionals; this was also addressed within the data collection. Participants suggested that ICT should be used to resolve barriers so that all relevant team members can use technology for collaboration and communication.

Caption 5.4.1.5 Physical Environment Issues Mentioned by the Survey and Focus Group

Architect: "*The problem is members of design teams have different office locations.*" (Q9.P025)
Architect: "*We spent more time travelling to meetings. It consumes too much time and energy; when we arrived at our desk after the meeting at other workplace locations, we were too exhausted and could not do anything.*" (F.BL.2.1.SP05)

2. **Time Schedule:** This barrier relates to schedule management. Different workplace locations create difficulties for collaboration among design teams. They have to spend more time travelling to meet other professionals. Time becomes an important barrier for collaborative design.

Caption 5.4.1.6 Time Schedule Barriers in the Collaborative Environment Issue

> **Architect:** "*Holding meetings becomes difficult for work schedules due to time mismatches*." (Q11.P005)
>
> **Architect:** "…*Time schedules are difficult when agreeing coordinated times, which are hard to deal with when holding meetings*." (Q11.P029)

3. **Collaboration method:** Usually, professionals or silos, design and after that they meet in co-located collaboration to decide on, or solve, problems together. Following physical meetings or after working together on co-location, designers often return to design in their discipline at their desk. Sometimes, they ignore collaboration or cannot communicate with other professionals, which leads to missed opportunities for problem solving in concept design. Carrara (2012) similarly pointed out that professionals sometimes focus only on their discipline and ignore communication and collaboration.

Caption 5.4.1.7 Issue of a Lack of Collaboration Mentioned from the Survey and Focus Group

> **Architect:** "*All members work together in concept design, but each member only works in their discipline without collaboration. As a result, the design is incompatible.*" (Q9.P004)
>
> **Engineer:** "*There is a problem in that design in concept design leaves problems in the construction phase due to a lack of collaboration. As a result, the design cannot be built in the construction phase*." (Q9.P037)
>
> **Architect:** "…*all members work together in concept design and schematic design. Each member acts only in their own works and lacks collaboration. As a result, a design is incompatible.*" (Q9.P004)
>
> **Engineer:** *"The lack of collaboration and communication poses problems that designers face when working alone without collaboration after a meeting. They need other hands to solve problems, as, when there is a mistake in their design it is too late."* (BQ1.1.B.1.4.SP03, SP04)

In addition, one participant in the case study focus group addressed an important barrier in collaborative design, namely when an architect is the main designer in collaboration. The participant noticed that, while the architect plays a role in design, a challenge arises when other designers have to wait to follow the architect's ideas in a more limited timeframe. Instead, the participant suggested that designers should have opportunity, or be encouraged, to co-design from the beginning to the end of collaborative design in concept design.

Caption 5.4.1.8 Suggestion to Build Collaboration from the Beginning

> **Architect:** "*When an architect thinks, it may pose limits for other parties when building a model, so that the rest of team can continue doing the design. It turns out that they have to follow my idea. So, if we can conduct a brainstorm in the first place, the work will be better than just me by myself*." (F.R.1.3.SP07)

Moreover, participants in the focus group noted that all relevant professionals can work together, both on co-location and de-location, depending on the situation and whether they are able to overcome the drawbacks of collaboration.

- Firstly, close collaboration is a good option, which can include collaboration on co-location, physical meetings, or whatever method supports members to design closely together. Although collaboration means it is easier to communicate and solve problems together, there are drawbacks. Firstly, collaborations may not address all information, and information can disappear or be lost (Gabriel, 2000). In addition, co-located collaboration can be inefficient when a large number of professionals gather at same time (Carrara, 2017).

Caption 5.4.1.9 Advantages and Drawbacks of Co-located Collaboration

Engineer: "*The advantage of working at the same place is that it is easy for face-to-face discussion, but it also has a disadvantage in that it is wide and has too much information. The record might not cover everything and the information can disappear*." (F.B.1.2.SP06)

Architect: "…*When many parts of a project team collaborate to offer comments, they can take a long time and not find conclusions*." (Q9.P027)

- Secondly, collaboration on de-location mean that individuals are not in the same place. One participant suggested that collaboration on de-location requires more communication, such as through text. Although information is text or voice rich, and often with more detail, the description is generally only provided in words, which might not be enough to visualise the design. This format has to expend a lot of energy in explaining and sometimes it may be inconvenient to only use text or voice (Gabriel, 2000).

Caption 5.4.1.10 Advances and Drawbacks of De-located Collaboration

Engineer: "*The advantage of working over long distances are that notes are in more detail. Because of the distance, it is always written down all the time, like who speaks. It is clearer. But its disadvantage is less variety and understanding. With distance, words only might not be enough to see a picture. It is inconvenient for being on the same page."* (F.B.1.2. SP06)

5.4.1.3 Communication issues

In Thailand, the modes of communication adopted for collaboration among professionals include meetings, e-mail, short messaging service (SMS), and social media applications, such as Line, WhatsApp, Skype, and Facebook (see Table 5.5, and Tables 7.4, 7.7, and 7.8 in Chapter 7). Basic communication can be achieved via e-mail, SMS, or social media applications. However, these communication tools cannot support intensive interaction. All 43 research participants in this study agreed that the content of communication was crucial for collaboration and could be an important source of evidence and knowledge.

> *The content of communication is important. It should be recorded as a resource of knowledge and evidence in decision-making and if problems arise in future.* (Q22.P015)

However, research participants report that managing the contents of collaborative design is not straightforward. Instant messaging and social media applications are difficult to use when describing image-based designs. This is the main limitation of adopting these communication tools.

> *Most common methods of communication are discussions in meetings and e-mail, in which I have not clearly managed the contents of collaborative design. (Q23.P011)*

> *There are a variety of communication channels, such as e-mail, letter, Line, Facebook, physical note, or SMS. Some collaborators avoid using an unfamiliar tool for team communication, and struggle to use digital tools due to problems receiving complete and up-to-date information. In addition, senders and receivers are not on the same page, therefore presenting a risk of a misunderstanding. (Q9.P016)*

> *Sometimes, collaborators are confused regarding which is the latest version of data in the communication on which they are working/designing. (Q9.P016)*

> *Communication tools, such as Line, WhatsApp or Facebook, can only be used for basic communication; they could not be used in design collaboration because it is hard to explain images. We do not have the perfect tool for communication and collaboration. (BQ2.6.B.2.4.SP04)*

Communication issues can arise among professionals in collaboration; for example, sharing and understanding the contents of communication can be difficult when diverse professionals are gathered in the design process. The issues consist of misunderstanding, different languages, and a lack of communication.

1. **Interpretation:** Each person has their own perception and interpretation, which may not be the same as others. A design problem is complex and collaboration problems easily occur when designers have a mismatch in their interpretation among the different disciplines. It is especially easy for this barrier to arise when design ideas are immature and

insufficiently concrete for concept design. Participants suggested that designers need to clearly discuss ideas and potentially use evidence or pictures to support communication. Participants therefore require a tool for collaboration that facilitates the same understanding in concept design.

Caption 5.4.1.11 Participants Suggestions to Solve the Interpretation Issue

Architect: "*The problem happening between collaborative design is a mismatch. If we have a tool that makes them see a similar picture, it will terminate conflict and error from the different understandings of each person.* *Besides, there is the problem that arises from the project concept being the issue in construction or engineering. It needs discussion to develop the concept to a real project at the end. If the problem can be detected faster, it will bring benefits in design development and projects will be efficient, faster, and completed."* (Q9.P023) **Engineer:** "*There is a difference between experiences and viewpoints. Although all members of a team can see the same problem, they understand it in a different way. This needs to be adjusted for all of them and more reasons used to clarify. Sometimes, evidence or experiments will be provided or presented to another side to understand and build a sense of togetherness or to accept to work together."* (Q11.P035)

2. **Misunderstanding:** The different methods and notational forms used in communication among relevant professionals can lead to misunderstanding. This is because each professional has their own specific knowledge, which other professionals may not have. Participants suggested that all members need to help their colleagues to build knowledge in order to overcome misunderstanding in collaborative design. Carrara (2012) recommended building knowledge with each other during collaboration. Thus, communication content becomes important for all members' building schema.

Caption 5.4.1.12 Participants Suggestions to Solve Issues with Misunderstanding

Architect: *"The problem is communication. Sometimes, there is wrong understanding and an understanding mismatch."* (Q9.P006) **Architect:** *"I think the problem is communication because we have different backgrounds, knowledge, ideas or language, leading to misunderstanding."* (Q9.P017) **Architect:** "*A barrier is a mismatch in understanding or misunderstanding in another party's specific knowledge. This needs improved understanding or the passing on of knowledge to other collaborators in each discipline*." (Q11.P002)

3. **Language:** As each discipline has specific knowledge and language, the language of professionals can comprise of jargon or vague communication, which can pose social problems when other professionals cannot clearly understand. It becomes a barrier that leads to misunderstanding and misinterpretation among professional communication and

collaboration. To address this, participants suggested that tangible graphics can be used in communication and collaboration.

Caption 5.4.1.13 Participants Suggestions to Solve the Language Issue

Architect: "*The barrier is language. I will use graphics in conversations to make sure that others can understand whatever I try to mention*." (Q11.P009) **Architect:** "*The barrier is the jargon of each discipline. It is used in communication and collaboration when it leads to misunderstanding and mistakes*." (Q11.P006)

4. **Communication issue:** Two issues are evident, which participants addressed in the data collection. The first is a lack of communication. Professionals work together in a physical meeting before returning to design or solve problems at their desk. They may only work within their discipline with limited communication and collaboration when developing their designs. One participant suggested that they should be encouraged to communicate and discuss with other professionals whilst working on the concept design.

Caption 5.4.1.14 Participants Suggestions to Solve the Communication Issue

Architect: "*I think that a barrier is communication. It can be solved by persuading them to talk more.*" (Q11.P004) **Architect:** "*The problem is we do not know other professions; because we will actually design schematically, we need to have other professions. When we design the schematic, we need to have lawyers, architects, engineers, and other systems to work together. We do not know other [areas of] work; for example, we do not know how the engineer thinks, or does. It will be in contrast [to our work].* *There is a lack of working together and communication. We only think that we will pass the work over after we finish it.*" (F.B.1.4.SP04) **Architect:** "*If each party looks only to its own part without looking at the overall project design, and lacks communication with other parties, the design will have errors. For example, when a structure is oversized it affects the building service system.*" (Q9.P024) **Architect:** "*My problem is we have less discussion with an engineer about systems and structures, so the problems in design are solved later. They accelerate its completion because of the due date. The problems will be rechecked and fixed later.*" (F.G.2.2.SP05)

Another issue is the content of communication, which becomes a barrier in collaborative design among professionals (see Table 5.16). Most manually record the contents of communication by taking notes and/or sketching. Usually, some parts of the content are recorded in the meeting document. There are many reasons for this, such as:

- Communication content is not the efficiently managed (including the content of meetings or collaborative design) and this can lead to other problems. Many channels of communication pose barriers when it becomes difficult to manage content. These channels are meetings and communication tools, such as email, Line, Facebook, and other social applications.

- Communication content can be lost or incomplete. This becomes an issue in collaborative design when they need to retrieve and consult such content.
- It is difficult to search/retrieve information when they need to use the content in a design or as evidence/knowledge.
- Time is wasted in transferring from hard copy to digital file.

For communication issues, participants agreed that misunderstanding and misinterpretation are important occurrences in communication and collaboration (see Tables 5.6, 5.7, and 5.8). All participants suggested the prevention of such communication problems, as follows:

- Relevant professionals need to be encouraged to communicate with each other.
- As well as using texts or single words, they should use tangible graphics in communication to increase understanding.
- They are advised to work closely, whether on co-location or delocation.
- They are advised to use a repository of knowledge from communication so that they can retrieve and share knowledge or information in teams of relevant professionals.

5.4.1.4 Tool issues

Participants described their experiences of current tools - both digital and sketch - for concept design (see Figure 5.2). According to participant's comments (Table 5.10), the results show that they only adopt digital tools in concept design to display their design ideas and use a design picture to communicate with team design members. Thus, a sketch tool rather than a digital tool is used to capture design ideas. Moreover, many participants mentioned that digital tools do not support concept design and they can obstruct the process of generating design ideas. Besides using sketches to capture design ideas (see Table 5.11), they described the use of sketch tools to communicate among collaborative design team members. They all agreed that it is an appropriate tool to effectively and rapidly capture and describe ideas.

Currently, digital tools are used in professional AEC practice (Architecture, Engineering, and Construction). Participants recommend the enhancement of these digital tools to increase efficiency and productivity in the design process. However, tool issues were addressed by participants in terms of their barriers to collaborative design.

1. **Tools in collaboration:** Current digital tools are used as stand-alone to present professional design ideas in collaborative design, such as AutoCAD, SketchUp, and Revit. Another tool is Sketch, which is used to capture ideas and to communicate among relevant participants in concept design.
   - Professionals have to learn many digital tools, and it is not easy to learn each tool.
   - In collaborative design, Sketch cannot sufficiently support all designers to work together on the same spot on a page or whiteboard.
   - These digital tools are appropriate for individual work at a desk because they are developed as stand-alone tools for personal computers or notebooks, which use methods to share and exchange files. Participants noted that different digital tools and the variety of versions mean it becomes difficult to work together.
   - In addition, participants stated that these tools cannot sufficiently support collaboration with other professionals in concept design.

Caption 5.4.1.15 Issues with of Current Tools addressed by the Survey and Focus Group

Architect: "*Designers spend too much time learning how to use these digital tools in concept design and hardly use them"* (F.B.2.4.SP04)

Engineer: "*For an analogue tool, it may be a table around which there are people sitting together with a whiteboard. It is difficult to work together to wait for others to write or sketch. On paper, it will be difficult to write or sketch because it is only a single page, except everyone writes on their own copy. This will solve that problem."* (F.G.2.4.SP03)

Architect: "*Tools are being used in the design process on a computer desktop. It is difficult to work together in meetings or in collaborative design like co-location."* (F.B.2.2.SP04)

Architect: "*There is a limited number of versions of digital tools. For example, I use Tool version 2017 but another professional uses the 2015 version*." (F.R.1.5.SP10)

Architect: *"... today, we have many platforms for the document, except Auto CAD which has many versions, and Revit, which cannot cross the version. We still have other file extensions and many versions of Sketch Up. If it does not include Microsoft Word and Excel on the same platform, we still have Windows and Mac."* (F.B.2.SP14)

Architect: "*Sometimes, collaborators confuse the latest versions of the data on which they are working/designing."* (Q9.P016)

Engineer: "*An architectural team uses many tools; Sketchup, AutoCAD, and others; an engineer requires only 2D. Although architects will export a 2D plan by cutting down from a 3D file format, the complex detail in terms of technique will come with that 2D drawing (such as layer, block, and others). It becomes an issue for engineers who do not need to continue to work with a complex file technique delivered by the designers."* (F.R.1.2.SP06)

Engineer: "*Current tools have limitations that do not enable all professionals in collaborative design to show their comments to each other and acknowledge other colleagues' comments to give a concrete picture*." (Q9.P039)

Architect: "*There is not a tool that all members can create and modify together in real-time collaboration on co-location or at a physical meeting."* (Q9.P027)

Architect: "*Today, there are many limitations, such as digital tools which cannot be used in our meetings or work together immediately."* (F.R.1.4.SP02)

According to Table 5.12, participants suggested the following in terms of improvements to current tools:

- BIM tools should provide a layer of concept design for designers and there should be no need to input complete data in the concept design.
- For digital tools, such as AutoCAD or Sketch Up, the tool should be improved for easier use and integrate a user interface for designers, such as Sketch.

2. **Tools for communication:** A communication tool is important to help participants work together. Furthermore email, SMS, and physical notes are frequently used communication tools. They also use social media applications for communication, such as Line, WhatsApp, and Facebook. They also confirmed sub barriers, which are:

- Participants noted that the variety of communication channels available can sometimes confuse professionals or prevent them from receiving information due to missed messages.
- Email is not the best choice for collaborative design in concept design.
- Current communication tools, such social media or email, can support only basic communication. These communication tools become inefficient when the process of collaboration is complicated and requires more detail.

Caption 5.4.1.16 Issues with Communication Tools addressed by the Survey and Focus Group

Architect: "*There are a variety of communication channels, such as email, letter, Line, Facebook, a physical note, or SMS. Some collaborators refuse to use unfamiliar tools for team communication and struggle to use digital tools for communication. It becomes a problem leading to the receipt of incomplete, or out of date data*." (Q9.P016)

Architect: "*One communication tool is e-mail, which we are using. It does not have an instant feature to support collaboration in the team. … there are a lot of emails each day … sometimes, I cannot open and read them all*." (Q11.P016)

Architect: "*It will only be difficult to work together in communication. Most of them share information and ideas and reply and comment on that information. It is good to use the tool in basic communication, but it is not available now. There is not a tool for professionals to communicate and collaborate*." (F.R.1.1.SP13)

In terms of improving current communication tools, participants suggested that: "*Designers need specific tools for communication that can enable sketches and communication".* (F.B.3.4.SP04). Participants also confirmed that professionals currently use stand-alone tools, such as AutoCAD, Revit, or Sketch Up, and adopt exchange and file sharing in collaboration. Social applications are used as communication tools for collaborative design, including Line, WhatsApp, Skype, or Facebook. They struggle to use applications without any choice of tool to support their requirements for collaboration and communication in concept design. An architect in the focus group and some architects from the survey stated that:

"*…There is not a tool for professionals for communication and collaboration*." (F.R.1.1.SP13)

"The problem happening between collaborative design is to see a mismatch. If we have a tool that makes them see a similar picture, it will terminate conflict and error that come from the different understandings of each person …. If the problem can be detected faster, it will bring benefits in design development and projects will be efficient, faster, and completed." (Q9.P023)

"There is not a tool that all members can create and modify together in real-time collaboration on co-location or at a physical meeting." (Q9.P027)

Thus, information and communication technology are required to support collaborative design in concept design so that all relevant professionals can communicate, access the sources of a discussion or knowledge, and work together both in different locations or the same place to increase efficiency (see Table 5.17). A new digital tool for collaborative conceptual design is discussed in the section 5.4.2.

5.4.1.5 Recommendations for Improvements to Collaboration in Thai AEC

Participant suggestion categories were analysed in terms of the: barriers and solutions (Table 5.5), misunderstanding and interpretation (in Table 5.6), conflict and solutions (Table 5.7), and developing the team's knowledge (in Table 5.8). These categories helped to define the recommendations for improvements to collaboration, which enabled the researcher to achieve the research objective. The recommendations for collaboration are shown in Table 5.19 and the participants' recommendations for improvements to collaboration are as follows:

- 1st Item: Close collaboration is necessary to overcome barriers and encourage relevant members to solve problems with each other and increase opportunities to build knowledge within design collaboration. Both co-located and de-located collaboration need to support professionals to work together.

- 2nd Item: Integration is required to build from the level of personality to design and knowledge. Members need to integrate with other colleagues in order to understand other disciplines and help others to build knowledge at the individual level. Moreover, design and knowledge need to be gathered and integrated to collaboratively solve design problems and conflict. Metthews & Howell, (2005) and AIACC (2014a) recommend sharing responsibility to increase opportunities for integration amongst design team members.
- 3rd Item: Communication and discussion should be enhanced within collaboration by enabling an easy understanding and interpretation from using tangible graphics. In addition, open communication was recommended by AIACC (2014), which is based on direct and honest communication among all participants.
- 4th Item: Increased opportunities to share knowledge and learning are supported amongst design team members through proposals, suggestions, and discussions. Moreover, Carrara (2012) advised that proposals, suggestions, and discussions should be recorded for collaboration. In addition, previous project data should be provided to enable members to access information and thus extend their learning.
- 5th Item: Adopting Information Communication and Technology enhances co-located and de-located collaboration and communication. ICT should be adopted and supported to increase efficiency in managing collaboration and communication information among relevant members.

Table 5.19 Integrated Categories define the Recommendation Category for Collaboration

<table>
<tr><th rowspan="2">The barriers are addressed:</th><th rowspan="2">Misunderstanding and interpretation can be solved by:</th><th rowspan="2">Conflicts can be solved by:</th><th rowspan="2">Method of team's knowledge development</th><th colspan="2">Integrated Category</th><th rowspan="2">No</th></tr>
<tr><th colspan="2">Recommendation Category</th></tr>
<tr><td>De-located collaboration enhanced by ICT</td><td>Co-location/
close work</td><td>Co-located collaboration/ Meeting</td><td>Co-location/
close working</td><td colspan="2">Co-located collaboration and de-located collaboration</td><td>1</td></tr>
<tr><td>Integrate his/her self to other</td><td></td><td>Integration</td><td>Gathering</td><td colspan="2">Integration</td><td>2</td></tr>
<tr><td>More communication</td><td>More communication</td><td>More communication</td><td>Communication/ discussion</td><td>Communication /discussion</td><td rowspan="2">Open communication /discussion using Tangible graphics</td><td rowspan="2">3</td></tr>
<tr><td>Using tangible graphics in communication</td><td>Using tangibles in communication</td><td>Tangible to solve problem together</td><td></td><td>Using tangible graphics to solve problems and discussion</td></tr>
<tr><td>Passing on knowledge to colleagues</td><td>Sharing knowledge</td><td></td><td>Learning</td><td colspan="2">Sharing knowledge and learning</td><td>4</td></tr>
<tr><td>Use ICT to enhance collaboration and communication.</td><td></td><td></td><td></td><td colspan="2">Use ICT to enhance collaboration and communication.</td><td>5</td></tr>
<tr><td>Table 5.5, p.149</td><td>Table 5.6, p.153</td><td>Table 5.7, p.156</td><td>Table 5.8, p.158</td><td colspan="2">See</td><td></td></tr>
</table>

5.4.2 What is Required of a Digital Tool for Collaborative Conceptual Design

Participants suggested ways to improve analogue tools, using ICT to improve collaborative design, and developing a new digital tool for collaborative conceptual design. These suggestions were analysed and categorised in Tables 5.13, 5.17, and 5.18. These categories were arranged in a table and enabled the development of a requirement category to design the digital tool (shown in Table 5.20). The categories of development requirements are as follows:

- 1st Item: Easiness is the necessary key, which includes portability, high security, and a large storage size to enable designers to use the prototype for concept design. Sketches are recommended by all participants to enable all users to describe their idea design or solutions. In addition, a portable device is recommended by participants to facilitate users everywhere.
- 2nd Item: Information retrieval is required to enable users to equally access all shared information, such as solutions or designs, the contents of a proposal, suggestions, and discussions.
- 3rd Item: Communication and tangible graphics can support users to deliver and store a user's message and sketch graphics so that users can easily interpret and understand.
- 4th Item: A new digital tool needs to support all conditions of a collaborative environment, thus enable all designers to work together, both in co-located and de-located collaboration and at the same or at different times.

Table 5.20 Requirements of a digital tool developed for collaborative conceptual design

Analogue tools can be improved	Using ICT to improve collaborative design	Requirements of a digital tool for collaboration	Integrated category Requirement of developing a digital tool	No
Ease of use		Ease of use	Ease of use to design anywhere with a portable device and with large storage (multi-device feature can be possibly be developed in later versions)	1
Portable device		Multi-devices		
		Security and a large size of storage		
	Information retrieval (access information; discussion, and others)		Information retrieval (Access information; discussion, and others)	2
Communication	Communication (suggestion and discussion enabling understanding amongst members)	Communication (suggestion and discussion)	Communication and discussion on which support to use tangible graphics	3
Different-time collaboration	Different-time collaboration	Different time sharing	Sharing space supporting all conditions of a collaborative environment (real time and different time collaboration; co-located and de-located collaboration)	4
Real-time collaboration	De-located collaboration	Real-time sharing		
	Co-located collaboration			
Table 5.13 (p.173)	Table 5.17 (p.184)	Table 5.18 (p. 188)	See	

Participants' recommendations are condensed to an empirical requirement model of a digital tool for collaborative design in conceptual design (see Figure 5.6). Firstly, the ease of use is important when supporting all users, such as professionals, owners, and/or other experts. All parts of the digital tool should be easy to input with sketch, including the use of text for communication, enabling the user to retrieve information, and sharing data in a collaborative environment. It should support users to share their design ideas in collaboration and communication.

Caption 5.4.2.1 Ease of Use in the Developed Prototype Helps the Focus Group Participants Share Ideas and Communicate with Each Other.

> *"The prototype is great and easy to use. It can help in sharing opinions, communicating with each other, and collaborating both in the same and at different locations."* F.P.2.5.SP10, SP11, SP12
>
> *"..After I used it, I realised it was an easy-to-use program. In fact, I don't have to understand any basics of Auto CAD, or Sketch Up. I can still use it because I understand the prototype."* F.I.2.SP12

Secondly, the tool for collaborative design should support all users' access and retrieval of information from a shared information resource. Information retrieval was mentioned as it enables the design team members to review the content of previous communication, develop their understanding, solve problems, access 'tacit knowledge', and access evidence (see Table 5.14).

Caption 5.4.2.2 Information retrieval assists users in their collaboration

> "*The prototype is a repository of communication and design ideas."* F.Y.2.1.SP14, Y.2.4.SP02
>
> "*The prototype could record all contents in collaboration, such as ideas, sketches, and the content of communication. This becomes important evidence."* F.G.2.2.SP06
>
> *"…This prototype could enable collaboration and the recording of all content, such as ideas, chat, or discussion. Users do not need to write memos, documents, or edit drawings. It is less chaotic."* G.2.2.SP04, G.2.4.SP12

Thirdly, the tool should support all users with tangible graphics and communication technology, which should also be clear and understandable. It should support design team members' proposals, suggestions, and discussions through open communication amongst all users, which helps them to build knowledge for use in problem-solving and design. This communication content could be stored in the same resource and become a repository for all shared information. Thus, it could support collaborative design from the beginning to the end.

Caption 5.4.2.3 Communication and Tangible Graphics Assist Users to Easily Communicate.

> "*If it's finished in one application, it's ok. But this isn't. We use Line – just to communicate, AutoCAD draws the plan, but this couldn't be drawn without our email. Although many tools can be used on a server, other teams could not access them in some cases, such as working together outside their*

offices. So, we would have something that can do everything. If we finish the plan, everyone can see what we sent without changing the tool." (F.B.3.3.SP07)

"*I want to have the function which really meets our need, both concept and schematic. Text it is only text and sketch is only sketch. I want to have them in the same format - note and sketch*." (F.B.3.4.SP04)

"*Designers can feed all their ideas into the prototype, such as sketching ideas or a message containing ideas."* (F.Y.1.3.SP08)

"*For working on co-location, Note and chat can be used to communicate within the design team so that everyone can understand and also record the contents of the communication."* (F.Y.1.5.SP12)

"...It could be a whiteboard to connect all involved who could easily leave comments or work together." (F.G.2.4.SP03)

Finally, the tool should support all designers to work together in both co-located and de-located collaboration and at the same and at different times. Each user could use the new digital tool everywhere and connect to each other through the Internet and a WIFI signal.

Caption 5.4.2.4 Collaborative Space can Enhance Users to Work Together.

"The prototype encourages designers to work together and meet, both in the same and in different places." (F.Y.1.2.SP05, F.Y.1.3.SP09, F.Y.1.5.SP12)

"The prototype can support relevant professionals and/or experts to work together in the same and different places leading to savings in time and expense." (F.Y.2.1.SP14)

"In collaboration, all designers struggle to sketch or write in the same place. Therefore, this prototype could be used to work together on co-location. It could be a whiteboard to connect all involved who could easily leave comments or work together." (F.G.2.4.SP03)

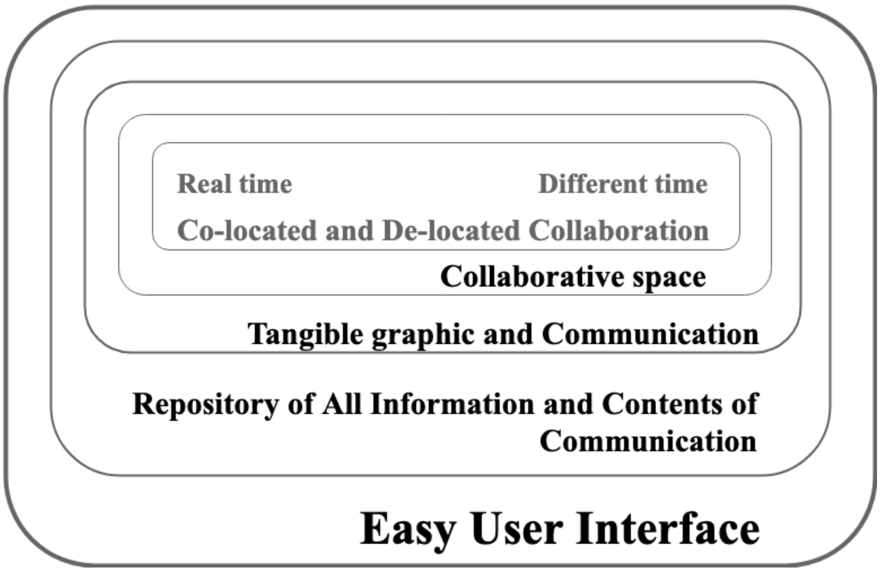


Figure 5.6 Empirical Requirement Model of a Digital Tool for Collaborative Design in Concept Design

5.5 Summary

This chapter gathered data from the first data collection and some responses from the focus group comprising professionals who are involved in concept design. The chapter has described the results of the qualitative data analysis, which were synthesised in the findings as the cause of problems and the basis of a required tool. The empirical data was condensed and identified that barriers obstruct relevant professionals when working together and communicating with each other. In addition, important requirements of a digital tool were that it is easy to use and able to integrate Cloud technology to connect relevant users.

The causes of problems in collaboration and communication were found to consist of internal, collaboration, communication, and tool issues. Firstly, collaboration gathers diverse professionals and experts and can lead to problems due to this difference. They might be encouraged to communicate with each other, whether in a physical meeting or through the internet. Secondly, time mismatches represent a collaboration issue in terms of different workplace locations and collaboration methods. They need close collaborative design, which requires technology for support. In addition, tangible graphics and discussion are important for collaboration and communication in order to ensure a clear understanding. Next, communication issues do not enable collaboration; difference is the main issue for misunderstanding and misinterpretation. Professionals require a tool for collaboration and communication, which encourages them to build knowledge so that they can address the issues.

Thus, a digital tool is required for three reasons. Firstly, to support collaborative design in concept design, secondly, the tool should be easily used to help share ideas and encourage all relevant designers to retrieve the contents of communication and collaboration. Finally, the tool should support collaboration and communication by enabling the integration of tangible graphics and communication technology.

CHAPTER 6: PROTOTYPE DESIGN AND DEVELOPMENT

6.1 Introduction

This chapter provides an overview of the software development approaches and the chosen approach that researcher considered for the design and development of this research. The chosen approach is discussed and adopted as a strategy to develop a digital prototype. Following this, the prototype specification is defined to guide the process, which identifies the prototype concept. The final section describes how the prototype was designed to follow the specification.

6.2 Prototype development lifecycle

The Software Development Lifecycle (SDLC) is used to describe the software lifecycle and the system that encompasses the software development (Ruparelia, 2010). When software is released to users, requirements or error reports become important resources for its lifecycle in terms of its evolution, error resolution and updates to its capability in meeting user requirements. On other hand, it can be understood as a system to develop software. Ruparelia (2010) stated that SDLC is a conceptual framework, or stage-structured process, to develop an application that begins with the initial requirement and continues through to its deployment and maintenance in the field. There are several approaches to software development, of which one was selected to design and develop the prototype in this research. Software development approaches, which are widely used for SDLC, are reviewed and a chosen approach is detailed that includes a description of how it was adopted in this research.

6.2.1 Software development approaches

A software development approach comprises networked sub-sequences, which can be arranged in linear, spiral, iterative, or incremental characters to follow the main strategy for each approach. There are several models, which include: waterfall, spiral, incremental, prototyping, and agile (Ruparelia, 2010). These best known software development approaches are described in the following sections.

6.2.1.1 Waterfall model

This approach is known as a step-by-step sequence for large scale software development systems. It comprises the following seven steps (shown in Figure 6.1): "system requirements, software requirements, analysis, program design, coding, testing and operations" (Royce, 1988, p.329). This model mainly uses documents to convey all issues in each step, which connect with other steps and communicate among relevant people, such as programmers, designers, and specialists. This approach is a simplified concept of the SDLC, which is still popular and a conceptual basic of other approaches; however, it is not very flexible (Isaias & Issa, 2015). Its advantages lie in that it provides a rigid schedule for work planning, a robust design concept before coding, and an extensive document of the entire process (Munassar & Govardhan, 2010, cited in Isaias & Issa, 2015). However, this model is not flexible and can detect errors for software development late in the process (Isaias & Issa, 2015).

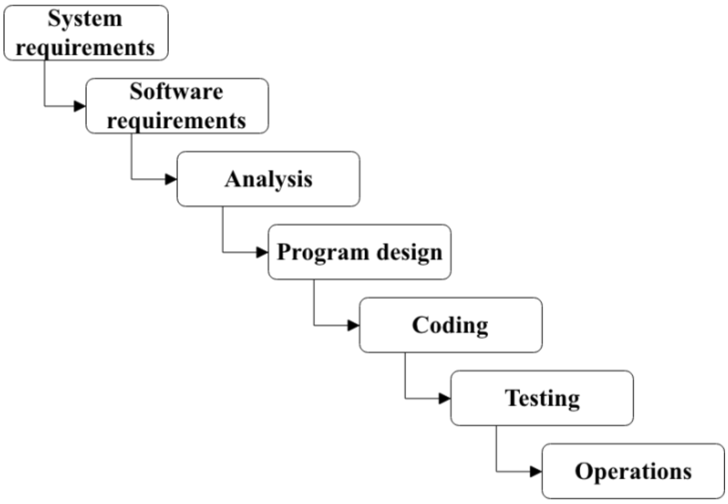


Figure 6.1 Waterfall Model
(Source: adapted from Royce, 1988)

6.2.1.2 Spiral model

In 1986, Boehm introduced the spiral model, explaining that it was developed from the waterfall model. It is an iterative cycle of prototype development that travels from the small to the complex through four quadrants. There are four strategic criteria in each cycle that relate to the four quadrants of the model (see Figure 6.2): 1) determining the objectives, 2) evaluating the alternatives and identify and resolve the risks, 3) developing and testing, and 4) planning the next iteration. These strategies become the function to move each cycle forwards when the software is developed.

The model begins with the identification of the objectives as well as the analysis of the alternatives and constraints. The risk considerations are established to determine the steps in order to meet the timeframe and degree of detail for each project; this also accords with the assessment of risk. Thus, if the developed prototype is sufficiently robust, the risks are reduced to an acceptable level. Next, the prototype is developed with a basic waterfall approach through the concept, requirements, design, and implementation (Boehm, 1988). When the prototype is nearing completion, the objectives and risk assessments are considered. The cycle stops when the risk level is acceptable or sufficiently reduced. Its crucial advantage is its emphasis on the evaluation of risk, which ensures major improvements and makes it an ideal model for large projects (Munassar & Govardhan, 2010, cited in Isaias & Issa, 2015). On the other hand, it is not efficient for small projects as the risk assessment increases the expenses associated with making the system.

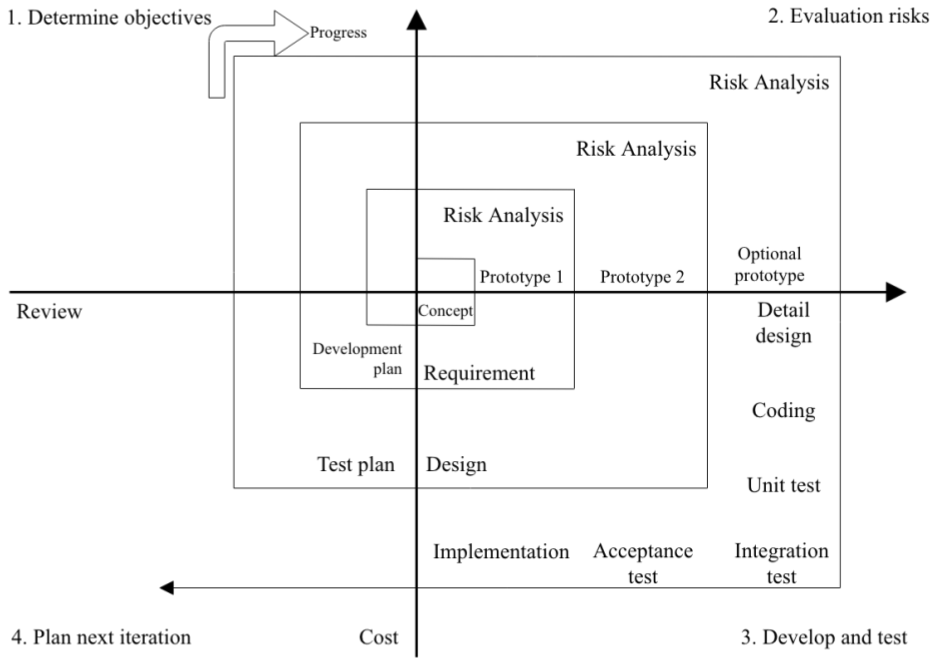


Figure 6.2 Spiral Model
(Source: modified from Boehm, 1998)

6.2.1.3 Incremental model

The incremental model is known as an iterative series that developed from the waterfall model. A number of iterations are made in order to incrementally represent and improve the functionality of the end product. This is a modification of the waterfall model and similar to the spiral model (Ruparelia, 2010). It aims to provide a more flexible process and a concise workplan (see Figure 6.3).

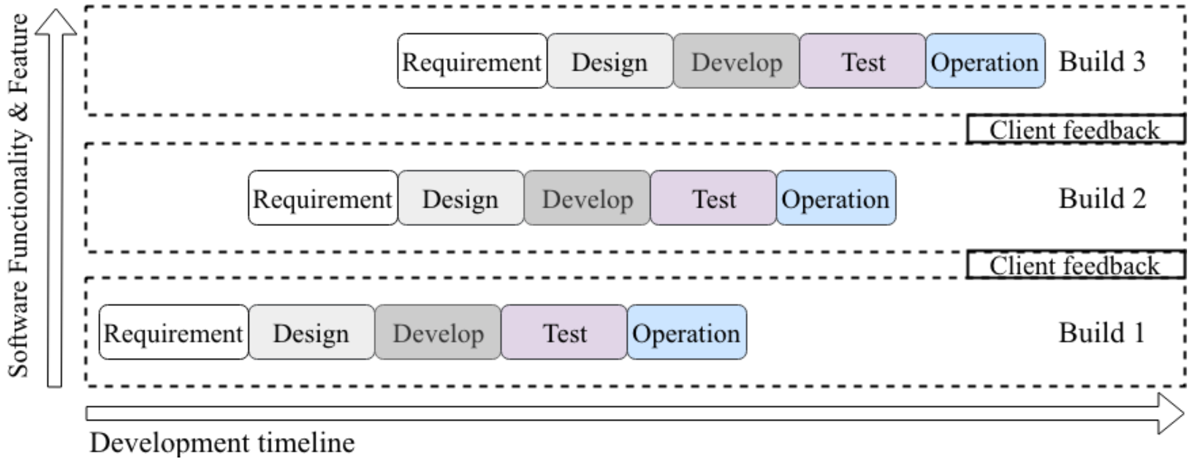


Figure 6.3 Incremental Model
(Source: Isaias & Issa, 2015)

The gradual addition of more features is its key advantage in that it develops a series of prototypes until the system is complete. User feedback and additional needs are incorporated within the requirements of the next iteration, which provides the opportunity to effect changes or improvements in its features, to resolve appended problems, and respond to users' needs. However, it is more costly to develop the range of prototype versions often required (Isaias & Issa, 2015).

6.2.1.4 Prototyping model

The prototyping model is iterative, and this quality has been at the centre of its agile approach to software development since the early 1980s. It is a process of creating the entire or part of a system in a pilot version and achieves its goal by building and refining various versions until a final product is reached (Carr & Verner, 1997). The prototyping model emphasises the creation of software instead of focusing on documentation. Furthermore, it requires user feedback to develop subsequent prototypes and the final product (Sabale & Dani, 2012). Carr and Verner (1997, cited by Isaias & Issa, 2015) explained that the prototyping model provides four different stages; users' requirements, prototype development, user testing, and the final released product (Isaias & Issa, 2015). This is shown in Figure 6.4.

This model is more dynamic and responsive to client requirements; it carries less risk, and greater efficiency (Carr & Verner, 1997). However, its weakness lies in the analysis and design planning for the development of the prototype (Isaias & Issa, 2015). This is appropriate small-scale software development, although Isaias and Issa (2015, p.34) also conclude that, "prototyping is ideal for larger projects and particularly for user-centric ones".

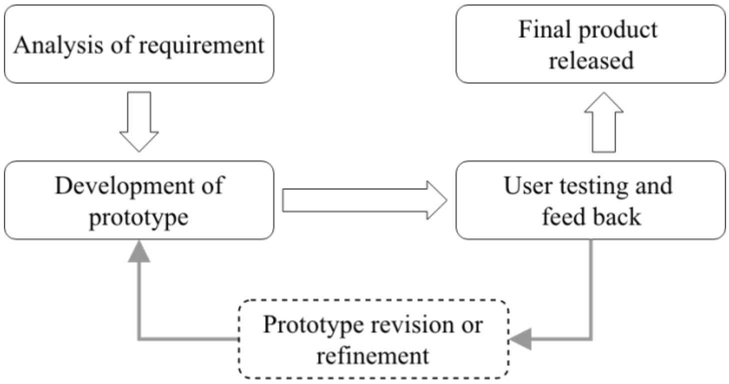


Figure 6.4 Prototyping Model
(Source: Carr & Verner, 1997 illustrated by Isaias & Issa, 2015)

6.2.1.5 Agile model

In 2001, seventeen software developers announced the development agile software; this aimed to bring the best traits of other agile-like models into one model. It can be outlined in four steps; 1) project selection and approval, 2) project initiation, 3) construction iterations, and 4) product release (Isaias & Issa, 2015). This is shown in Figure 6.5.

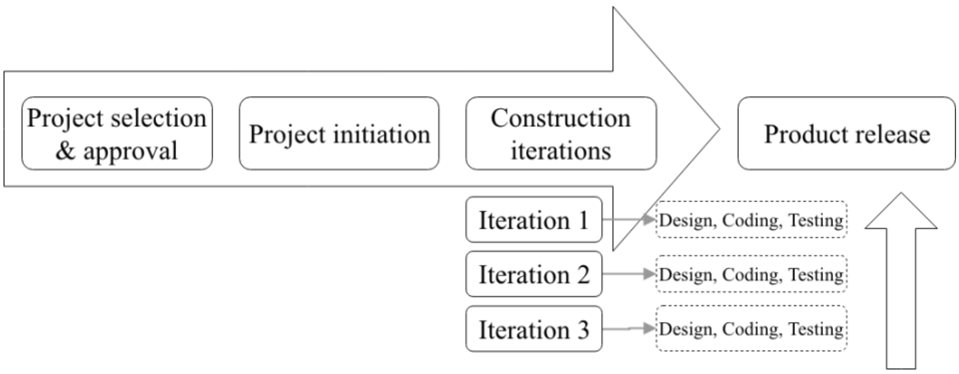


Figure 6.5 Agile Model
(Source: Isaias & Issa, 2015)

The first step defines the scope, purpose, and requirements of the product from a team, managers, and customers. In addition, different alternatives are analysed to establish goals and to risk assess each idea (Bhalerao, Puntambekar, & Ingle, 2009). Project initiation is the second step, which aims to prepare and establish a working team and a work-plan timeframe and schedule (Ambler, 2009, cited in Isaias & Issa, 2015). The third step is construction iterations. Each iteration gathers its planning and building to comprise subsequent procedures, such as design, coding, and testing. Successive increments are made and requirements are updated that are outlined by various stakeholders. This step requires close collaboration to ensure efficiency and the quality of the working software (Ambler, 2009, cited in Isaias & Issa, 2015). The final step is the product release, which consists of two sub-stages. First, the entire system is tested, when the final documentation and other reworks are completed. Second, the product is released for which training is provided to users. The maintenance of the project is the responsibility of the working team who support users in any product improvements (Bhalerao et al., 2009).

6.2.1.6 The Chosen Approach

According to the aforementioned software development approaches, the SDLC follows important phases that are vital for developers, such as planning, analysis, design, implementation and testing. These models of software development have been developed since 1970 (Balaji & Murugaiyan, 2012). An approach for this research is selected and considered in relation to the conditions of this study. The criteria for selecting the approach are as follows:

- The researcher is a programmer and documentation is not necessary for the collaborative process of this research.
- The prototype will be on a small scale.
- Both iterative and incremental processes are extremely important when building the prototype.
- Collecting information from users or research participants provides an opportunity to understand what they think about the prototype.

These methodologies include complex phases "...based on iterative and incremental development…" (Balaji & Murugaiyan, 2012, p.26) and involved developers who emphasised the management of both documents and collaborative process within or across teams. They do this through using, for example, the waterfall, incremental, and spiral models but not with agile and prototyping models. Although the agile approach does not emphasise documents in its process, teamwork is still important as it encourages face to face conversation as the basis for successful collaboration among a working team.

The prototyping model is more appropriate for developing a digital prototype due to its small-scale approach, which enables the subdivision of the project into many segments, and a greater ease-of-change during the process, including iterative modifications (Centers for Medicare and Medicaid Services, 2008; Davis, 1992). Davis (1992) explained the cycle of software development that comprises system development, user testing, feedback, and developers. According to Carr & Verner (1997) and Isaias & Issa (2015) these can be clustered into three groups, which are: 1) requirements, 2) prototype development, and 3) user testing (see Figure 6.6).

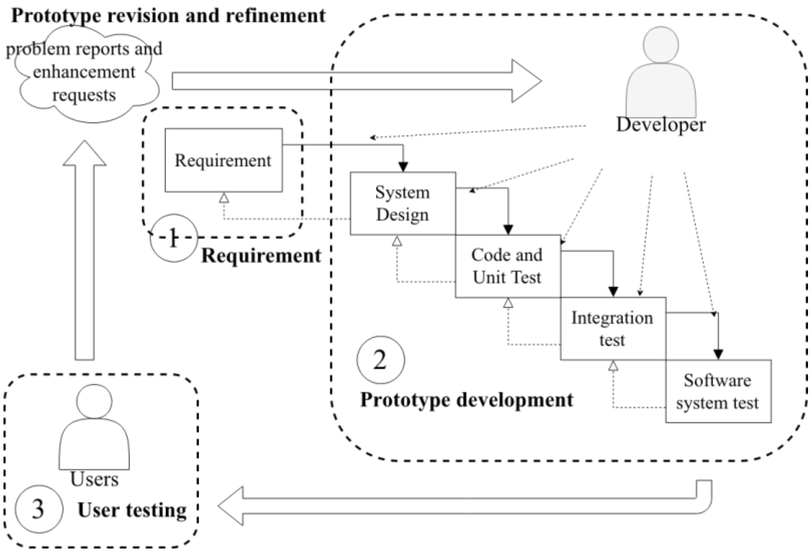


Figure 6.6 Prototyping Model
(Source: modified from Devis ,1992)

The prototyping model development approach is illustrated in Figure 6.6. The prototyping process starts with: 1) requirements, followed by; 2) the prototype development, which consists of the system design, the coding and unit testing, the integration test, and software system testing (each of these procedures provide iterative loops), after which, the prototype is required; 3) the user testing collects feedback on problems or requests that are reported to the developer for revision and refinement in the next version.

Thus, the researcher considered these approaches from the criteria. The prototyping model is the best choice and more appropriate for building a digital prototype in this research. Prototyping can be emphasised as an experimental approach that uses the essential features of a prototype system to collect research participants' ideas (Floyd, 1984). The chosen prototyping approach is adapted to conform to the research methodology, which is discussed in the next section.

6.3 Discussion of the Adapted Strategy

When the prototyping approach was chosen for this research, it was applied to the design and development phase. A strategy adapts the development stage of the prototyping model to provide an approach that integrates the concept design and an incremental process for the successful development of the digital prototype. The concept design focuses on integration within the strategy and all stages are rearranged. The incremental process is described in this section, whilst the strategy adopted in the chosen approach is discussed in the next section.

6.3.1 Concept and System Design

The user interface and interactive design are important for the efficiency of a system design. The interface and interaction affect users in terms of their use and may pose problems for users after release into their contexts. Lawson (2006) and many other researchers note the existing problems of digital tools in AEC projects in terms of their complex user interfaces and interactions. Although software design indicates creation, it is also a way of scientifically analysing and solving problems for a system (Waldo, 2006). These points represent the reasons why prototyping should be integrated as part of concept design to enhance the creative element of the user interface design. It enables a balance in design between the system and the user's application.

Concept design can help the development of ideas concerning the user interface and interaction by understanding and analysing the definition of design and concept design, including creative and critical thinking (discussed in Chapter 3). These definitions can develop designs, which are integrated into the prototyping approach. The user interface and interaction design can be encouraged through creative and critical thinking in the concept design by transforming abstract into concrete ideas. This helps designers to gradually develop abstract ideas rather than to design concrete elements through the model of Lawson (2006). The problem-solving model of Lawson shows that creative and critical thinking represents analysis, synthesis, and evaluation (Figure 6.7).

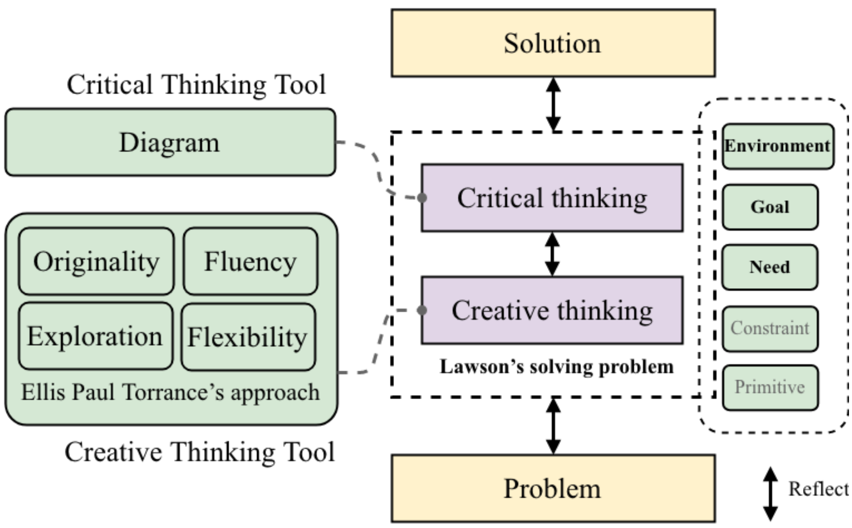


Figure 6.7 Creative and Critical Thinking in Problem Solving for Design (Source: Researcher's own)

According to the problem-solving model of Lawson (2006), the model can be used as a thinking tool in concept design for the user interface and interaction design. This is because the model contains analysis, synthesis, and evaluation which fit creative and critical thinking. In Chapter 2, both thinking processes have been explored and described in detail. Thus, the model can be integrated into Ellis Paul Torrance's approach and diagram for creative and critical thinking; the model includes the criteria design of five components from the specification.

In terms of the user interface and interaction for a prototype, the system and user requirements will be analysed to produce logical activities and include data types that will interact with the user's activities and the system. All logical activities and data types can be arranged and gathered in the same problem or task groups and then externalised into vague diagrams and texts to leave the designer's mind free to produce ideas or solutions for the user interface and interactions. Significantly, each vague diagram will become an explicit idea that provides a crucial resource from which to build several creative ideas. The advantage of a diagram is that it can encourage creative thinking for design exploration.

The problem tasks gathered from logical activity and data types can be supported from creative thinking in terms of diagrams. These diagrams will be continuously developed for use in the concept design parts of the user interface and interactions; these can be enhanced using Ellis Paul Torrance's components. These diagrams can also develop the abstract design ideas of a user interface and interactions. Background knowledge in programming skills is important in assisting a developer or designer to evaluate the feasibility of these creative design ideas. A novel digital prototype can be created and accepted if it is a new design idea that can be developed on the system.

When Lawson's model includes these tools, the model can help the designer/developer to address problems in the concept design. Specifically, the diagram will be used from the analysis and evaluation of critical thinking to construct ideas or solutions, which will become problems for creative thinking in creating alternative designs. The tool for concept design is illustrated in Figure 6.8.

A stage of concept design is formed to support the user interface and interactive design; moreover, it is integrated in the prototype development before the system design. This stage can use the tool to solve problems in design (according to Figure 6.8) to help the developer or researcher adopt creative and critical thinking.

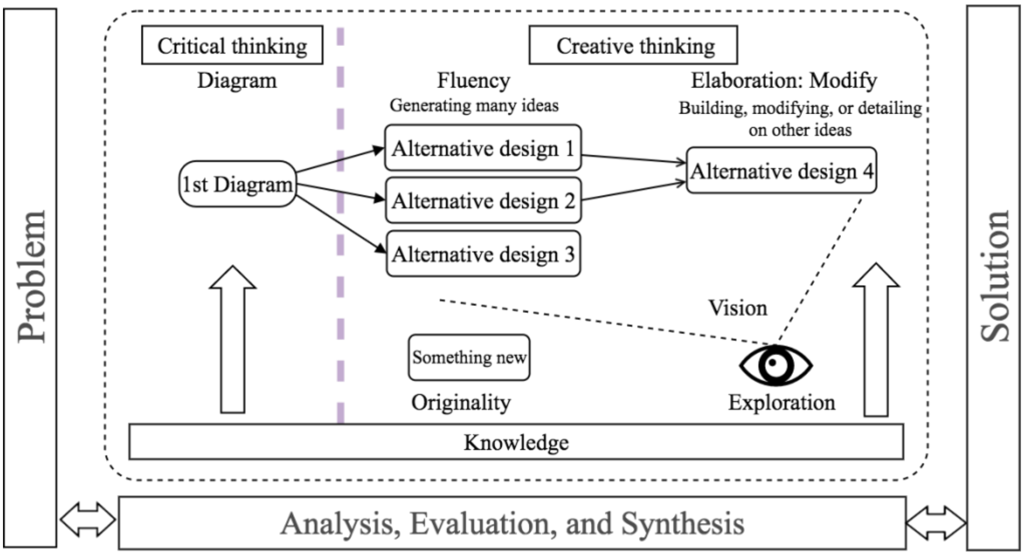


Figure 6.8 Tool for Problem Solving in Design
(Source: Researcher's own)

For this research, the prototype development, or the improved phase, is subdivided into three main stages (see Figure 6.9). First is the concept and system design, where the conceptual design is integrated with the system design. Second is the coding which blends both the coding and unit test because, when the code is built, the unite test can undertake the same activities at the same time as a modern programming tool which supports building and debugging features. Next, all coding tests, such as the integration or software system test, are gathered in the test stage.

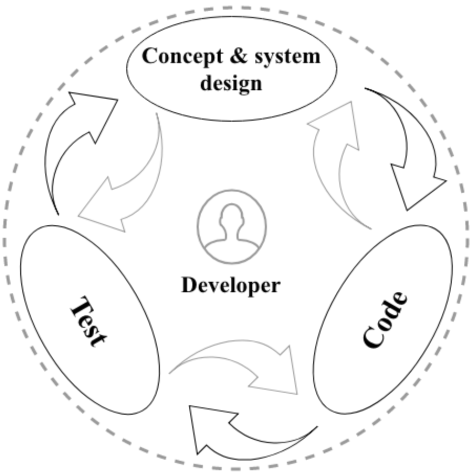


Figure 6.9 Prototype Development Phase for this Research
(Source: Researcher's own)

6.3.2 The Integration of the Incremental Process

According to the incremental model, its series feature is adapted from the iterative waterfall model and becomes the strength to provide a more flexible process and concise workplan for software development. This has been adopted in the development phase of the agile model with gradual incremental iterations (see Figure 6.10).

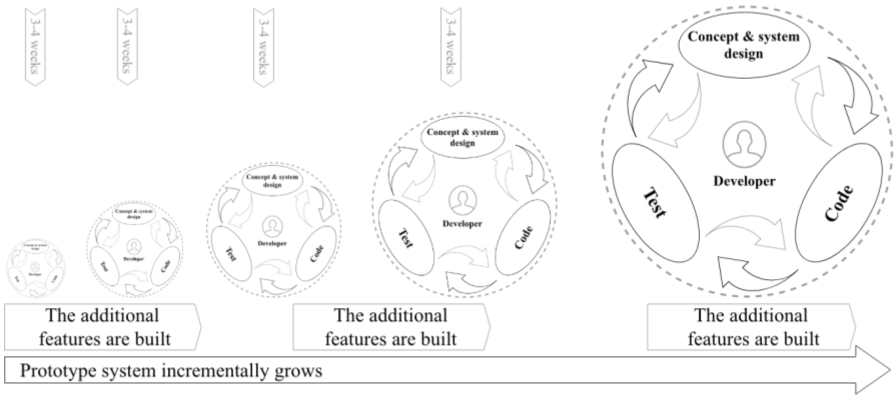


Figure 6.10 Incremental Process
(Source: Researcher's own)

The distinguishing feature of the incremental model is adopted and integrated into the prototyping model in order to help develop the prototype. There are advantages to integrating the feature, as follows:

1. The incremental iteration feature helps to increase the additional functionalities and features for the prototype development.
2. It helps to improve and update code for the next iterative development.
3. It is a more flexible process for changing the requirements for the next iterative development.

6.3.3 The Strategy Adopted in this Prototyping Development

The design and development phase provides a bridge between the survey case study and the evaluation case study, which forms the main element of this research methodology. The prototyping approach is adapted as a strategy for the design and development phase, which is rearranged into three main stages; concept and system design, coding, and testing. Critical and creative thinking can enable the transformation of abstract to concrete ideas in concept design. Moreover, the incremental iteration process helps to gradually build the prototype until it is developed and complete for the next phase of the research methodology. All phases are connected with the knowledge, which is important to enable the retrieval of knowledge and experience, or to learn new a technology and/or issues to solve problems in the process. The Modified Prototyping Approach Model is illustrated in Figure 6.11.

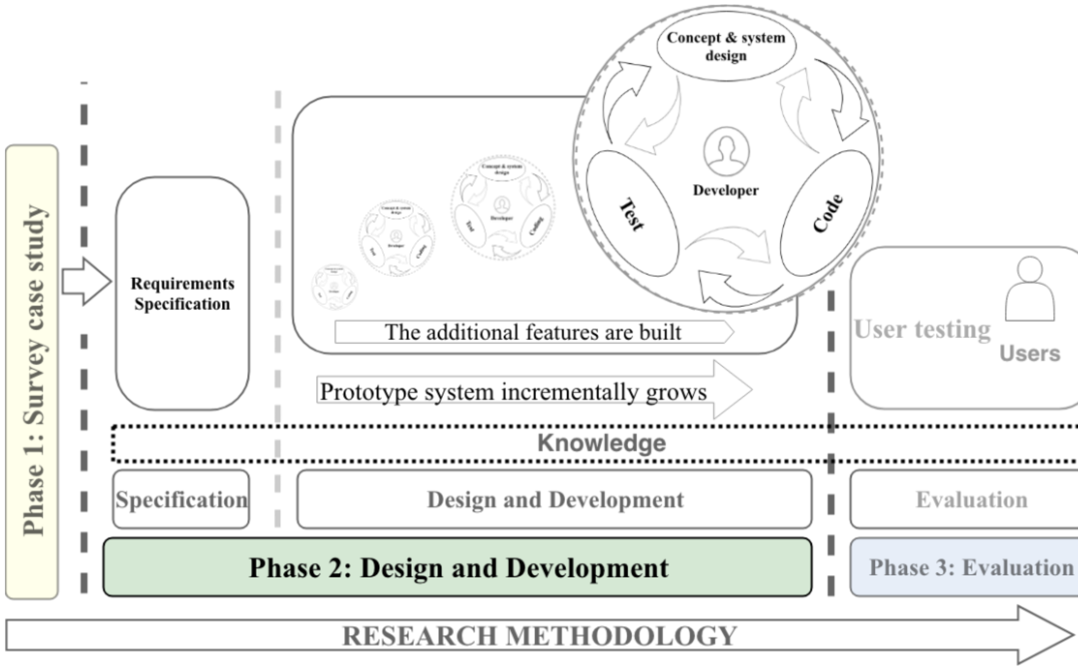


Figure 6.11 The Modified Prototyping Approach Modified for this Research (Source: Researcher's own)

6.3.3.1 The Requirements Specification

The information analysed from the data collection is delivered in this phase and condensed into the requirements specification that identifies the specific needs, environment, and goal for a digital prototype. The requirement specification prepares guidance to describe what is required, how to build it, and who uses the digital prototype. There is a tactic to organise the software requirements specification. These are chosen from the sub components within the standard software requirement specification (Wiegers & Beatty, 2013), and develop the specification for this research. These are as follows:

1. Introduction of the prototype scope, which provides a short description of the prototype under specification and its purpose; it relates the prototype to the user or objective and strategies.
2. The overall description presents a high-level overview of the prototype and its environment, the anticipated users of the prototype, and the constraints addressed. The context of the prototype describes the system environment in which the prototype will operate, such as the hardware platform, operating system, versions, and database.

3. The system features describe each feature of the prototype in terms of its function and functional requirement.
4. The data requirements are defined and introduced to various aspects of the data. A logical data model is described, which uses a visual representation of the data model to illustrate the process and relationships between the data objects, which can describe a business operation.
5. The external interface requirement provides information in terms of the communication between users and the external hardware or software elements. The user interface describes the characteristics of the user interface with which the prototype is designed to connect, joining the prototype and other software components (identified by the name and version) such as the database. Moreover, the hardware interface describes the characteristics of each interface between the software and hardware components, which might include the supported device types.
6. The quality attribute is a specified non-functional requirement, which concerns the usability of the prototype. The usability proposes issues to deal with the ease of use and the efficiency of interaction, which helps to design the user interface and interactions.

6.3.3.2 Design and Development

Regarding the modified prototyping model (illustrated in Figure 6.11) the design and development phase was adapted to inject the concept design stage into the process, reorganise all phases to three main stages, and integrate an incremental iteration process. This improvement helps to break down the architectural system to a series of functionalities and features, which incrementally develops each iteration step-by-step. Each iteration consists of the concept and system design, code, and test.

1. **Concept and system design:** the concept design and system design comprise two parts. Firstly, the concept design provides an opportunity to develop the user interface and interaction, for which the intuition of the user provides the crucial criteria. In addition, the abstract idea of the system will be designed along with ideas from the user interface and interaction. Secondly, the system design is part of the system problem-solving. This will involve object-oriented design, algorithm design, and database or data persistence design. The abstract ideas from the early phase will be developed into concrete ideas and applied to the system design. Both are adopted to generate ideas and consider possibilities.

2. **Code:** The code and unit test phase is a stage of the code programming practice and test. Each object and algorithm part will be written and tested to identify errors and solve problems.
3. **Test:** This stage is used to test parts built in the code stage to detect the gathering unit errors. This stage includes the integration test and system test. The integration test phase determines when parts of the project system are united. All variables and procedures are involved and the communication between these parts is tested and checked for errors. After the integration test is applied to the code, it is also tested in the entire software system test.

This modified approach helps the researcher to manage a concise work plan and to gradually deal with the complex code that increases the capability of the system. The prototype is fragmented to ease the design and development. The prototype is built from small to complete functionalities and features, and is carried out to the design from diagrams, code, and tests. From this, the complete prototype is employed for user testing in the next evaluation phase of the research methodology.

6.4 Prototype for the "Conceptual Design Team Collaboration"

The requirements specification and concept design of the prototype were created and developed to follow the results of the first data collection. This found that the first requirement was for an easy to use tool and, second that this tool should be a repository of knowledge to gather the communication contents to help designers work together within conceptual design. Next, the crucial components are the collaborative space and communication support by Cloud technology.

6.4.1 Prototype specification

6.4.1.1 Introduction of the Prototype's Scope

For collaborative concept design, the goal of this digital prototype is to enable designers to follow the aptitude of their profession to work together in real or at differing times to share all data segments though Cloud technology. The prototype provides a shared space for sketching and a stack of layers. Sketch's data type is a vector object, which can be modified, such as through moving, rotating, and scaling. Their ideas can be managed on an idea space, which structures idea objects, such as tree nodes. In addition, the prototype restores the discussion contents of communication as a knowledge repository. Unlike text or chat applications, the communication part of the prototype will allow users to sketch on a discussion space and post their comments as a node around the sketch area. All users are implied as designers (architects and engineers), who use this prototype to co-design and co-solve problems on a shared space, and all have the right to their layer stack.

6.4.1.2 Overall Description

A digital prototype is a sketching tool to help users streamline their ideas when they are considering concept design and discussing this among team members. The context diagram in Figure 6.12 illustrates the external entities and system interface, which is connected to Cloud technology by the internet from each device. This enables collaboration among designers in order to share and retrieve segments of sketches and discussion data from several locations or the same location.

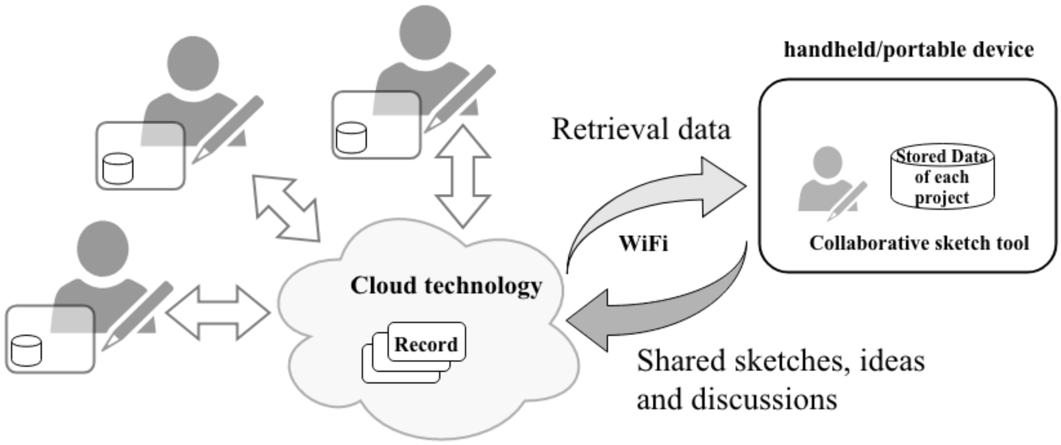


Figure 6.12 Context Diagram of the Prototype
(Source: Research's own)

In terms of user classes and characteristics, a group of professionals consists of relevant designers, such as interior, architects, engineers, and other relevant specialists. The architect, interior designer and engineer are the main targets, identified as designers, to use this digital prototype. They are expected to engage as a collaborative group of about 10 designers to use the prototype and the same features of the prototype. One individual is provided with the function of monitoring access to all contents.

This prototype is developed on a handheld/portable device, which, in this research, is an iPad Pro device running on an iOS system version 10 operating environment (or later versions). All data will be sent to the Cloud; the Cloud technology used for the prototype is the CloudKit framework, which is retrieved by into the device. The CloudKit is a significant mechanism for collaboration technology. However, complex data becomes a constraint that needs addressing in order to retrieve data in an appropriate amount of time. This is the rationale for the prototype's system to integrate the persistence framework and store these retrieved data in the device.

6.4.1.3 System Feature

The features of this digital prototype are proposed to support designers' collaborative designs and communication in concept design. The three feature components are: collaborative sketching, an ideas map, and a message board for communication.

Firstly, the collaboration components comprise the following functions and features:

1. The collaborative sketch space is a stack of paper view where each view can be controlled by the following actions: zoom, pan, and select another paper view.
2. The collaborative sketch allows users to work together as a stack of layers where each has the right to only work on their own layers and not to modify other users' layers.
3. The layer control of each user can be controlled from the show, hide, and lock modes where the objects created in each layer will behave upon the modes triggered.
4. The sketch provides functions for modification: select, move, adjust scale, delete, copy and paste, and ruler.

Secondly, the component of an idea design map comprises the following functions and features:

1. This component provides an idea design map, which is shown as the node of an idea and the lines denote the relationships between them.
2. An idea sketched in the current view space is copied and linked to an idea node.
3. The idea design map provides functions for generating, inheriting, and deleting ideas.
4. Each idea is a node that can be moved around the space of an idea design map.

Thirdly, the communication component comprises two function and feature sub-components, as follows:

1. Public message board:
   - 1.1. This component provides a public message board and uses the characteristics of a list for communication amongst all shared users.
   - 1.2. The list of a message board can move around and help users to communicate with other shared users.
2. Discussion node:

2.1. The node of a discussion is created and dropped on a page in the space of a collaborative sketch.

2.2. The interacted node connects with a list of discussion objects.

2.3. The discussion list can be moved around and help users to communicate with other shared users.

6.4.1.4 Data requirement

The logical data model (partial data model) is illustrated in Figure 6.13, and describes the entities and relationships of the digital prototype in this research. Its perspective is used to describe adaption in terms of the CloudKit framework and the system persistence framework. The partial data model shows that the project entity is referenced by: the user profile, message board, idea map, and page entities. These entities contain the object references of the project entity. The relationships form the concept details, as follows:

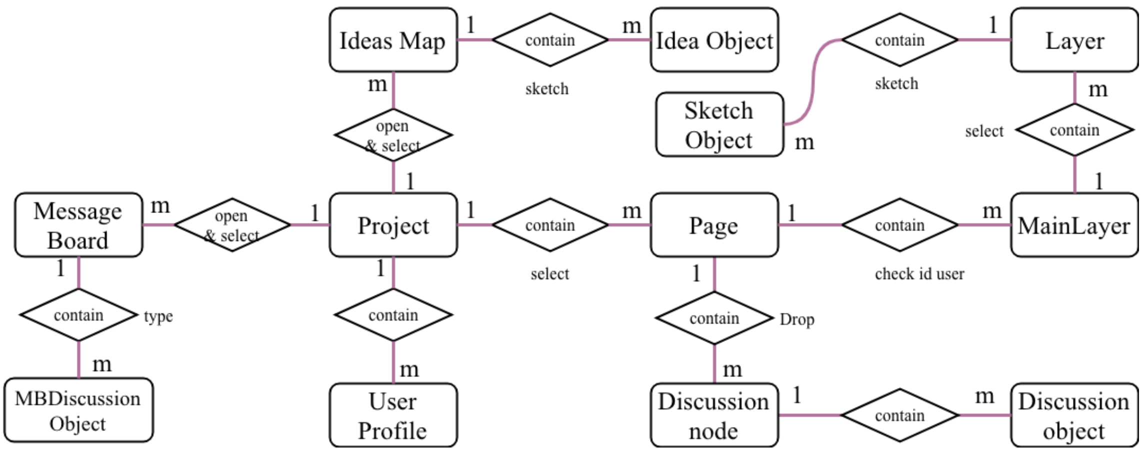


Figure 6.13 Partial Data Model of the Digital Prototype Model
(Source: Researcher's own)

1. User profile entity contains all attributes of the user, such as the user identity, name, family name, multi-discipline, reference of the project file and other relevant attributes.
2. Page entity contains the attributes of the page, such as the page identity, name page, page details, creator (user identity), and reference of the project file.
3. The main layer entity contains the attributes of the creator (user identity), its name, on-off, and the reference of the page.
4. The layer entity contains the attributes of the current mode, the on-off mode, lock mode, layer name, layer details, and the reference of the main layer.
5. The sketch object entity contains the attributes of the enclosure mode, the fill colour mode, its degree, the object name (object identity), frame data, frame point, and point

structure. The data type of the point structure is text (JSON format) to store all points of the object.

6. The idea map entity contains attributes of the idea identity, idea name, idea details, reference of the project file, and the reference of the idea map entity.
7. The idea object and discussion object entities are similar to the entity of the sketch object whose objective is to contain a point structure.
8. The message board entity contains attributes of the node identity, the name topic, content message, group references of the user entity, and the reference of the project file.

6.4.1.5 External interface requirement

The external interface requirement is generally a description of the user interface, software interface, and hardware interface. In this research, the digital prototype does not connect with other systems or software, so the software interface will not be addressed. The user interface describes the logical characteristics of the interface between the digital prototype and users. The Graphic User Interface (GUI) standards of the iOS will be adopted along with four parts of the user interface, as follows;

1. File management component:
    1.1. Files will be managed to create, delete, and open this part of the user interface.
    1.2. This component is required to support file sharing with other users.
2. Collaborative sketch component:
    2.1. The data of pages, layers, and main layers need to be grouped in the main interface and linked to the sketching space.
    2.2. All actions are required to be located on the top of the interface, such as sketch, select, move, scale, rotate, and delete. These actions should be designed as interactions between the user and interface to encourage the user to apply both hands (bimanual interaction).
    2.3. The sketching space needs to be controlled using zoom and pan actions.
3. Idea map component:
    3.1. The idea map is a node to contain relevant data, such as the name or other details structured by the JSON format.
    3.2. The node needs to create relationships with other object nodes, present a line connection, and cancel the relationship.

3.3. The node contains and links the sketch object data in a collaborative sketching space.

4. Communication component (message board and discussion nodes):

   4.1. A message board is easily called and hidden. Its user interface uses a list control to support records containing messages.

   4.2. Discussion nodes:

      4.2.1. The discussion node is an object that the user the drops on the sketching space or working page.

      4.2.2. The discussion node is used to open a list control for discussion among designers on only one page.

   4.3. Note is provided to leave details:

      4.3.1. Note is an object which the user also drops on the sketching space or working page.

      4.3.2. Note is like a button to open a control containing a text box for noting on the page.

In terms of the hardware interface, this prototype is developed on an iPad Pro and requires the pen device of an Apple pencil to facilitate the designer in their creative work and thus sketch what they conceive. The 12.9-inch model of the iPad Pro has a 2732-by-2048 Retina Display at 264 pixels per inch. Its resolution is required to develop a function of scale in the collaborative sketch. It provides its component system to support an Apple pencil for pressure sensitivity and angle detection.

6.4.1.6 Quality Attributes

The prototype is required for usability. The usability is addressed in the next chapter in the evaluation process. Its attitudes consist of learnability, efficiency, errors, and satisfaction. The prototype should concern these attitudes in the process of the design user interface and interaction.

6.4.2 Concept design of the prototype

The GUI design and interaction of the prototype is developed with the GUI standard of the iOS operation system on a handheld/portable device. The conceptual design idea of this digital prototype consists of four components; collaborative environment, collaborative communication, idea design map, and bimanual interaction. These follow the requirements and goal of the framework for this prototype to enhance the conceptual team design collaboration (see Figure 6.14).

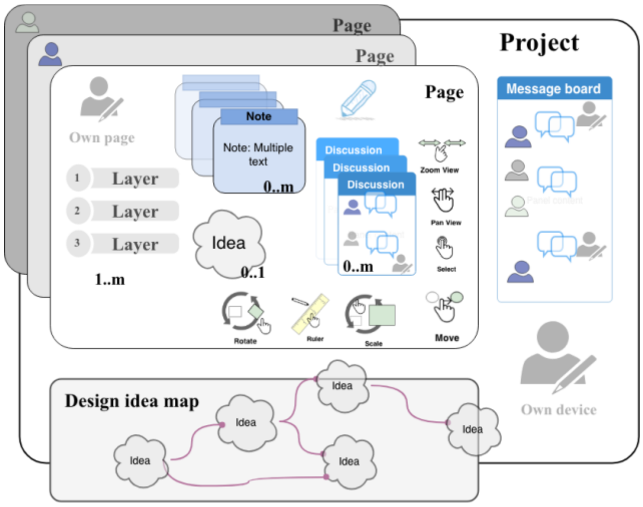


Figure 6.14 Concept Design of the Prototype
(Source: Researcher's own)

6.4.2.1 Collaborative Sketch Environment

After the project is created and shared amongst relevant users, the collaborative environment provides the shared space between users who accept the file sharing. The collaborative environment (illustrated in Figure 6.14) comprises pages, users, layers, and sketch objects. Users can create pages and share these with other users who have the right to read and write their own data. Each page supports the owner to create their own layers and use their layers to contain all created/modified sketch objects (see Figure 6.15). With respect to the rights of each participant, users can only have the right to manipulate their own layers and objects. All users are able to create and manage their own layers and objects but cannot modify or select other users' layers and objects.

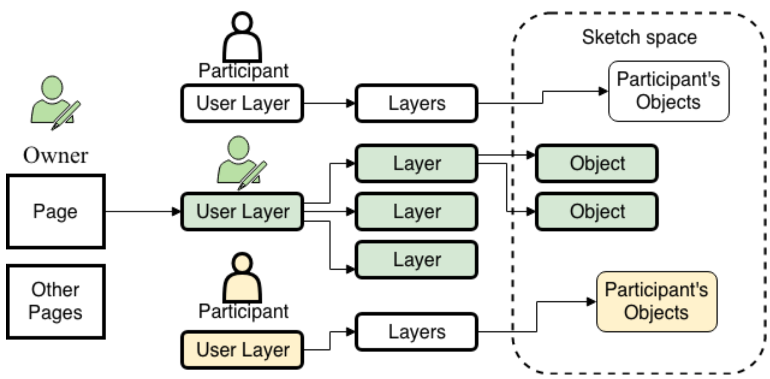


Figure 6.15 Relationship of Pages and Layers on the Collaborative Environment
(Source: Researcher's own)

6.4.2.2 Collaborative Communication

This prototype provides three types of communication channel, which have the characteristics of note and discussion on the page, and message board for public communication. The objective is to collect information concerning the conceptual collaboration team design, which allows all relevant users to share and retrieve communication information. Note (1) and discussion (2) are firstly dropped with the node objects on the page and then note and discussion are opened when the user acts at the node objects. The node object is used to open and hide the note and discussion to follow the user's gesture, such as double clicks. The system supports users to create multiple notes and discussions to drop the nodes on the working page. The relationship between note and page is one to many, and the relationship of the discussion is also the same. Moreover, the message board (3) is called or hidden from the button in the main menu.

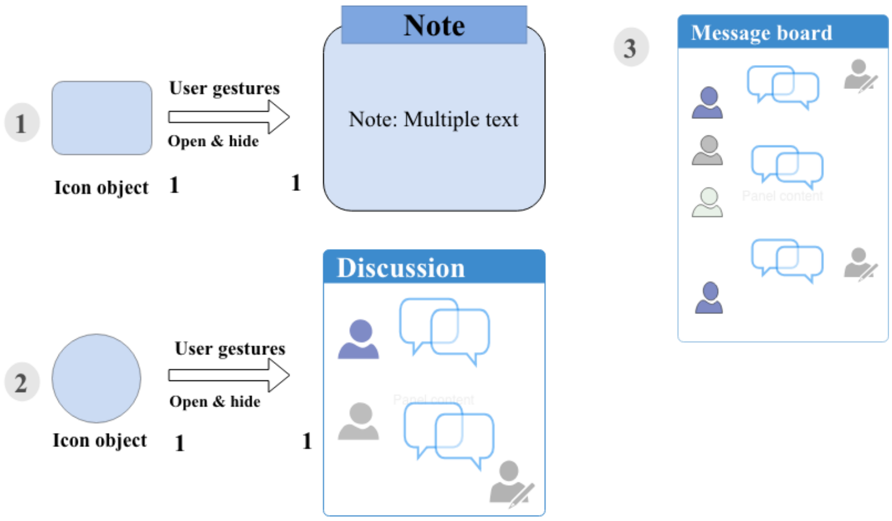


Figure 6.16 Note, Discussion, and Message Board
(Source: Researcher's own)

6.4.2.3 Map of the Idea Design

The idea design map is used to encourage designers to build creative ideas from which the initial novel concept can be developed into several ideas by modifying or detailing the original. This is supported from Ellis Paul Torrance's creative thinking approach and was addressed by Cotton (1991) and Hsiao et al. (2006). It comprises fluency, flexibility, originality, and elaboration (see Figure 6.8). Usually, all most designers tend to create and develop several design ideas for each prototype, focusing on originality, fluency, and elaboration, until they can identify a final design. This is supported from the first data collection where each user in the concept design generates two to three design ideas. This prototype proposes a map of creative design ideas to enable designers to explore and access their design ideas from the map on which they can make notes and input details into each idea to record information (illustrated in Figure 6.14). This provides crucial reminders to build new designs for the collaboration team design.

6.4.2.4 Bimanual Interaction

Human centred design principles and intuitive user interfaces are the principles of design that form part of the interaction. Oviatt's (2006) human centred design principles suggest that, to increase efficient performances in tasks, the user's mental resources can be released without distracting their attention to deal with problems and associated thinking processes. Users can input data through the sketch method with their hand and a digital pen, which allows them to deal directly with the thinking process. This is a way of reducing their cognitive load. Additionally, according to McKey (2013), in the intuitive user interface principle, the prototype can also support forgiveness, understandability, and discoverability functions. This prototype also provides an 'undo' and 'redo' function to allow users to fix the unwanted or mistaken actions with an undo or redo command. In addition, a visual graphic is combined in the commands, for example rotate, scale, and ruler; it can also support users to understand and discover performances that can aid their thinking process.

Both the multi-touch and digital pen interactions are provided to enhance users' experiences of bimanual interactions. Users are encouraged to adopt a digital pen which this prototype has developed to store attributes from the drawing on the screen. They can use both their hands to perform these tasks. One hand can be used to sketch with a digital pen, while the other can work the multi-touch interaction to control the view, including the zoom, and pan, to control commands, such as a ruler, and select and modify objects by using scale, move, and rotate actions (as illustrated in Figure 6.17).

Before triggering the modify commands, such as scale, move, and rotate, users need to trigger the selection command, which is designed to use the drawing of a polygon shape to group a sketch object or all selected objects. These modifying object commands are designed for use by the movement of the user's finger around the centre of the screen, which provides a visual graphic to support the user's exploration. In addition, the ruler object control is part of the GUI and built to support the zoom mode and allow a snap to the ruler's edge. The user can sketch a line on the edge of the ruler and estimate the dimension, which is shown both in the units of the ruler and the degree of the ruler, depending on whether the view is zoomed in or out.

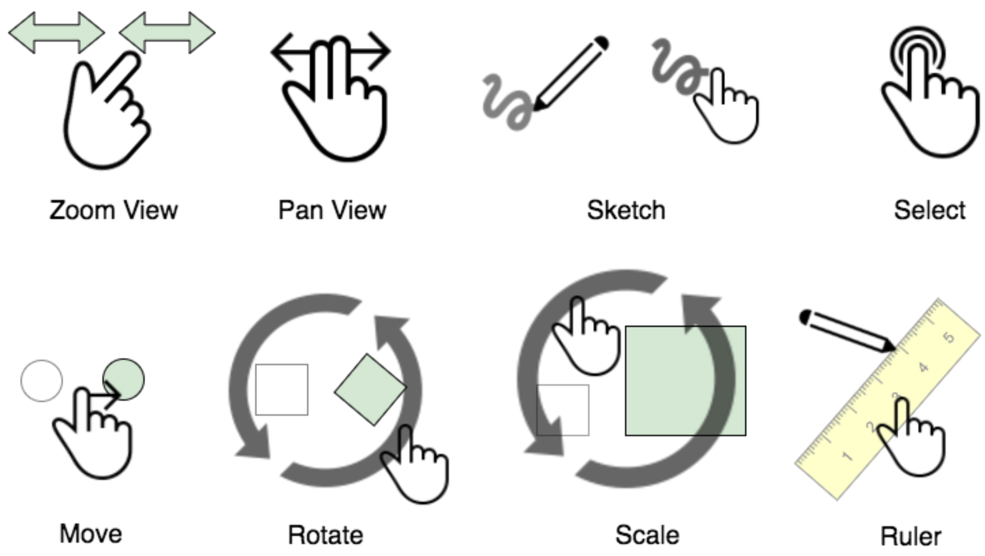


Figure 6.17 Bimanual Interaction of Prototype
(Source: Researcher's own)

6.4.3 Data Persistence and the CloudKit Framework

In considering the design and development, data persistence and data transfer are important mechanisms for developing the prototype on a mobile operating system (namely, the IOS platform of Apple). The operating system can use the core data framework to store data on a disk on both Apple IOS and OSX. Furthermore, they provide the new CloudKit framework technology for data transportation. Both data persistence and the CloudKit framework are applied to the prototype to manage the data.

The CloudKit framework is defined as a document-oriented database or document store, which is a subtype of the core NoSQL Systems, and was created as a component system for Web 2.0 services (Tudorica & Bucure, 2011). This contrasts significantly with the Traditional Relational Database (RDB), which stores data in separate tables and uses keys to link data between tables. It stores all information in accordance with string types, namely; Int64, Double, Bite, Location, Asset, Reference, and a list of these types is held in a record that includes the reference objects to link between the records. All records are kept in the container, which consists of public, private and shared databases; moreover, customers can create zones in both public and private databases. All records are designed to store the information of a prototype, which can be a shared zone from the private database of an owner or the shared database of other participants (as illustrated in Figure 6.18).

It takes time to conduct the data transaction from the application of the device to Cloud storage, and the time taken depends on the size of the data. Furthermore, the CloudKit framework has constraints on the size of the record, which trigger on more than 1MB per record, with the exception of the asset types, such as pictures. Thus, this constraint needs to be taken into consideration for all types of data in each record and the management of the data objects in the prototype. The CloudKit framework becomes a second mechanism, which runs in the background threads, to enable the retrieval of data from cloud and to transfer all data to cloud. In comparison, the main mechanism for the management of data in current memory becomes the core data framework in the main thread.

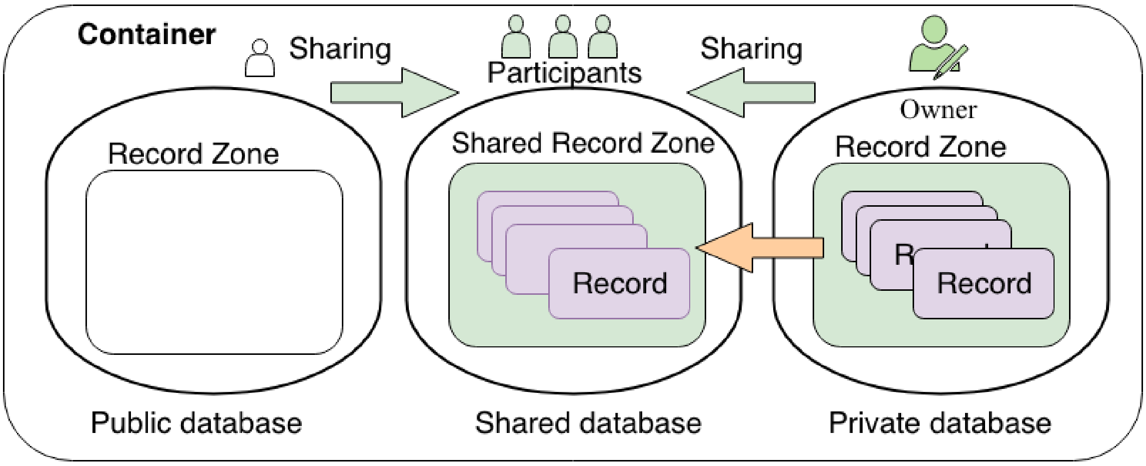


Figure 6.18 The CloudKit Framework and the Sharing of Records
(Source: Research' own)

The core data framework is used to manage the model layer objects, which provide generalised, persistent, and automated management through the object lifecycle and the object graph management of all objects, which links the entities in memory, according to the Apple technology document. The advantage of this framework is that it can effectively reduce time in managing the object lifecycle, especially with writing the data into the dish. The framework provides entities and each entity can contain the name and value type attributes, for example String, Float, Double, Int, and so forth. It can also include the attributes' types of relationships between the entities in terms of one to one (1:1) or one to many (1:m). In addition, the core data framework can support the work process in concurrent/synchronised functions, with the data in more than one queue at the same time. Thus, the management of the core data framework is assigned to the centre of both actions for data retrieval from CloudKit and for the transferral of data to CloudKit through concurrent/synchronised functional/management tasks (as illustrated in Figure 6.19).

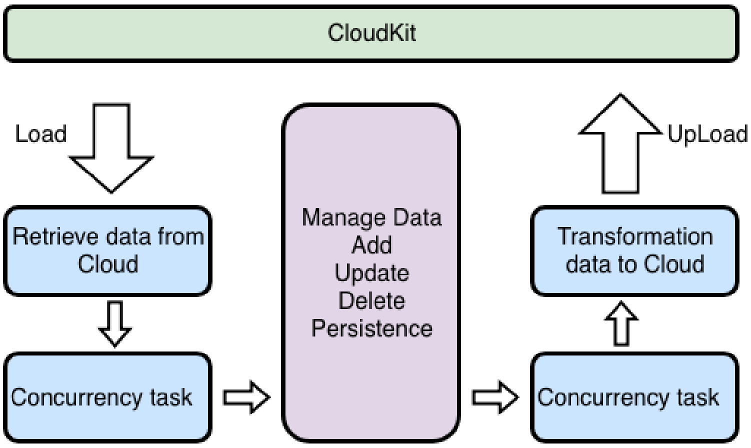


Figure 6.19 Management of Data between Data Retrieval from Cloud and the Transferral of Data to Cloud (Source: Researcher's own)

This digital prototype will not be able to efficiently operate data without these parts, which manage the object lifecycle from the core data, the transfer data and the data retrieval from a modern storage-CloudKit. However, the CloudKit captures data as a record using a data reference to connect each record; the core data provides one entity linked among entities with relationships. Thus, both the core data and the CloudKit frameworks can communicate with each other from the same type of data and can be operated from a device system. The modern storage-CloudKit becomes the main mechanism to transfer data between all devices. Furthermore, the data persistence (the core data framework) of each device is also significant in supporting the process and increasing the efficiency of the prototype when dealing with the transferral and retrieval of data from the CloudKit framework task in the background of a prototype system.

6.5 Using the Prototype

The digital prototype is developed to support all designers within conceptual design team collaboration working in the same or at different workplaces and either at the same or at different times. The digital prototype supports the user to create a project to share with relevant users when designing in a collaborative space using a sketch and building their own ideas on a design idea map. The prototype allows these users to communicate with each other through dropping notes or discussions on a working page, and to use a message board to chat within the project. This section describes how the prototype is to be used to create and share projects, to sketch and modify in a collaborative space, to manage idea designs on the map, and to communicate with each other on the same project.

6.5.1 Creating and Sharing a Project

The prototype begins with a view of project management. The project management view allows the user to create projects and share a chosen project with other users who already have their own Apple ID and devices. The user information is protected, and all data are stored under high security by the system operation policy. The prototype assures this benefit and adopts user information to identify individuals involved in the prototype. When the user (creator) creates and shares projects with another user and this user (receiver) accepts the project, the user information is automatically integrated into the prototype. The process is illustrated in Figure 6.20, which shows how to create (1) and share (2 and 3) a project as well as accept a shared project (4 and 5).

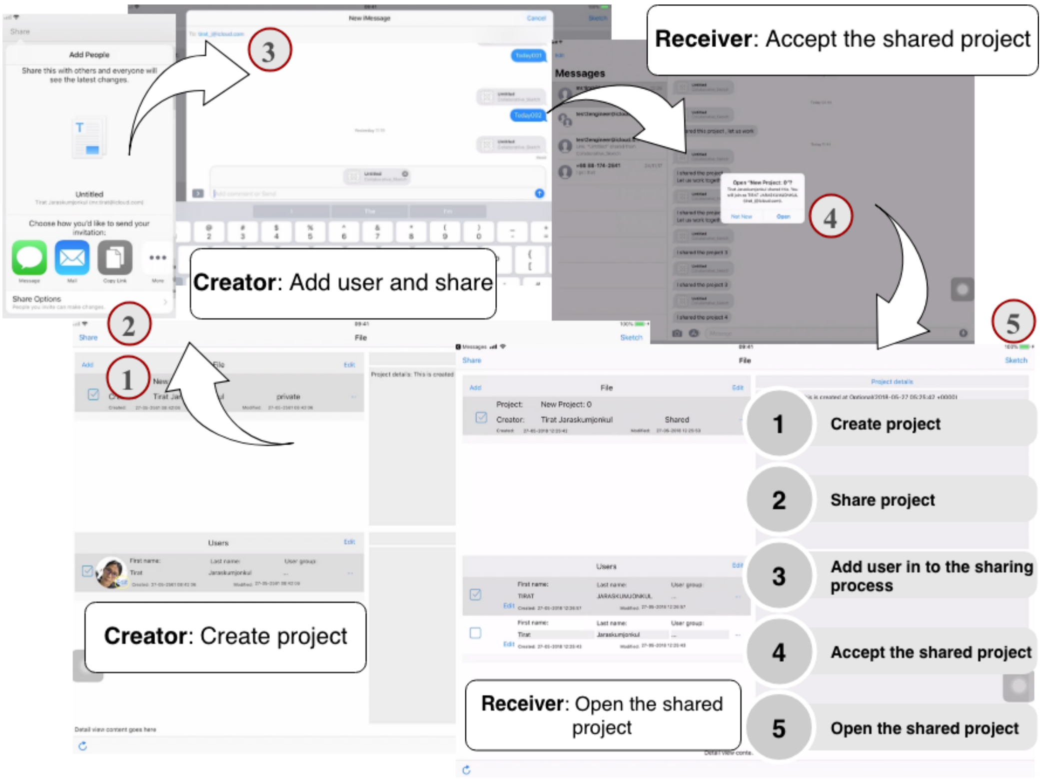


Figure 6.20 Create project and sharing to another user
(Source: Researcher's own)

Firstly, when the project management view is shown, the user or owner device uses the 'Add' action (1) to create a project and they can remove this by using the 'Edit' action. The created project needs to be selected so that the creator can use the 'Share' action to share the project with other users (2). An 'Add People' pop-up provides channels for sharing through iMessage or Email (Apple ID). The creator only uses another users' Apple ID for sharing the project and inputs the message to another user (3). In this case, the researcher uses iMessage to share the project and message other users.

Secondly, the receiver is notified by the operating system when a message and an attached record of a project arrives. The receiver clicks the attached project, and then accepts by clicking the 'Open' action within the dialogue box (4). The prototype is opened and all records are downloaded from Cloud into the receiver's device. The user can click 'Sketch' to open the shared project and go to the next view of the collaborative space.

6.5.2 Working in the Collaborative Space

After creating and sharing the project, the user opens the project to sketch in the collaborative space. Figure 6.21 illustrates an overview of the actions showing how to create and modify in the collaborative space. In this part, the page and layer are controlled by the main control, which allows the user to manage the pages, and each page contains a group of layers. When working in a collaborative space, the user can sketch and modify their sketch by selecting, moving, rotating and scaling as well as use a ruler for measuring.

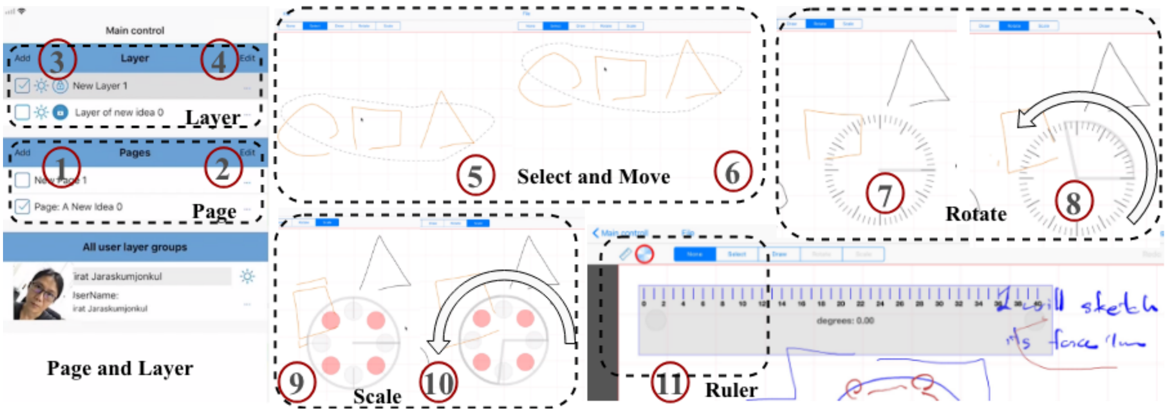


Figure 6.21 Managing the Page and Layer in the Main Control and Modifying the Objects in the Collaborative Space
(Source: Researcher's own)

The page and layer are provided with a default mode. The page can be added without an idea from the 'Add' action on the group of pages (1). The layer can be also added from the 'Add' action on the group of layers (3). To delete a page and layer, the user can apply the 'Edit' action to delete both (2 and 4).

A digital pen helps the user to sketch better than when using their fingers. Actions are laid on the main toolbar at the top of the working view space. If a user needs to measure the angle or dimension, they can use the ruler (11), which can be moved around and rotated. To modify actions, object sketches first have to be selected, and these objects can then be modified as follows:

1. **Move**: these selected objects are moved around after selecting the 'Move' action (see 5 and 6 in Figure 6.21).
2. **Rotate**: this action provides an object control to help users input values at the centre of device screen by applying a finger movement around the centre, whether clockwise or counter clockwise (see 7 and 8 in Figure 6.21). The object control passes the angle value to the selected objects to modify the vertices position.
3. **Scale**: this action also provides an eight-object control at the centre of the device screen that is used to modify the selected objects (see 9 and 10 in Figure 6.21). The object control involves 8 sub-objects that control the scale value of X, Y, and XY. There are three types of scale: firstly, the X scale is modified with 2 sub-object controls on the X axis; secondly, the Y scale is modified with 2 sub-object controls on the Y axis, and thirdly the XY scale is modified with 4 sub-object controls on XY.

6.5.3 Using the Design Idea Map

Usually each designer can create two or three design ideas. When professionals design together through team collaboration for conceptual design, many ideas are generated. This prototype provides a map of the design idea to support users in managing their design ideas (see Figure 6.22).

Firstly, after the user sketches to create objects (idea 1) on a working view; these sketch objects need to be selected. Next, the user opens a design ideas map from the 'Idea map' button (see 1 in Figure 6.22). The idea map view is opened over the working view and can be closed when user clicks 'Close' in the same position as the 'Idea map' button.

The second stage represents the initial method to build an idea object and an idea view. The user can create the idea view and idea object, which is linked to these selected objects from the working view by touching and holding the idea map view. The idea view is created at the chosen position in the ideas map; it shows that these objects are linked with the ideas object from the 'contain' control in the idea view (this is marked as 2 in Figure 6.22).

The third stage is also the second method to build the idea object and idea view, when a new page will be created to contain the idea. However, the sketch objects will be created after this method and the user will have to select these objects and open the idea map view to link the objects into the idea object and idea view. This has the following considerations:

1) When a user applies this method, the idea object and idea view are created from which a new page will be also created without any sketch objects from the working view of the new page.
2) The idea view can inherit ideas from other idea views. The user selects the current idea view by double tapping and the idea view will activate its yellow colour boundary.
3) From this, the user selects the 'Add' action or '+' on another idea view (see 3 in Figure 6.22). The relationship line will appear, and the sketch objects of the inherited idea view are created and embedded on a new layer of the page (see 4 in Figure 6.22).

In the fourth stage, the user sketches new objects (idea 2) on the working view of the new page, and then selects these objects (see 4 in Figure 6.22). Finally, the user opens the idea map view while these objects are selected. From this, the 'contain' control is marked to input the data of these objects into the idea view and idea object (see 5 in Figure 6.22).

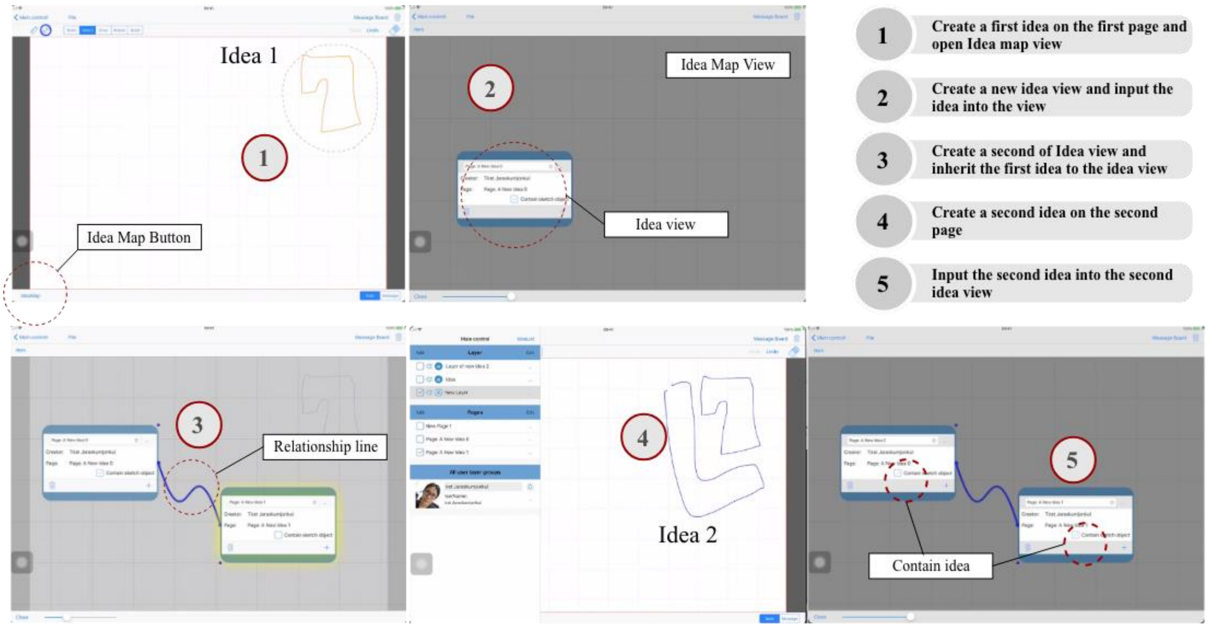


Figure 6.22 Create Idea and Link Ideas on the Idea Design Map (Source: Researcher's own)

6.5.4 Communication in a Project

Each page provides two types of communication, of which one is note and the other is discussion. Note is a one-way communication to address the objectives or show a text-like memo. In comparison, discussion is a two-way communication to support the sending and receiving of messages amongst users. Both can be applied more than once. However, two types of communication are addressed; the prototype provides a message board to communicate across pages in the same project. These are explained as follows:

1. **Note**: The user clicks the note button to open the note mode. A node object (rectangular) is created and dropped in the working view by using a finger touch and by holding on the screen (see 1 in Figure 6.23). The user can open or close the note view by using a finger touch and holding the note node (see 2 in Figure 6.23).
2. **Discussion**: After the user clicks the discussion button to open the discussion mode, a node object (circle) is dropped on the working view by using a finger touch and by holding on the screen (see 3 and 4 in Figure 6.23). A discussion view is opened or closed by using a finger touch and holding on the discussion note.
3. **Message board**: The message board view is opened and closed from the message board button, which is embedded at the top of the toolbar (see 5 in Figure 6.23).

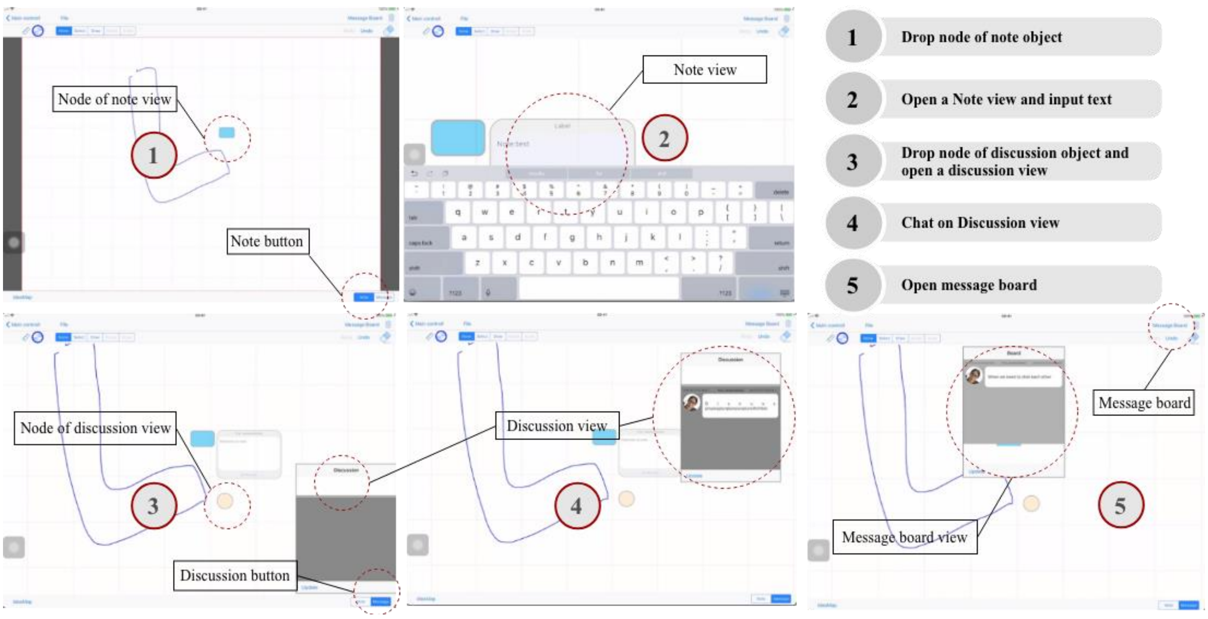


Figure 6.23 Note, Discussion, and Message Board
(Source: Researcher's own)

6.6 Summary

This chapter presented sections on the initiation, and the design and development of the digital prototype. In the initiation section, the software development approaches were explored; this aimed to provide an understanding of the different processes and approaches considered. An appropriate approach was chosen for adoption in this research and, significantly, the prototyping approach was chosen which was adapted for the prototype development lifecycle.

Next, the requirements specification was illustrated to describe the goal, requirement, constraints, and environment of the digital prototype of this research. This was based on the iOS operation system and an iPad Pro device. The requirements specification was used to create the concept design which included four parts: the collaborative sketch environment, collaborative communication, the idea design map and bimanual interaction. Both were designed to build the graphic user interface controls (GUI Controls) to support the designers to co-design and co-solve problems in the concept design stage of the AEC sector. These GUI controls were developed and the core data framework and CloudKit were adopted and integrated to support collaboration between designers. After the prototype development was complete, the prototype was evaluated, which is described in the next chapter.

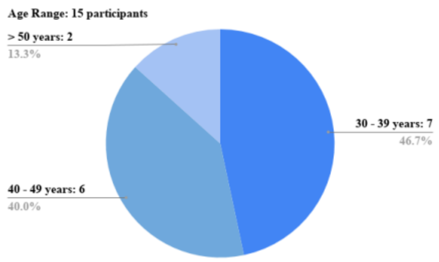
CHAPTER 7:
THE PROTOTYPE EVALUATION

7.1 Introduction

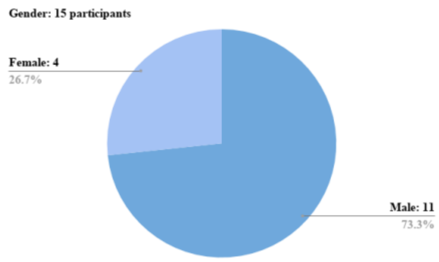
This chapter discusses the conduct of the evaluation case study research comprising the prototype evaluation and the usability data collected in terms from professionals in design practice. First, the chapter presents a profile of the participants who contributed to the prototype evaluation. It then discusses the data collection methods in terms of the usability, which consists of a performance measure, a System Usability Scale questionnaire, a focus group, and an interview. The performance measure is an analysis of participants' activities, which were recorded when they used the digital prototype to calculate the effectiveness and learnability values. The System Usability Scale was adopted to evaluate the digital prototype for usability issues or user satisfaction. The focus group was held to examine the digital prototype to identify participants' recommendations after its use. Finally, interviews were conducted to examine the prototype evaluation process in order to analyse its effectiveness.

7.2 Participants of the Prototype Evaluation

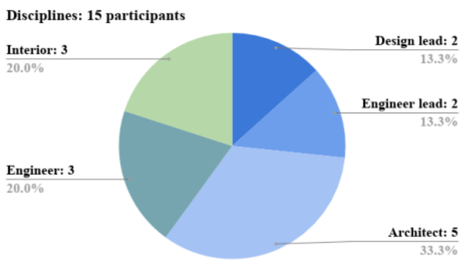
Thai professionals are involved in collaborative design in concept design. Information was gathered to identify the characteristics of the professionals who engaged in this prototype evaluation (see Figures 7.1).



1. Age range of participants



2. Gender of participants



3. Disciplines of participants

Figure 7.1. Participants Characteristics: Group Evaluation Phase
(Source: Researcher's own)

Participants consist of two design project leads, two engineering leads, five architects, three engineers, and three interior designers. In terms of their age ranges, two participants were older than 50 years of age, six participants were aged between 40 and 49 years, and seven participants were aged between 30 and 39 years. The prototype evaluation was conducted from 19 May 2018 to 16 June 2018 in Thailand. In total, 15 participants were grouped into five teams with each team comprising three participants. Each group came to a specific location for the testing and spent three to four hours involved in the group evaluation processes. In addition, five participants were interviewed over the following days.

7.3 The Prototype evaluation process

The process of prototype evaluation is a part of the case study evaluation. In this section, the usability test is described in detail from the introduction to the debriefing process and this structure is used to integrate the focus group. In addition, the six thinking hats technique is described, which focused on the application of the technique in the evaluation focus group. The case study evaluation was already addressed in the research methodology is described in detail in this section when the structure of the usability test is modified and integrated with the group collaboration task and the focus group. The prototype testing results are then illustrated in this section, including the interview results.

7.3.1 The Usability Test

When part of a software development cycle and following their complete development, software prototypes are tested, and their usefulness are evaluated. Determining usefulness is the goal of an evaluation and can be broken into two components, namely utility and usability (Grudin, 1992, cited in Nielsen, 1994). When the functionality of the prototype is able to do what is needed, this means the prototype has ‘Utility’. However, it is difficult to design and develop a prototype with sufficient ‘Usability’ to support users to easily apply the prototype and its functionality (Nielsen, 1994).

Usability involves multiple components and its five attributes form the criteria in a usability test; these are learnability, efficiency, memorability, errors, and satisfaction (Nielsen, 1994). These attributes form the criteria for measuring usability in this research, which are defined as follows:

1. Learnability: The system should be easy to learn so that the user can rapidly start getting some working done with the system;

2. Efficiency: The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible;
3. Memorability: The system should be easy to remember, so that the casual user is able to return to the system after a period of non- use, without having to learn everything all over again;
4. Errors: The system should have a low error rate, so that users make few errors, and, if they do make errors, they can easily recover from them. Furthermore, catastrophic errors must not occur;
5. Satisfaction: The system should be pleasant to use, so that individuals are subjectively satisfied when using it, namely they like it (Nielsen, 1994).

The evaluation uses both qualitative and quantitative (numeric) data in the usability testing. Quantitative data is measured from the number of tasks considered, the completed tasks of a participant, the time used for each task by the participant and expert user, and the questionnaire. Moreover, qualitative data can be collected from the subjective opinion of participants; this involves a questionnaire, an interview, and the direct observation of the user's action.

A usability test typically has four stages (McClelland, 1995; Nielsen, 1994), which are illustrated in Figure 7.2 and described as follows:

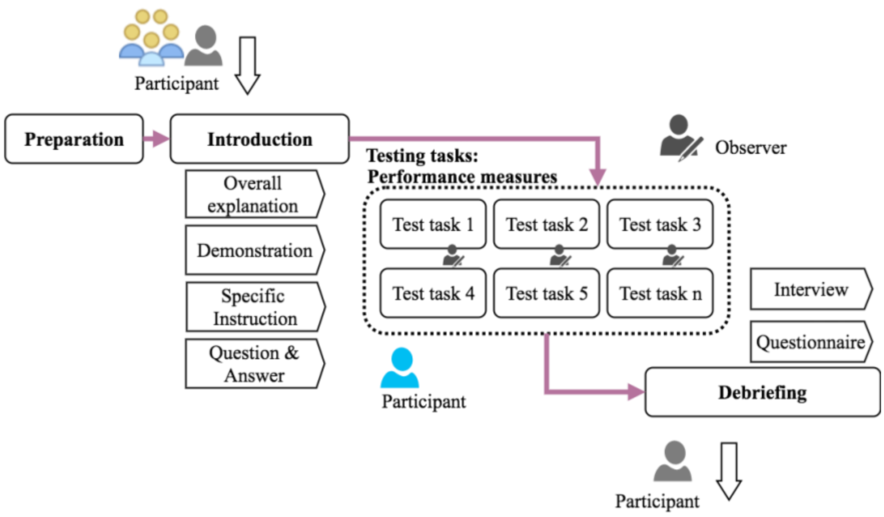


Figure 7.2 Process of a Usability Test (Summarised)
(Source: Nielsen, 1994)

1. **Preparation:** The experimenter should prepare the test room for the experiment. The equipment is placed in the room, such as a computer system, camera, microphone, and/or the electronic devices specified in the test plan. All test materials, instructions, and questionnaires should also be available.

2. **Introduction:** In the introduction process, relevant test information is briefed to participants regarding the test procedure, equipment, test place, and specific instructions. The prototype is demonstrated in detail, in terms of how to use it and/or a tutorial document should also be prepared. After that, the experimenter encourages participants to ask questions about using the prototype, and answers their questions to ensure participants understand.
3. **Testing tasks:** The use of the prototype is subdivided into tasks, which are planned for testing by the participants. These participants may be required to perform each task by thinking about what they need to know in the introduction to the study. Each task needs around 3-5 participants. Observers may be procured to record participant action in these tasks and to assist the participants in operating the interface in the case of problems.
4. **Debriefing:** After the test, the participant is debriefed and asked to complete any subjective satisfaction questionnaires and/or to attend an interview. During the debriefing, participants are also asked for any comments about the system and for any suggestions for improvement. Such suggestions may not always be improvements, and depend on the considerations of the designer and developer.

The methods are selected and used in the evaluation section to measure and observe participant actions. The aim of the evaluation is to ensure that the digital prototype that has been fully assessed by participants. The methods used to collect data from the user trials comprise the following categories:

1. Performance measures.
2. Questionnaires to collect data on attitudes.

7.3.2 The Six Thinking Hats Technique

An important element of the research objectives is the data collection from the group of professionals in terms of their 'recommendations'. This requires participants to generate ideas for a digital prototype for design team collaboration. A suitable method of data collection for groups of participants is a focus group, which is used to interview and generate a discussion amongst participants on a specific topic (Johannesson & Perjons, 2014). All information is captured from conversations, activities or movements in the discussion group, which is the main advantage of the method; it is also cost-effective and a relatively natural way to capture data through conversation. On other hand, a disadvantage lies in the risk that conflict can arise amongst the group, which is influenced by clashing ideas amongst strong members

(Johannesson & Perjons, 2014). In addition, the group method can be ineffective in the generation and evaluation of ideas (Schirr, 2012). Peterson and Lunsford (1998) pointed out that, for participants in the group, facts, emotions, and new ideas all flood in at once when they are confronted with a problem, which can leave them confused and tends to be amplified in a group. The group usually thinks at cross purposes to each other. Moreover, when confused, it can be difficult for individuals to think and explain their thoughts; it can be hard to explain ideas and harder to consciously articulate them to other people in the group (Peterson & Lunsford, 1998).

Parallel thinking assists a group to think along specific lines rather than at contrary purposes (Peterson & Lunsford, 1998). All participants of a group can think and make proposals in the same direction. De Bono (2016, p.53) states that:

> Parallel thinking simply means laying down ideas alongside each other. There is no clash, no dispute, no initial true/false judgment. There is instead a genuine exploration of the subject.

It allows all participants of a group to offer their ideas in parallel without discussion and argument about each of the ideas suggested. A popular method for parallel thinking is the 'Six thinking hats' technique (De Bono, 2017). The Six Thinking Hats consist of six directions and each direction is a chosen hat, which is symbolic of a particular thinking direction. It also functions as a reminder to participants to pay attention to the current direction. The six coloured hats are white, red, black, yellow, green, blue, which correspond to the six directions of thinking. De Bono (2017) summarises each colour and its relationship to its function as follows:

1. **White hat:** This deals with objective facts and figures in a neutral and objective way. It focuses on the data and information needed to ensure all participants have sufficient understanding of the objective information to create own schemata. In some cases, participants need to build their own map of ideas before the other thinking hats are considered. White hat types of questions include:
   - What information do we have?
   - What information do we need?
   - What information is missing?
   - What questions do we need to ask?
   - How are we going to get the information we need?

2. **Red hat:** This is based on feelings and intuitions, which give an emotional view and are not focused on having to qualify or justify. When the red hat is used, opinions are expressed as a feeling. For example, the red hat thinker could say:
    - They like/dislike, love/hate, are pleased/not pleased, are happy/unhappy.
    - This is how I feel about the matter.
3. **Black hat:** This concerns caution and care, which is developed from experience, logic, and judgment and notes the weaknesses or examines a topic and the feasibility of ideas. This also resonates with the focus of the white hat thinking. The hat needs participants to support their thinking with logic and reasoning. For example, typical black hat types of questions are:
    - What will happen if we take this action?
    - Will it be acceptable?
    - Do we have the resources to do it?
    - How will people react?
    - How will competitors react?
    - What can go wrong?
    - What are the potential problems?
    - Will it continue to be profitable?
    - Should we proceed with this suggestion?
    - What are the weaknesses that we need to overcome?
    - What may go wrong if we implement this suggestion?
4. **Yellow hat:** This is involved with constructive thinking, which covers hope and positive thinking. It concerns the benefits and value, and supports the process in logical and positive ways. Karadag, Saritas, and Erginer (2009) illustrate yellow hat types of questions, which are:
    - What is the best aspect of this?
    - What are its advantages?
    - Who can benefit from this?
    - How can these advantages be brought to light?
5. **Green hat:** This is focused on creativity and the generation of new ideas without judgment. This hat needs time and attention from participants to think more creatively. Karadag et al. (2009) offer some examples of green hat questions:
    - What are some new ideas on this ...?
    - What is interesting about this idea?

- What are the differences in these ideas?
- What is the effect of going forward with this idea?
- When this idea is compared with what I know, what will happen?

6. **Blue hat:** This is concerned with control, organisation, and the use of the other thinking hats in the process. Usually, the meeting facilitator wears the blue hat to manage the process and acts as a thinking coordinator. Typical blue hat questions include:
   - What should we do next?
   - What have we achieved so far?
   - What should we do to achieve more?

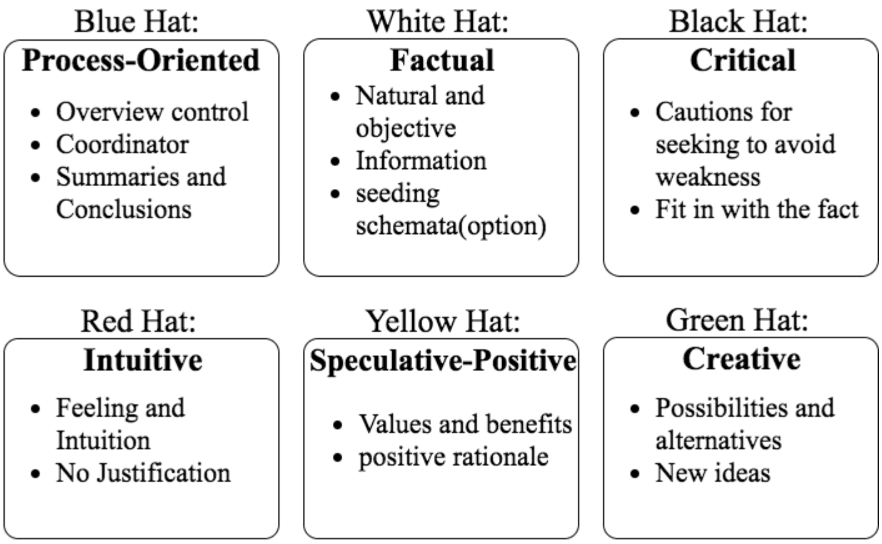


Figure 7.3 Six Thinking Hats (Summarised)
(Source: De Bono, 2017)

The six thinking hats aim to encourage all members to propose their ideas in a sequence that follows the classification of the hats, and is managed by the meeting facilitator who wears the blue hat. Its sequence is arranged in advance and typically adopts the following order: white (Factual), red (Intuitive), black (Critical), yellow (Speculative), and green (Creative). Some cases do not require the use of all hats; in such situations the sequence may be comprised of two, three, or more hats (Bono, 2017). Although individual interviews are the best way to collect data after a performance measure, this would consume time and mean that participants would be waiting around for their interview slot. Therefore, the groups adopted a group brainstorming technique to foster the generation of ideas amongst participants (Schirr, 2012).

In this evaluation, the focus group was the best choice of method and used the six thinking hats to encourage all participants to think in parallel ways after the performance measure steps of the prototype demonstration and the special tasks test. The white hat proposed neutral information and allowed participants to spend more time thinking individually or brainstorming to create their own schemata for the other hats. The sequence started from the white (Factual), then red (Intuitive), black (Critical), yellow (Speculative), and green (Creative) hats; the blue hat (process-oriented) oversaw this format.

7.3.3 Application of the Six Thinking Hats for the Evaluation Focus Group

In This process, the focus group is the final part of the group evaluation method in this process and uses the six thinking hats technique. This process operated in the same room as that used for the collaboration task in the group evaluation. Following the completion of the collaboration task and after a break, the room was arranged in tables for the focus groups. All participants for each focus group shared a meeting table so that they could see and communicate with each other and use the space on the table to note thoughts. All tables were prepared with recording instruments, such as paper, pencils, coloured pens, erasers, a projector, computer, and video camera. All coloured hats were made from coloured paper and distributed to all tables when the focus group meeting started.

The experimenter put on the blue hat and started the process by introducing and explaining the six thinking hats and the importance of involving all members of the group. Participants of the group are asked to put on or change their hat when the blue hat requested this. The use and arrangement of the thinking hats are described below:

White hat: The experimenter neutrally presented and briefed the group on the concept design and tools used in current design collaboration. The experimenter gave time for participants to consider what they had seen and their use of the digital prototype from the demonstration process and collaboration task. All participants were asked to brainstorm/consider how the prototype could be used for improvements in the design team collaboration in Thailand; this followed the themes of the other thinking hats. Then, they were also asked to map their ideas on paper; this activity took around 20 minutes.

Red hat: In the red hat activity, participants were asked to discuss how they had used the prototype for collaboration and communication. After that, the experimenter asked the group a question, which was:

- "How do you think you would feel if you used the current tools for colocation collaboration and delocation collaboration, and as a mixed process of colocation and delocation collaboration?"

- “How do you think you would feel if you used this prototype for concept design in design team collaboration?”

Black hat: In the black hat activity, the weaknesses of the current tools for design team collaboration were discussed including when these tools have been used in concept design. The group then discussed these weaknesses in relation to the prototype. Questions about this activity were raised in the group, which were:

- “What are problems in terms of collaboration and communication in concept design in Thailand (co-location/de-location/both co-location and de-location)?”
- “What are problems with current tools if your team works together, in the case of co-location/de-location/both co-location and de-location”
- “What are the weaknesses of the current tools for collaboration and communication that need to be addressed?”
- “For collaboration and communication in concept design, what are weaknesses of the prototype?”

Yellow hat: After the weaknesses were addressed under the black hat, the yellow hat activity considered the benefits and value, which were based on logical and positive thought. Questions asked of the group were:

- “What are would be the advantages if the prototype was used for design team collaboration in concept design or design?”
- “How could the advantages of using the prototype improve design team collaboration?”

Green hat: The green hat activity concerned creativity and new ideas, which were proposed in the group without bias. Questions adopted to guide the group discussion were:

- “What do you think of this prototype for AEC practice in general?”
- “How would you use this prototype to improve problems with design in practice?”
- “How could the prototype improve design team collaboration in concept design?”

Blue hat: The experimenter was the operator who donned the blue hat. The group was encouraged to conclude the results in this phase. The blue question was:

- “What are your recommendations for using this prototype to improve design team collaboration?”

7.3.4 The Case Study Evaluation

The case study evaluation was addressed in the research methodology, which described the sequential multi-phase approach that comprises a usability test, group evaluation, and process assessment. Nielsen (1994, 2012) described some evaluation testing methods of evaluation testing, which were chosen for integration in the case study evaluation; namely the performance measure and questionnaire. Moreover, the group evaluation consists of the collaboration task and focus group. Significantly, the six thinking hats technique was used in the focus groups for a group evaluation. These main procedures were arranged as illustrated in Figure 7.4 and described as follows:

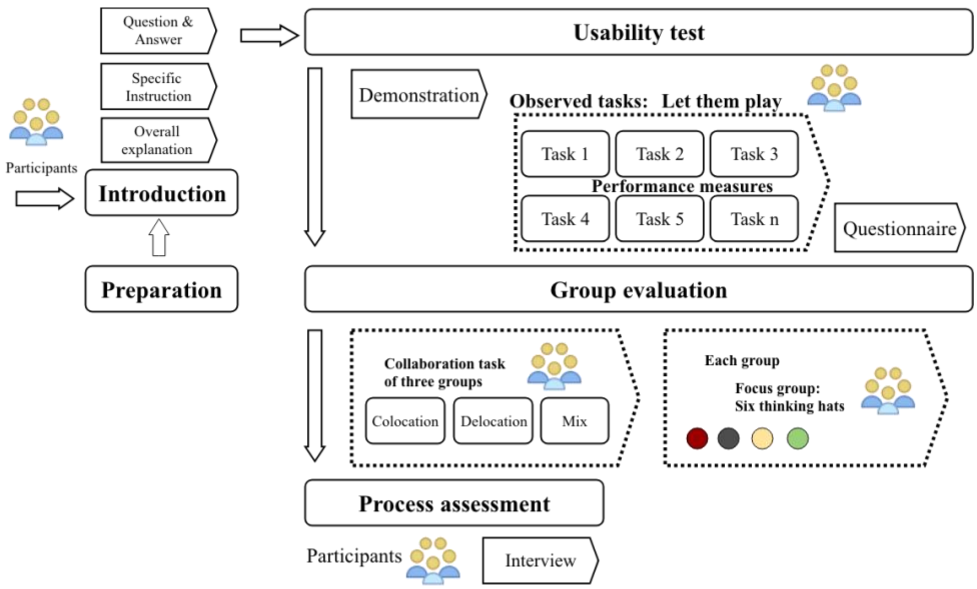


Figure 7.4 Case Study Evaluation
(Source: Researcher's own)

7.3.4.1 Preparation and Introduction

Initially, two steps were prepared to facilitate the process and participant groups. The first step involved the preparation that entailed the setting up and provision of devices; the second step was the introduction. These steps are detailed as follows:

1. Preparation: A test room was prepared for the case study evaluation process. The equipment was placed in the room, such as the electronic devices specified in the test (iPad Pro, and Apple pencil), projector, digital recorder, and internet system checked. All test material and questionnaires were prepared and checked to ensure that all devices were available and ready.
2. Introduction: Relevant information was briefed to participants in terms of the test procedure, equipment, test place, and specific instruction. After that, participants were

encouraged to ask questions to ensure they clearly understood the requirements to participate the process.

7.3.4.2 Usability Test

The usability test adapted in the case study evaluation comprised three sub procedures, which were: demonstration, 'Let them play' (performance measure), and a questionnaire. The prototype was divided into four main tasks (17 sub tasks), which were demonstrated, and each group was encouraged to experiment with the prototype in the 'Let them play' phase.

1. Demonstration: The prototype was prepared as a tutorial digital file, which was shown to all participants twice. The tutorial presented how to use each task in detail and/or provided a tutorial document. After that, all participants were encouraged to ask questions about using the prototype. The questions were answered or the activities demonstrated again to ensure understanding.
2. Let them play: The experimenter encouraged each group of participants to 'play with each other' from the first to the final task. They were required to put on a small camera to record all activities while they played with the prototype and this helped to measure their performances. All activities were recorded for observation in the test room.
3. Questionnaire: All participants were required to complete the Software Usability Scale (SUS) questionnaire.

7.3.4.3 Group Evaluation

The group evaluation method comprised two sub parts. The first was the collaboration task that supported participants to use the prototype to work together, and the second was the focus group that collected the recommendations after completing the collaboration task.

1. **Collaboration task:** Three sub tasks were provided for the participant groups; co-location, de-location, and a mixture of both. Each group was required to do a small amount of work in each of the sub tasks. These sub tasks were: 1) Co-location, which allowed all participants in the group to work together at the same table; 2) Delocation, which allowed participants to work together but all members were in separate rooms/areas/tables; 3) The mixture allowed some participants to work together while other participants were in a separate room/area/table and to collaborated with others.
2. **Focus group:** Each group was organised to run in parallel following the discussion theme. It used the six thinking hats technique where the experimenter wore the blue hat, and all other members were requested to adopt or change the hat colour following

the directions of the blue hat (experimenter). Firstly, the experimenter introduced information about, and the objectives of, the focus group and described the thinking hats technique. Next, the white hat phase required all members to individually brainstorm to generate ideas in terms of the keywords or questions for the other coloured hats. Following this, the other coloured hats were processed. These also considered the aforementioned objectives and questions.

7.3.4.4 Process Assessment

After the completion of the group evaluation was complete, five participants from the full group were asked for an interview in accordance with the case study evaluation process. These participants were interviewed face-to-face over the following days.

7.4 Prototype Testing

The prototype testing started after the demonstration finished. All participants from each group tested the prototype from the observed tasks or through the 'Let them play' phase when they were encouraged to use the prototype. Their activities were recorded while they were playing with the prototype in the demonstration. The recorded activities were used to measure their performances. In addition, they were asked to complete the SUS Questionnaire.

7.4.1 Performance Measure

There were four main tasks comprising the performance measure, which were; initial functions, objects and modification, idea management, and communication. These consisted of 17 sub-task functions (listed in Table 7.1). All participants from each group watched the tutorial presentation and listened to the tutor or experimenter who explained how to use the prototype. Then, the experimenter encouraged them to play with the software two to three times for each sub-task.

Using the prepared devices, each group accomplished all sub-tasks of the four main tasks using the prepared devices. All activities recorded in the evaluation process were measured to compare the actual completion time with the time allowed, which was defined in this evaluation. The actual time of the completed task needs to be less than the allowed time for the task completion so that only valid tasks are counted. The average results of the tasks demonstrated that they were achieved within the allowed time, and are listed in Table 7.1 and Figure 7.5. The first task was completed in 2.75 tasks or 91.67%. Next, the second task was completed in 5.75 tasks or 95.83%. For the third task, participants achieved 2.67 tasks or 88.89%. In addition, the fourth task was completed in 4.17 tasks or 83.33%.

Table 7.1 Tasks of Function Group in Performance Measure

Main task	Function group	Sub-task	All tasks	Average tasks completed on limited time from 12 participants
1st Task	Initial functions	Create project	3	2.75
		Create page		
		Create layer		
2nd Task	Objects and modify	Sketch	6	5.75
		Color		
		Select object		
		Move object		
		Rotate object		
		Scale object		
3rd Task	Idea management	Idea map	3	2.67
		Create idea node		
		Link idea node		
4th Task	Communication	Node of note	5	4.17
		Note detail		
		Discussion node		
		Discussion		
		Message board		

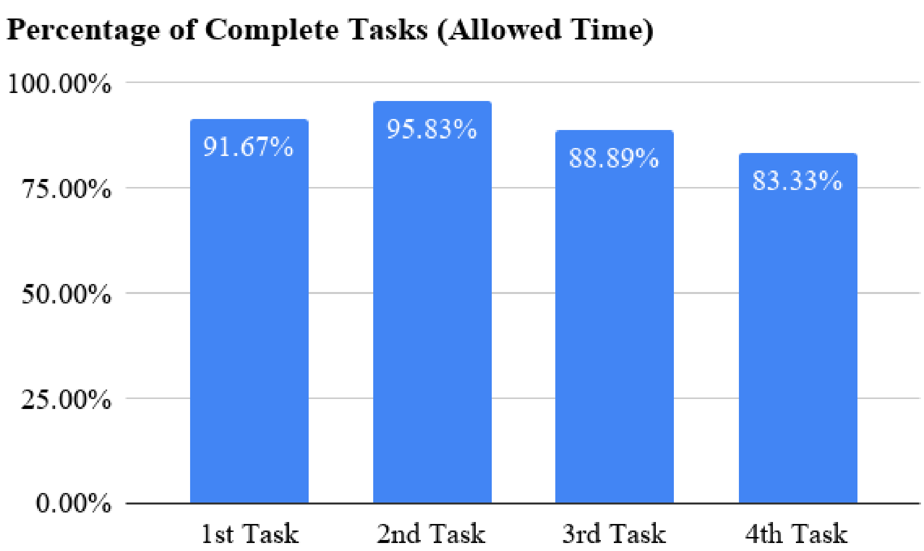


Figure 7.5 Percentage of Complete Tasks (Allowed Time)
(Source: Research's own)

All participants completed all tasks, thus 100% was achieved. However, there were different participant frequencies within the time limit (see Figure 7.6). Two participants completed all tasks or 100% within the allowed time. Three participants completed 94.12 % of all tasks and six participants were able to finish 88.24 % of all tasks. Only one participant finished 70.59% of all tasks within the allowed time.

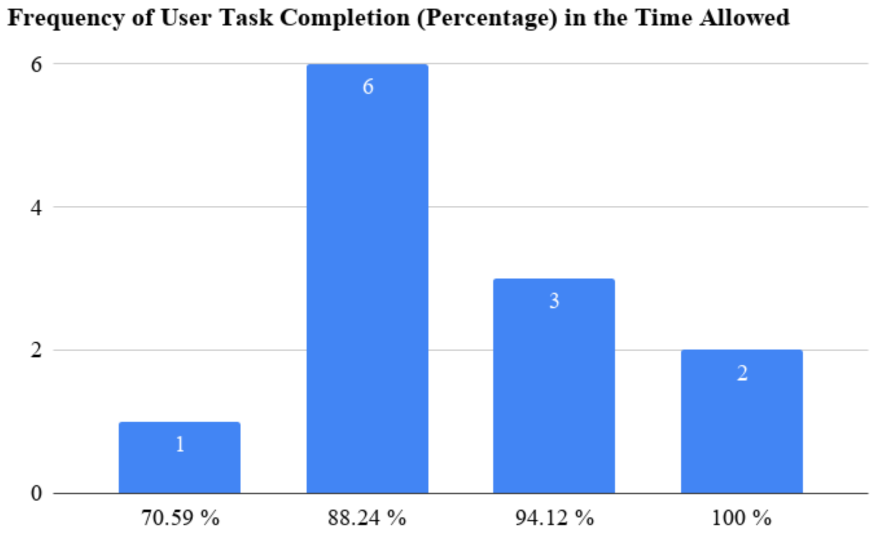


Figure 7.6 Frequency of Users' Completion (Percentage) in the Time Allowed (Source: Researcher's own)

According to the performance measure above, 15.33% tasks were completed within the time limit and all performance measure (17) subtasks were calculated to determine the effectiveness and learnability values (see Table 7.2). The effectiveness value identifies how the prototype is used; for this digital prototype, the effectiveness was **0.90**. In addition, participants could easily learn to use the prototype and move from a beginner to an expert level in a short time. Therefore, the prototype does not demonstrate a high learning curve. This measures 1) the time taken by participants and the effectiveness value, and 2) the time taken by expert and the effectiveness of experts. Thus, the learnability value was **79.97**.

Table 7.2 The Effectiveness and Learnability of the Prototype

Measure value			
Total of subtasks:	17	Average of completed tasks within the time limit for all participants:	15.33
Expert time:	28	Time average of all participants:	31.35
Effectiveness:	**0.90**		
Time tasks of experts	0.029	Time tasks of participants: 0.036	
Learnability:	**79.97**		
Errors: (times)	Can be recovered when the prototype was started. In addition, WIFI signal problems occurred.		

7.4.2 Result of the Software Usability Scale (SUS) Questionnaire

The Software Usability Scale (SUS) score is a summary of ten items, which range from 0 to 4 or 1 to 5. Items 1, 3, 5, 7, and 9 are positive scores which are represented on the scale position at minus 1. If the positive score is at a higher level, the SUS score is higher. The other items 2, 4, 6, 8, and 10, are negative scores, which are subtracted from 5. If the negative score is at a high level, the SUS score reduces. Twenty participants completed the SUS questionnaire after the observed task; this collected the scores concerning their opinions in terms of the prototype usability (see Table 7.3 and Figure 7.7).

For the second, fourth, and sixth items, participants understood that the process for using the prototype was unnecessarily complex, scoring at around 1.83 on average or 20.83%, and inconsistently around 2.0 as an average score or 25%. The results indicated that participants did not need to be supported by technical employees and they could use this system without technical issues. Moreover, for the eighth and tenth items, the digital prototype system was found to be complex at around 2.08 as an average score or 27.98%. Participants had to learn 17 sub-tasks in part of the demonstration and the tenth item was given an average score of 4.17 or 79.17%. However, this does not indicate that the participant was obstructed in using the tool, as participants were required to frequently use the prototype, and, according to the first and third items, it was easy to use.

For the first and ninth items, participants needed to frequently use the digital prototype and to feel positive and confident in doing so. Both items received the same average score at around 4.25 or 81.25%. Meanwhile, the third and seventh items saw participants agree that the prototype would be easy to use in their practice and that most people could learn to use the prototype very quickly. Both items had the same average score at around 4.25 or 81.25%. Finally, for the fifth item, participants indicated that there was inconsistency in the prototype; however they confirmed that the variety of functions in the prototype were well integrated at around 4.17 and an average score or 79.17%. Overall, the Software Usability Scale (SUS) was 75.21, and the value of the SUS illustrates that this prototype was acceptable.

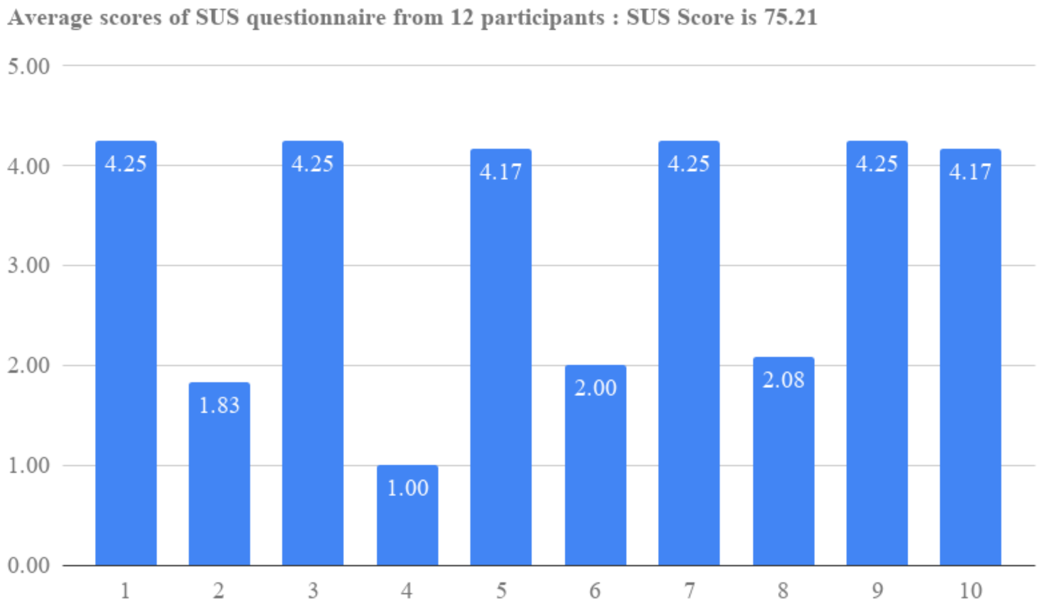


Figure 7.7 Average scores of the SUS questionnaire (from 12 participants)

Table 7.3 Percentage of the SUS average scores

No.	SUS questionnaire from 12 participants	Average Score:	Percentage:
1.	Participants thought they would like to use this system frequently.	4.25	81.25%
2.	Participants found the system unnecessarily complex	1.83	20.83%
3.	Participants thought the system was easy to use	4.25	81.25%
4.	Participants thought that they would need the support of a technical person to be able to use this system	1	0.00%
5.	Participants found the various functions in this system were well integrated	4.17	79.17%
6.	Participants thought there was too much inconsistency in this system	2.0	25.00%
7.	Participants imagined that most people would learn to use this system very quickly	4.25	81.25%
8.	Participants found the system very cumbersome to use	2.08	27.08%
9.	Participants felt very confident using the system	4.25	81.25%
10.	Participants needed to learn a lot of things before they could get going with this system	4.17	79.17%
	SUS score is:	**75.21**	• <50: Not acceptable • 50–70: Marginal • >70: Acceptable

The prototype was tested and observed by 12 participants; the results revealed that its effectiveness was 0.90 and its learnability was 79.97. In addition, the usability of this prototype was assessed through the Software Usability Scale score as 75.21. The various functions in the prototype included the spaces for collaborative design, idea management, and communication, which were all well-integrated. The digital prototype was easy to use and sufficiently quick to learn for collaborative design. Participants confirmed that they were confident to use the prototype, which would be required for use within collaborative design in concept design.

7.5 The Results of Focus Group in Group Evaluation

In a collaborative workshop, all participants from each group completed the collaboration task by using the digital prototype; the aim of this was to understand how to apply the prototype. This was addressed after learning and individually testing it within the ‘let them play’ phase. After completing the collaboration task, all participants gathered around the same table to brainstorm and collect their ideas in a focus group through the six thinking hats technique. This technique was used to collect data in the focus group through four themes, which were: the Red hat, Back hat, Yellow hat, and Green hat. For the focus group, there were five groups and fifteen participants.

7.5.1 The Red Hat

The red hat theme focused on feeling, when participants were encouraged to discuss the tools they used in collaboration and how they feel about them. After they had used the prototype, they responded in terms of their feelings about the using the prototype (see Tables 7.4 and 7.5). Participants were also asked about their feelings in using current tools for collaboration (see Table 7.4). Participants use both analogue and digital tools in concept design, such as sketch, AutoCAD, SketchUp, Revit or ArchiCAD, and used file sharing in their collaborations. For communication, they used email, telephone, SMS, and social media apps, such as Line, Whats App, Skype, or Facebook. In terms of the collaboration tools, participants need to work with each other by using the same technique and tool. BIM tools, such as Revit or ArchiCAD, are still too complicated for concept design. Currently, they felt that digital tools do not sufficiently support collaboration, and sometimes, file sharing is not convenient, too slow, and becomes a problem when using different versions and platforms. In addition, these tools cannot support immediate collaboration, such as meetings or working around the same table or in different places. However, they felt that communication tools were good when used in basic collaboration, although difficult for complex collaboration.

Table 7.4 RQ1 Summary of the Responses in the Red Hat Theme

RQ1: "How do you think you would feel if you used the current tools for collaboration?"	
No.	Participants' responses
RQ1.1.	Current tools used in collaboration are: hand sketch, AutoCAD, SketchUp, BIM tools, Line, Whats App, Skype, and Facebook
RQ1.2.	Communication tools are good for basic exchanges, but difficult for collaborative work. R.1.1.SP13
RQ1.3.	The BIM system is complicated. It poses obstacles for concept design. R.1.2.SP04
RQ1.4.	Digital tools are complicated and time is wasted reworking the same drawing sent from other teams. R.1.2.SP06
RQ1.5.	These digital tools are too slow to be used in collaboration with file sharing. R.1.3.SP07
RQ1.6.	These digital tools do not support the collaboration team enough because they cannot immediately respond. R.1.3.SP02
RQ1.7.	These digital tools do not support the immediate sharing of ideas in a collaborative design team. R.1.4.SP04
RQ1.8.	Digital tools cannot support work when we have to work in different places. R.1.5.SP10
RQ1.9.	Sketch is intuitive and fast. R.1.2.SP05

In terms of the digital prototype, participants were asked how they felt after they finished the group testing process (see Table 7.5). Participants felt that the digital prototype could help all relevant professionals and/or experts to work together, both in the same or in different places, as if it provided a large whiteboard that everyone could easily sketch on, post/chat, or otherwise engage though the internet. The message function still needed to be used for communication, although they were working together around the same table. One participant explained that:

> *When we work in the same place, we need to use a message function. Sometimes, two people discuss but another doesn't know. I want everyone in the team to know the same thing*. P.2.5.SP12

Table 7.5 RQ2 summary of the responses in the Red hat theme

RQ2: "How do you think you would feel if you use this prototype for concept design in design team collaboration?"	
No.	Participants' responses
RQ2.1.	The digital prototype is a new one which can enhance all designers to work together at the same time. It can help to brainstorm on a whiteboard that all participants can work on R.1.2.SP13
RQ2.2.	I think it reduces the distance between designer/architecture groups who are in different locations. R.2.2.SP05
RQ2.3.	I think using the prototype is fun and can help communication with others. It can assist the design team to see problems at the beginning. R.2.2.SP04
RQ2.4.	I think the idea map of the prototype is useful in managing designers' ideas. R.2.2.SP06
RQ2.5.	We think that the prototype is faster for collaboration and exciting. It encourages us to have a greater feeling of teamwork. R.2.3.SP09, SP08
RQ2.6.	The prototype is nice and useful. It can help designers to share and update work in both delocation and colocation, as if they work on the same board. R.2.4.SP04
RQ2.7.	The prototype is great and easy to use. It can help in sharing opinions, communicating with each other, and collaborating both in the same and at difference locations. P.2.5.SP10, SP11, SP12
RQ2.8.	I think that the message function of the prototype is still important, although we work in the same place. P.2.5.SP12

7.5.2 The Black Hat

The black hat theme focuses on experience, logical thinking, reason, or criticism. Participants were encouraged to discuss the problems for concept design when using both current tools and the prototype for this study (see Tables 7.6, 7.7, 7.8, and 7.9). Collaborative design is not easy and in Thailand, relevant professionals and/or experts face many problems, such as physical issues, a lack of collaboration and communication, or misunderstanding and misinterpretation (see Table 7.6). Table 7.6 BQ1 Summary of the Responses in Black Hat Theme

BQ1: "What are problems in terms of collaboration and communication for concept design in Thailand?"	
No.	Participants' responses
BQ1.1.	While members of design teams are meeting or working together in the same place (colocation), all information cannot be recorded, and some records disappear or are

BQ1: "What are problems in terms of collaboration and communication for concept design in Thailand?"	
No.	Participants' responses
	lost. When working in different workplaces (delocation), words are not enough to visualise a picture, and are easy to misunderstand. B.1.2.SP06
BQ1.2.	Misunderstanding and misinterpretation are problems in collaboration and communication. B.1.3.SP07
BQ1.3.	The lack of collaboration and communication are problems that designers face when working alone without collaboration after finishing a meeting. They need other hands to solve problems, as, when there is a mistake on their design it is too late. B.1.4.SP03, SP04
BQ1.4.	Current communication and collaboration tools present problems in collaborative design. B.1.5.SP12, SP10

In concept design, there are problems when designers have to use many tools whether analogue or digital (see Table 7.7). For digital tools, crossing versions and platforms poses problems for collaboration, which requires the use of file sharing. A typical analogue tool is Sketch; although Sketch is generally admired for its use in design, participants raised the issue of loss and that it is difficult to retrieve what they have sketched.

In terms of communication tools, participants stated that basic communication is not a problem, but complex collaboration and communication are difficult to achieve with the current communication tools. The work and conversation contents are not the same, and it is difficult to fully explain a picture through just words. One participant stated that:

> *For the communication part, recently tools have become quick enough. Line, Whats App, or other applications can respond to most communication types. It is difficult to work together in communication. Most share the information and ideas as a reply and comment to that information. It is good to use the tool in basic communication, but it is not ready now. There are no programs that work like a sketch on paper* R.1.1.SP13

Table 7.7 BQ2 Summary of the Responses in the Black Hat Theme

BQ2: "What are problems with current tools when your team works together in concept design?"	
No.	Participants' responses
BQ2.1.	Designers use a variety tools in design. The problem with current tools is that digital tools cannot cross the version and platform. B.2.1.SP13, SP15, SP14

BQ2: "What are problems with current tools when your team works together in concept design?"	
No.	Participants' responses
BQ2.2.	Digital tools are being used in design processes based on the computer desktop. It is difficult to work together in meetings or collaborative design in the same place (colocation). B.2.2.SP04
BQ2.3.	Analogue tools or sketching on paper or other surfaces can mean loss or difficulties in finding the work. B.2.2.SP05
BQ2.4.	Some tools cannot support collaborative design. This is because they are designed and developed to be standalone systems, such as Sketch Up. These tools cannot support collaboration in the same place or table. Designers have to adapt to send files through email, a thumb drive, or Cloud storage. Sometimes, designers call to work together, which it is not efficient. B.2.2.SP05, B.2.5.SP10
BQ2.5.	For problems with file sharing in collaboration, there are problems with different versions and in improving/updating files. File sharing is a problem because collaborators have to send/update back and forth, which wastes time. B.2.3.SP08
BQ2.6.	Communication tools, such as Line, Whats App and Facebook, are used for just basic communication; this could not be used for our design because it is hard to explain pictures. We do not have an appropriate tool for communication and collaboration. B.2.4.SP04

In terms of the communication tool, participants were asked what they wanted to improve in the tool (see Table 7.8). They suggested that a new tool for communication should be developed to support collaboration and communication. In the design process, they need to pack both work contents and conversations in the same file.

Table 7.8 BQ3 Summary of the Responses in Black Hat Theme

BQ3: "What are the weak points of the tools to used recently in communication and team working recently that you want to solve or improve?"	
No.	Participants' responses
BQ3.1.	There are too many emails and 50-60 messages from Line, which are difficult to manage. It is too much. Designers need tools for communication to work within Line or email. B.3.2.SP05
BQ3.2.	Design problems are difficult to describe/explain with words and without pictures. Sometimes, designers have to explain visuals many times to others so that they can 'be on the same page'. Designers need to tools that can communicate both pictures and contents, and interact with each other. B.3.3.SP08, SP07, B.3.4.SP04

For the digital prototype, participants discussed how to improve the prototype for the next version (see Table 7.9). A significant issue concerning development is that the prototype has to remain easy to use. The first version required improvements in terms of its graphic user interface, its picture insertion, and its capability for use without the Internet.

Table 7.9 BQ4 Summary of The Responses in Black Hat Theme

BQ4: "What are the weak points of the prototype for communication and collaboration which you want to improve?"	
No.	Participants' responses
BQ4.1.	The prototype could be developed to import pictures or pdfs. B.4.1.SP14, B.4.3.SP08, B.4.5.SP10
BQ4.2.	The main control could use colour to group information, layers and pages so that user can recognise them easily. B.4.1.SP14
BQ4.3.	We need to have a grid scale function that can modify its distance. B.4.1.SP04
BQ4.4.	The idea map should show how these ideas are different. It may use colour or whatever. B.4.3.SP07
BQ4.5.	Buttons should be easy to use symbols to communicate with users. B.4.4.SP04
BQ4.6.	Other participants' sketches should look different so that the owner's device will not confuse the sketches. B.4.4.SP04
BQ4.7.	A designer needs to know where the page is being worked on. B.4.4.SP03
BQ4.9.	The prototype should have the capability to support a designer as a standalone without WIFI. B.4.5.SP10
BQ4.10	This prototype does not need to connect with AutoCAD or BIM systems, because the user interface becomes too complex. This should keep its easiness. "*Sketching is easy and not complex, but in design practice, it will be complex at some points, or use grids. I told you that the file can be imported as a jpg or a pdf. Even if we can take CAD in, it will be another user interface that will mean the user interface will be not the same interface as that tested today. Providing that we open CAD, the user interface will change. There will be many commands and it will become difficult for the prototype. It needs to keep its easiness.*" BL.3.3SP07

7.5.3 The Yellow Hat

The yellow hat concerns with the benefits and value, which are based on logical and positive thought and considered after focusing on the weaknesses in the black hat theme. This hat will therefore identifying the advantages (see Tables 7.10 and 7.11). The advantages of using this digital prototype in the team design process were discussed in the focus group (see Table 7.10). Participants stated that the prototype would help them to work together on the same platform from the beginning to the end of the design process. Working on the same collaborative space could reduce the complexity of collaborative design; this would enhance capacities for problem-solving and enable opportunities to learn together.

In addition, a collaborative design system, such as this prototype, could better help designers to work together than linear working systems. This prototype could adjust the activities of relevant designers in the design process. A participant supported that:

> *I think it has the advantages of working and updating the work, but I look at what it will be next except the architect and engineer. It will include other systems, like a document system or working as a connected (not standalone) system, a linear working system, a 1 to 2 to 3 to 4 to 5 working system, or a working system that may not sit together. It can adjust the work system. I think this is good to develop further in collaborative design.* Y.1.4.SP02

Table 7.10 YQ1 Summary of the Responses in the Yellow Hat Theme

YQ1: "What are the advantages of this prototype when it will be used in the team design process?"	
No.	Participants' responses
YQ1.1.	The prototype can help designers to work together on the same platform. They can see whatever is shared. Y.1.1.SP15, SP13
YQ1.2.	All designers can be encouraged to work since the beginning. Some problems can be solved at the beginning, and will be better if the designers can fix these first. Y.1.1.SP15, SP13, Y.1.2.SP04, Y.1.3.SP09
YQ1.3.	The prototype can be used to collect designers' ideas in the same place. As a result, these ideas will be concluded together. Y.1.2.SP06, SP05
YQ1.4.	The prototype can help relevant everyone to follow/stick to the process. Y.1.2.P33, SP05
YQ1.5.	The prototype encourages designers to work together and meet, both in the same and in different places. Y.1.2.SP05, Y.1.3.SP09, Y.1.5.SP12
YQ1.6.	The prototype will reduce the complexity of the collaborative design process to send or update the design information back and forth. It is time saving and reduces redundancy. Y.1.3.SP08, SP07

YQ1: “What are the advantages of this prototype when it will be used in the team design process?”	
No.	Participants’ responses
YQ1.7.	Designers can feed all their ideas into the prototype, such as sketching ideas or a message containing ideas. Y.1.3.SP08
YQ1.8.	The prototype will gather all designers to the work, which can reduce the problem of work overlaps and save time. Y.1.3.SP08, SP07
YQ1.9.	The prototype will enhance the collaborative thinking process, which will not be a linear process. Team members can learn together from the problems that occur during the collaborative design process. Y.1.3.SP08, SP07, Y.1.4.SP02
YQ1.10.	Its advantage leads to adjustments to the design method. Y.1.4.SP02, SP07, R.2.1.SP13
YQ1.11.	For working on colocation, Note and chat can be used to communicate within the design team so that everyone can understand and also record the contents of the communication. Y.1.5.SP12

Besides the advantages of using the prototype, it can help to address problems in collaborative work (see Table 7.11). The character of the tool, which connects all relevant professionals with the same tool and repository tool for design ideas and communication, can overcome barriers to collaboration and communication. The prototype can reduce meetings, the time required, and the energy from the physical barriers to collaboration among relevant professionals and/or experts. One participant explained that:

> *This prototype reduces the time to travel in Bangkok by at least 2-3 hours. Let’s think of that 2-3 hours as cost; we can save a lot, including our energy. When we’re back at the office, we do nothing because of exhaustion.* BL.2.1.SP05

Table 7.11 YQ2 Summary of the Responses in Yellow Hat Theme

YQ2: “How can the advantages of this prototype improve team working?	
No.	Participants’ responses
YQ2.1.	The prototype can support relevant professionals and/or experts to work together in the same and different places leading to savings in time and expense. Y.2.1.SP14
YQ2.2.	The prototype is a repository of communication and design ideas. Y.2.1.SP14, Y.2.4.SP02
YQ2.3.	The prototype can improve the design team by reducing the problems with complex collaborative processes, time-consumption, and delays in decision-making. Y.2.3.SP08

YQ2: "How can the advantages of this prototype improve team working?	
No.	Participants' responses
YQ2.4.	Designers can use the prototype to reduce iteration in current collaborative design. Relevant professionals can be connected to work together with the same prototype from the beginning. Y.2.2.SP04, SP05

7.5.4 The Green Hat

The green hat theme focuses on new ideas/innovation, when participants were encouraged to discuss how the prototype could be applied (see Tables 7.12, 7.13, and 7.14). Participants thought that the digital prototype could be used in some parts of the AEC industry, such as education and collaboration, among relevant professionals and/or experts (see Table 7.12). Education is important when the prototype becomes an instrument for AEC schools. An experienced participant who was invited to lecture in such a school explained that:

> *As teaching in a design workshop, it works well. I was invited to talk about this once. They didn't understand much but they had to do a project after that taught by themselves. They didn't want to disturb me. But this one I can explain to the students. It's a saving of resources of time, energy, and cost. I don't have to fly to teach them a design workshop in their studio. I don't have to be in a same place to explain. It's good for teaching too*. G.1.3.SP07

One participant suggested that the prototype could be used by students in education:

> *It can be used with various careers, including students working in a concept and schematic design studio. The students will find this convenient. They have a communication tool. They would enjoy working more. Compared with me, when I was a student. I didn't have anything like this. I had to carry around all my equipment, which was cumbersome. This one is convenient, and every profession can use this to present their ideas*. BL.3.2.SP08

Furthermore, the digital prototype could be a widely used tool for brainstorming, collaborative design, and communication.

Table 7.12 GQ1 Summary of the Responses in the Green Hat Theme

GQ1: "How would you introduce this prototype for use in Architecture, Engineering, and Construction Professional Practice?"	
No.	Participants' responses
GQ1.1.	This prototype could be used for education, which all design students use for recommendations from professionals and experts. G.1.1.SP13, G.1.3.SP07

GQ1: "How would you introduce this prototype for use in Architecture, Engineering, and Construction Professional Practice?"	
No.	Participants' responses
GQ1.2.	The prototype could be adapted for use in any project to brainstorm with all collaborators and catch up on their ideas. G.1.2.SP06
GQ1.3.	The prototype could be used in collaborative design processes or from concept design to construction. G.1.3.SP08, SP04, SP07, G.1.4.SP03, G.1.5.SP12,SP10
GQ1.4.	This prototype could be used as a communication tool for design; for example, it could be used to urgently identify a conclusion. G.1.4.SP02, G.1.4.SP04

In professional practice, the digital prototype could be used in the design process (see Table 7.13). The management of a design project, from concept to construction, requires a repository and design management tool for the collaborative design team. This prototype could be used to co-design, communicate, provide a repository, and function as a large whiteboard for professionals.

Table 7.13 GQ2 Summary of the Responses in the Green Hat Theme

GQ2: "How could you use this prototype to improve the problems of design in practice?"	
No.	Participants' responses
GQ2.1.	This prototype could be used in managing a design project from concept design to the construction phase. It could become a repository and design management tool for the design team. All ideas and information content including communication in the design process could be collected and managed in this prototype. G.2.1.SP13
GQ2.2.	The design process could have two parts; individual and co-working. This tool could be used to solve problems associated with collaboration in order to support collaborative design both for the individual and co-working parties. For co-working, this could function as a design management tool that collects all information, such as the contents of communication and design ideas or problem solving. G.2.1.SP13
GQ2.3.	The prototype could record all contents in collaboration, such as ideas, sketches, and the content of communication. This becomes important evidence. G.2.2.SP06
GQ2.4.	The current problem lies with less communication while the designer works on individual parts. This prototype would help to review and solve this problem from the beginning to the end of the process. G.2.2.SP05
GQ2.5.	In the construction phase, there are many problems. Therefore, this prototype could enable collaboration and the recording of all content, such as ideas, chat, or

GQ2: "How could you use this prototype to improve the problems of design in practice?"	
No.	Participants' responses
	discussion. Users do not need to write memos, documents, or edit drawings. "It is less chaotic." G.2.2.SP04, G.2.4.SP12
GQ2.6.	The prototype could be used to solve the problems of collaboration experienced at every step. This prototype could be used as a collaborative tool in brainstorming among relevant professionals or members. It could be used to undertake programming together such as with an architect, engineer, or interior. G.2.2.SP07, SP13 All relevant persons could use this to work together and discuss including the owner, interior designer, and architect: "We can talk to each other. I want the owner, and interior designer to use this together because it has a tool for discussion". BL.5.3.SP10
GQ2.7.	In collaboration, all designers struggle to sketch or write in the same place. Therefore, this prototype could be used to work together on colocation. It could be a whiteboard to connect all involved who could easily leave comments or work together. G.2.4.SP03

Thus, the prototype would be an important tool for a collaborative design team in concept design (see Table 7.14). The contents of work and communication (text or words) could be packed in the same format, which increases the efficiency of the collaboration and communication. In addition, design ideas could be stored in the tool with the idea map feature, which helps to manage the design ideas of the collaborative design team.

Table 7.14 GQ3 Summary of the Responses in Green Hat Theme

GQ3: "How could the prototype improve design team collaboration in concept design?"	
No.	Participants' responses
GQ3.1.	The problem with different versions or formats could be solved by using this prototype and connecting with each other. It uses an import picture or pdf function and enables easy communication. G.3.1.SP13
GQ3.2.	The prototype is the central repository of all information so all designers can work together. For example, the tool can connect and work with my team who is in a different place while I am in a meeting. G.3.1.SP15
GQ3.3.	During work, this prototype records all the time, like we are discussing the front-line work, we're sketching… it's like taking a minute of front-line work to show the process. Which steps are mistaken and who did it? Did anyone protest? Is this what they really want? It could be kept as evidence as to who did it. G.3.1. SP06, SP04

GQ3: "How could the prototype improve design team collaboration in concept design?"	
No.	Participants' responses
GQ3.4.	This prototype could help to manage all the ideas from all designers, with a map of ideas. G.3.3.SP08
GQ3.5.	This prototype could help to solve collaboration problems to connect all multidisciplinary teams. The systematic process is not linear anymore, but the tool will support this as a collaborative design process. G.3.3.SP02, SP03, SP01 Nowadays, the works are divided into parts and the engineer is always in the last part. With this prototype, all designers could be combined. G.3.5.SP12

According to all themes, using a variety of tools in concept design usually means that different platforms and versions present issues for file sharing within collaborative design. The characteristic of a large whiteboard could help participants to respond in a positive way and encourage them to work together with the same tool. In addition, the tool responds to their needs in terms of working at the same and in different places. This is a characteristic they admire within this tool.

For communication in collaboration, leaving notes in a collaborative space and using the chat function can combine the contents of communication and objects which will support users' information retrieval. This feature is accepted as easy to understand and can support the building of knowledge. This characteristic of the digital prototype can be used in several ways, such as brainstorming, collaborative design, education, or as a repository of communication and collaboration. It can increase the efficiency of design project management, which can gather professionals to collaborate using the same tool to develop a concept design idea before they develop a concrete design. Moreover, the tool can increase the efficiency of the collaborative design system to encourage all relevant professionals to work together from the beginning to the end.

7.6 Interview Results

In this evaluation, many parts of the process were gathered to prepare the participants of each group to test the digital prototype in the observed tasks and collaboration task. The participants of each group discussed their findings in the focus group. The interview collected data to understand participants' experiences of the process. The data collected from the interviews reveal the weaknesses, advantages, and suggestions for the evaluation process. Five participants were asked to an interview to assess the prototype evaluation process in which they had participated (see summaries form Tables 7.15 to 7.22).

7.6.1 Overview of the evaluation process

Participants were asked for their overview of the evaluation process (see Table 7.15). The evaluation process was admired as well organised. It was suggested that the demonstration period was shorter and the 'let them play' process should be extended to enable all participants to explore fully by themselves. They felt they needed to become more familiar with the prototype before the evaluation group met because they had never used the prototype before. Participants stated that:

> *It is quite boring having to wait to use the prototype. You can tighten up the demonstration. When I waited for a long time, I forgot what you explained to me. I prefer to do it along with the demonstration or in a faster way, like having the tool in my hand, and you teach me to use it, to draw lines, and I follow this during the demonstration*. I.1.SP05

> *Actually, the introduction and demonstration should be the same process. We should keep using or playing with the prototype in order to become more familiar. However, the preparation of the introduction was too long so we had only a little time to become familiar with it. Unfortunately, if I stopped using it, I eventually forgot how to use it.* I.1.SP07

Table 7.15 IQ1 Summary of the Interview Responses

IQ1: What is your over view of the process?	
No.	Participants' responses
IQ1.1.	Participants felt that process spent a long time with an introduction and demonstration. But I felt that the letting them play parts was too quick. "The introduction and demonstration processes were too long, but parts that allowed users play with the prototype were too quick. All participants were still confused because they had not known the system. Although you sent information to all participants, we were busy and could not study them." I.1.SP07 A participant needs to have a short part of introduction and demonstration. In addition, the letting them play part needs to be extended so that all participants become more familiar. I.1.SP07
IQ1.2.	Around 3-4 hours as a time period for the group evaluation is enough. We could briefly learn from a demonstration and play with the prototype. If the workshop needs to extend its time longer than this, or up to a day, the workshop needs to include a break. I.1.SP08
IQ1.3.	This workshop is a good procedure that is completely clear. The timing of workshop is around 3-4 hours. I.1.SP04, I.1.SP05

IQ1: What is your over view of the process?	
No.	Participants' responses
	The period between the introduction and the demonstration could be reduced; when participants had to wait, they forgot what the experimenter explained in the demonstration. The demonstration has to be short and let participants play by themselves and teach themselves. "It could be faster between explaining the project and starting the program. It is quite boring to wait to use the prototype. You could tighten up the demonstration. When I have waited for a long time, I forgot what you explained to me. I prefer to do it along with the demonstration or in a faster way, like having a tool in my hand, and you teaching me to use it, to draw lines and I follow this during the demonstration." I.1.SP05
IQ1.4.	The evaluation process is planned and well-organised, easy to understand, and clear during the presentation. The process length is appropriate at around 3-4 hours. I.1.SP12

7.6.2 Performance Measure or 'let them play' Task

After demonstrating the digital prototype, participants were encouraged to test it and record their activities for the performance measure in the 'let them play' task. The conductor showed them how to use the prototype and, then participants explored and trialled the prototype by themselves. They were asked how they felt during the 'let the play' phase (see Table 7.16).

Participants felt that the 'let them play' task was interesting, easy and quite fun. All stated that the trial enabled them to learn how to use the prototype by themselves. It relieved any banality or boredom that could be experienced in a classroom setting when learning about processes. The task prompted them to use their intuition to learn what they wanted to know. For example, one participant stated that:

> *It is that I want to play with the prototype, and either get it right or wrong by myself. It's like a mother teaching a kid to eat food. She gives him a spoon and a plate first. He doesn't know how to use it. He may knock the spoon with the plate. Then someone teaches him how to use it correctly. This is just my first feeling*. I.2.SP05

Table 7.16 IQ2 Summary of the Interview Responses

IQ2: How is your feeling about 'the let them play' phase when using the prototype after the demonstration?	
No.	Participants' responses
IQ2.1.	The 'let them play' the prototype phase is quite fun and easily understandable. This part needs to be extended so that participants can become more familiar. I.2.SP07
IQ2.2.	The 'let them play' the prototype phase makes the participant excited, and they enjoy it, as it is like playing with a new toy directly involved in their career. I.2.SP08 In addition, participant needs to trial and error the prototype instead of only listening to a demonstration. "I felt bored listening to the experimenter demonstrate how it was to be used. This is because I only sat and listened. It was like we listened to a teacher teaching us something and we did not touch the prototype. If we could play while you were teaching us each point, I could remember better. It would be fun learning." I.2.SP08
IQ2.3.	Participants have positive attitudes when they are encouraged to play with the prototype; "The prototype is very helpful…. I feel I want to use this program to help me solve problems in my job" I.2.SP04
IQ2.4.	The participant feels curious and pays attention when playing with the prototype and knowing how it works by himself. I.2.SP05
IQ2.5.	A participant feels excited to trial the prototype and becomes happier when it is an easy-to-use prototype, which they discover in the 'let them play'. "I'm excited because I have never trialled this prototype. I was quite afraid about whether I could use the program. After I used it, I realised it was an easy-to-use program. In fact, I don't have to understand any basics of Auto CAD, or Sketch Up. I can still use it because I understand the prototype." I.2.SP12

There are many subtasks in the 'let them play' the prototype phase. The experimenter demonstrated twice how each subtask would be used, and after that participants were allowed to trial the prototype twice. Participants' views on the task are summarised in Table 7.17.

Two participants wanted to conduct the trial and error by themselves for more than two rounds while the other three participants stated that the number of subtasks was sufficient. One participant proposed the use of real problems in the prototype evaluation, such as task collaboration on the site analysis so that participants could understand how they could use the prototype in practice. Participants need to explore how the prototype would be used, whether right or wrong, by themselves using their intuition. They confirmed that the ‘let them play’ phase encouraged them to explore and learn by trial and error:

> *I think that another technique, such as step by step, is a general technique, which makes us memorise or learn how to use the program by memorising; but in this technique, we can explore by ourselves, then, if we have a question we can ask the speaker*. I.3.SP04

Table 7.17 IQ3 Summary of the Interview Responses

IQ3: How was the ‘let them play’ the prototype task?	
No.	Participants’ responses
IQ3.1.	Many subtasks are not enough to support the participant to become more familiar; it would be better if the task involved real work in our practice, such as collaboration on site analysis. “If we start to create a project or something serious, it will be interesting, and I will understand the real purposes, such as a collaboration on the site analysis.” I.3.SP07
IQ3.2.	A participant needs to extend the period of each subtask and experience more rounds. In addition, they need to explore the prototype by themselves. “The part when you guided me was enough, but the part that I did myself wasn’t. I think I could do more by myself and my team. I needed more time to explore it by myself.” I.3.SP04
IQ3.3.	The ‘let them play’ method was different to the step-by-step method. A step-by-step method makes us memorise by learning how to use the prototype as steps. In the ‘let them play’ method, the speaker encourages participants to ‘play’ by themselves after the demonstration. The participants can ask questions when they cannot do the work.
IQ3.4.	“The ‘let them play’ subtask is easy to understand. A participant, who does not have any basic skills in current digital software (AutoCAD, or Sketch UP) can learn easily.” I.3.SP12
IQ3.5.	“The ‘let them play’ subtasks were appropriate.” I.3.SP08, SP12, SP05

7.6.3 Focus group: Six thinking hats technique

The evaluation group consisted of two subtasks, namely the collaboration task and focus group. After participants completed the collaboration task, they were introduced to the focus group process, which used the six thinking hats technique. The participants’ interviews on their experiences of the focus group are summarised in Tables 7.18, 7.19,7.20, and 7.21.

Participants were asked how they felt engaging in the focus group using the six thinking hats technique (see Table 7.18). They stated that it is creative technique that assisted them, and put less pressure on the focus group. In addition, they felt that the technique could help to focus on topics and narrow their ideas:

> *It's fine because we are normally distracted and talk much without coming to the point. It's good when it's defined - that is what this is about. We can focus on colour groups and get to the point better than without topics. We have to keep explaining. The coordinator or head should draw everyone's attention to the point. If we firstly indicate our hats' colours or what the types are, the point will be narrower*. I.4.SP07

Table 7.18 IQ4 Summary of the Interview Responses

IQ4: How do you feel about engaging in the focus group, which uses the six thinking hats technique?	
No.	Participants' responses
IQ4.1.	"The six-thinking hats technique is good when its colour can be used to focus on each topic; it avoids distraction or too much talking without making points. Each topic can be narrowed." I.4.SP07
IQ4.2.	All topics are structured in the focus group as an order. All participants see each colour clearly, which will guide the participants' discussion and narrow our ideas down. "I think it shows opinions in order, like the first, second, and third answer in each content. This is an important order. This is a benefit of the six thinking hats. You can clearly branch out in each colour aspect. In some questions, my ideas were too wide. This reminds us that more detail is needed." I.4.SP08
IQ4.3.	The six thinking hats is a detailed technique, which separates the issues into the different hats and covers all sides of the issue. However, a participant has difficulty adapting his/her thoughts when the hat is going to change to another coloured hat. "I am okay if we go into every detail; we can use more ideas and explain our ideas. This is just like an academic seminar. It seems that it was set to key parts; it does not look smooth. Like, when we finished this topic, then, we will change to the another topic immediately and it is difficult to change" I.4.SP04
IQ4.4.	"A participant feels that the six thinking hats is interesting and is able to keep all participants' focus on the topic." I.4.SP05
IQ4.5.	A participant feels great offering a new vision and feels less pressure when using the six thinking hats technique, which shows that the technique is very creative. "I felt great. I think it gives me a new vision. It gives us less pressure and is a very creative style." I.4.SP12

Parallel thinking is core to the six thinking hats, therefore, participants were asked about their experiences of parallel thinking in this focus group (see Table 7.19). They felt that parallel thinking helped them to develop a quicker, more direct way to reach points and share ideas in the discussion group without emotion or bias in order to clearly focus on topics and avoid confusion. Moreover, it allowed participants to develop new ideas based on existing shared ideas.

Table 7.19 IQ5 Summary of the Interview Responses

IQ5: What do you think of the parallel thinking in the six thinking hats is?	
No.	Participants' responses
IQ5.1.	"The parallel thinking technique can speed up discussion to focus on a narrower point and issue." I.5.SP07, SP12 "It helps us to shorten the ways we get to the point. If there is no frame, participants will be distracted and discuss without making a point." I.5.SP07
IQ5.2.	One participant thinks that parallel thinking is designed to share opinions among collaborators in a discussion group, which needed to collect various ideas or develop from collaborators' ideas. "Parallel thinking is a sharing opinion. Everyone has various ideas. Those who use this technique can get various ideas to answer or continue that idea." I.5.SP08
IQ5.3.	A participant understands that parallel thinking helps all members to understand and follow the defined theme without emotions or bias to clearly focus on topics with no confusion. "Parallel thinking can control the aspect by using a flag to set the aspect. We just think about the truth and understand the truth; it can help to get the detail easier. It may not be scattered. All members will think around and understand the need to follow the defined theme without other emotions and distractions. It will focus on the topics clearly and with no confusion." I.5.SP04
IQ5.4.	Parallel thinking helps the team to keep everyone off topics in the focus group and to go in the same direction. "It helps us keep everyone off topics in the meeting. It is going in the same direction." I.5.SP05

The participants were asked about the disadvantages of the six thinking hats technique (shown in Table 7.20). Three participants suggested that this technique does not have a disadvantage. Some participants did not feel familiar enough to respond to the technique and they needed breaks before changing to next theme.

Table 7.20 IQ6 Summary of the Interview Responses

IQ6: What are the disadvantages of the six thinking hats technique used in the focus group?	
No.	Participants' responses
IQ6.1.	A participant may not be sufficiently familiar to respond to the themes of the six thinking hats. "We are not taught or trained to answer like this. We always answer for an entire point" I.6.SP07, SP08
IQ6.2.	"There are many ideas, which will increase by developing these ideas and following the frame of the six thinking hats. Actually, its disadvantage is that each hat may consume time if all members try to develop ideas together." SP08 "There are many, various ideas. They just flow but are still in the frame of the six thinking hats. They have these themes. There are more advantages than disadvantages. The weak point is that it is too detailed about time. But it has more benefits than weaknesses. It can go into detail that we might forget to think of. The weak point is about the timing. It took too much time. Sometimes, it isn't concise." I.6.SP07
IQ6.3.	There were no breaks between the six thinking hats. Participants need time to refresh their mind. "When we spend a long time in a meeting, our brain works hard or the participants' stress increases, and they may need to have a break to relax. It could be helpful to have many breaks." I.6.SP04
IQ6.4.	There are no disadvantages in the six thinking hats technique. "I think it saves us a lot of time in discussion. It prompts us to talk in particular periods, so it saves a lot of time." I.6.SP05
IQ6.5.	The process is not a problem. "It depends on persons, whether they can or can't accept other's opinions. If they can accept and share ideas like this, it is excellent. In addition, it's better than a discussion group that wastes time without making a point" I.6.SP12

On the other hand, participants were asked about the advantages of the six thinking hats technique (a summary is provided in Table 7.21). Participants agreed that this technique was beneficial in collecting data on many themes, and helped them to focus on each particular theme. They could develop ideas from previous shared ideas in the group without irrelevance and obstruction. Significantly, the technique helped participants to decrease negative attitudes and keep their thoughts along a more 'middle path' because they discussed all sides of an aspect, and this was supported by the themes of the technique.

Table 7.21 IQ7 Summary of the Interview Responses

IQ7: What are the advantages of the six thinking hats technique?	
No.	Participants' responses
IQ7.1.	"The six thinking hats technique helped the group of participants to collect ideas or answers from each topic under discussion. These participants can focus on the theme of each hat and get the best ideas/answers." I.7.SP07
IQ7.2.	All participants can see other aspects of other participants in the six thinking hats technique. It is not like copying others' ideas because they are thinking in the same direction involving each other in their main points. Therefore, they can enumerate many more issues. "Yes, we can see other aspects from others. It's not like when we copy others' ideas. It may be the issue we're thinking of, but there are subordinate issues or other issues involved in the main point. Therefore, we can enumerate many more issues." I.7.SP07
IQ7.3.	"The six thinking hats technique is more useful and could encourage participants to go into more detail that they may otherwise forget to recall." I.7.SP08
IQ7.4.	The six thinking hats technique can assist participants to collect and develop shared ideas or solutions in a group discussion. "We can go in depth in each part, each colour because someone may answer quite narrowly but in sharing ideas, we can continue at more depth" I.7.SP08
IQ7.5.	The six thinking hats technique can make participants clear which theme they are considering in discussion. This technique helps participants to express their thoughts without irrelevance and obstruction. "It's clear which part I am. We can narrow our thoughts to focus on the target. When we separate each part, it is easy to limit the frame and get into small detail without irrelevance and obstruction in collecting our thoughts." I.7.SP04
IQ7.6.	The six thinking hats technique can save a lot of time in discussion. "I think it saves us a lot of time to discuss this. It helps us to notices what we are talking about in any period, so it saves a lot of time. Now you're asking about its weaknesses. I haven't seen one so far." I.7.SP05
IQ7.7.	The six thinking hats technique can assist participants to decrease negative attitudes toward this prototype and keep their thoughts more along the 'middle path'. "It decreases the negative attitude toward this prototype. When we use the six thinking hats to ask each question, we see every angle of this prototype because it has pros and cons. We know how to improve it, and help each other solve problems. If we use this technique in other aspects, it would keep our thoughts more focused on the 'middle path'." I.7.SP05
IQ7.8.	In the six thinking hats technique, setting colour themes is a good process to help participants see an overview and, then, topics will be gradually discussed by participants in more detail and in greater depth according to each colour hat.

IQ7: What are the advantages of the six thinking hats technique?	
No.	Participants' responses
	"I think its colour theme is a good step. We know the problems and overview. We can be more specific about the problems. It's not only a wide-view. We can check the steps in each scope." I.7.SP12

7.6.4 Participants' Suggestions

All participants offered their suggestions for the next evaluation of the digital prototype, which are summarised in Table 7.22. All required breaks in the process, which would extend the process to more than three hours; indeed, participants suggested between five to six hours. The demonstration should be short and they suggested extending 'the let them play' task and focus group phases. In addition, they stated that the process could finish with the interview on the same day after the focus group.

Table 7.22 IQ8 Summary of the Interview Responses

IQ8: Do you have any suggestions in terms of the future evaluation of digital prototypes?	
No.	Participants' responses
IQ8.1.	"Participants cannot finish this workshop within three hours. One participant recommended that the prototype evaluation could extend its length of time more three hours. It could be arranged into two parts - one in the morning and one in the afternoon – at around five to six hours including a break and lunch. The workshop needs to reduce the time spent on the introduction and demonstration, but increase the length of time for the 'let them play' prototype task in the morning. After lunch, the group evaluation could be continued in the afternoon." I.8.SP07
IQ8.2.	"The workshop could be extended but not take more than six hours. Parts of the introduction and demonstration could be reduced in time and the conductor could let participants play with the prototype." I.8.SP08
IQ8.3.	The prototype evaluation should be improved to extend the timing to around six hours, especially for the 'let them play' phase and the focus group. Time breaks should be provided after each part of the process to reduce tiredness. "It might be better to extend the time in the prototype session or focus group session. Moreover, the process should have breaks so as to avoid leaving the participants tired." I.8.SP04
IQ8.4.	"The process of the prototype evaluation is already good enough. Some participants should be interviewed on the day that they finish the prototype evaluation." I.8.SP05
IQ8.5.	This prototype evaluation process is quite complete, as it does not need to reduce some parts of the process. Participants need some breaks after finishing each part, such as the demonstration, collaboration task, or group discussion.

IQ8: Do you have any suggestions in terms of the future evaluation of digital prototypes?	
No.	Participants' responses
	"We can have a break after finishing each part, such as after the demonstration, then after the group demonstration, and after the group discussion" I.8.SP12

Responses indicated that the prototype evaluation process, which consisted of preparation, introduction, demonstration, group evaluation, and completing the process, was a good process to support the group evaluation. All participants were positive about the 'let them play' tasks and the group evaluation that used the Six Thinking Hats technique. The 'let them play' task enabled them to have fun in the process subtask, and to explore and learn to use the prototype by themselves with the support of a tutor. Moreover, the Six Thinking Hats technique was admired as a good technique for the focus group. It assisted participants in the group discussion when discussing in-depth views and on keeping their thoughts on the 'middle path' without bias and negative thinking.

7.7 Summary

This chapter described the prototype evaluation method that was used to examine collaboration with the digital prototype. This chapter presented the second data collection phase of the study, which focused on the usability of the digital prototype and focus groups with participants who are professionals in the Architecture, Engineering, and Construction industry. The usability data collection consisted of the prototype measure and the Software Usability Scale questionnaire. All participants completed the prototype measure, which showed 90% effectiveness and 80% learnability. The total usability score revealed that participants are satisfied with the digital prototype for collaborative design in concept design as all questionnaires scored above 75%. Moreover, the digital prototype was required for use in design practice by all participants who addressed their requirements in the focus group. In addition, participants were interviewed to collect data to evaluate this prototype. The interview result revealed participants valued the process; they felt that the 'let them play' subtask was interesting to learn with support from a tutor, whilst in the focus group, the Six Thinking Hats was a good technique to help collect their ideas. However, they recommended time breaks in the process, which would have meant extending the overall engagement from three to four, to five to six hours.

CHAPTER 8:
CONCLUSION

8.1 Introduction

This chapter presents an overview of the research and conclusions from the previous chapters to highlight the research findings, contribution to knowledge, and recommendations for future research.

8.2 Overview

This research has investigated the role of electronic sketching in supporting collaborative conceptual design; specifically, it explores the meaning of design and concept design for the design process in the UK, USA and Thailand, and for collaboration among professionals in concept design. The investigation of the tools used in concept design, such as thinking, analogue and digital tools, concluded that the disadvantages of analogue and digital results in professionals choosing sketch for collaborative working. The aim of this research was to investigate how the use of electronic sketching improves team collaboration in conceptual design in Thailand. The research objectives were as follows:

1) To critically analyse current design team collaboration, identifying challenges and opportunities.
2) To identify existing tools and technology used for conceptual design team collaboration.
3) To develop a methodological approach for the design and development of a digital prototype to improve conceptual design team collaboration in Thailand.
4) To design and develop a digital prototype for improving conceptual design team collaboration in Thailand.
5) To provide recommendations to improve conceptual design team collaboration in Thailand.

To achieve the research aim and objectives, an abductive research approach was adopted and a case study research design was developed; this examined conceptual design collaboration among relevant professionals in Thailand. Moreover, a pragmatic methodological position was adopted, which involved the building and testing of a model or framework The case study strategy was categorised as combined, including exploratory and evaluation research, over three phases, as illustrated in Figure 8.1:

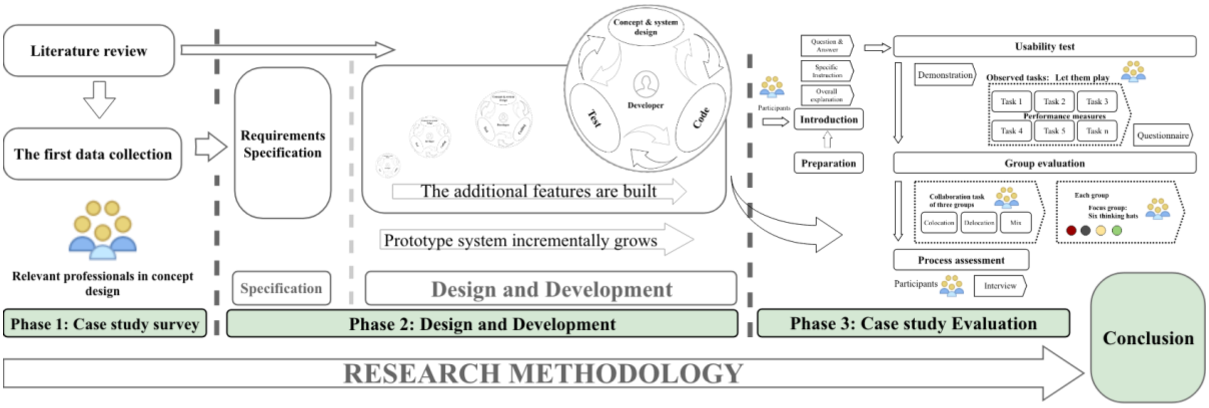


Figure 8.1 Three Phases of the Research Methodology
(Source: Researcher's own)

Phase one: The case study research relied on a survey of relevant professionals in concept design collaboration for the data collection. The literature review formed the initial step, which was followed by the collection of primary data via a qualitative questionnaire. In this case, the data was obtained from the completion of a survey by 43 AEC professionals in Thailand who possessed varying experiences, backgrounds, knowledge, and IT skills in concept design.

Phase two: The methodological approach for the prototype design and development emerged from an exploration of the Software Development Life Cycle (SDLC) approach. The prototype model was chosen and tested with users. Feedback was collected and used to modify the model, and appropriately integrate an incremental iteration approach.

Phase three: The case study evaluation was conducted, incorporating a usability test, group evaluation, and process assessment. The evaluation process was conducted in Thailand with fifteen invited professionals who were divided into groups of three. Firstly, the usability test measured the prototype performance according to participant use. Secondly, the group evaluation included a collaboration test and focus group with participants. The collaboration test brought each group of participants together to test the prototype in different collaboration conditions: co-location, de-location, and a mix of co-location and de-location. When each group completed the collaboration test, all members of the groups were brought together to discuss their recommendations using the Six Thinking Hats technique. The final stage involved the process assessment, in which five participants were interviewed to evaluate the process of participation.

8.3 Main Conclusions from the Research Questions

This research involved a literature review prior to the data collection, in order to understand existing knowledge when defining design and concept design, international design process approaches, collaboration among relevant stakeholders in the UK, USA, and Thailand, and the tools used in concept design. The literature review resulted in the development of the research objectives, a methodology, and the acknowledgement of gaps within the current field of research. These gaps can be summarised as follows:

1. What is the situation in collaborative conceptual design?
2. What does the architecture of a digital tool for collaborative conceptual design need to look like?
3. What is the methodological approach for prototype design and development?
4. What are the results when professionals evaluate the prototype tool for real-time collaboration and communication?
5. How do professionals recommend the adoption of digital prototypes for collaborative conceptual design teams?
6. How effective is the evaluation process in a group evaluation?

8.3.1 The Current Situation of Conceptual Design Team Collaboration

Approaches to the design process in the USA and UK have been developed with the aim of increasing efficiency by enabling a collaborative environment. In the USA, there are two approaches; the traditional design approach and Integrated Project Delivery (IPD). The traditional design approach, or design-bid-build method, has been adopted for the majority of projects. This uses a linear approach to aid collaborative working and enables fragmented teams to work together (Architecture Institute of America, 2007). Although the majority of projects use a traditional design process, they still suffer from reduced productivity and efficiency.

The IPD approach has been adopted since 2007, with an updated version introduced in 2014. This approach differs from the traditional design approach in that it emphasises collaboration among relevant stakeholders from the early phase to the construction phase, within the context of co-location. The American Institute of Architects (2007) reported that IPD results in greater efficiencies than the traditional design process, according to an estimate from the United Kingdom's Office of Government Commerce (UKOGC). UKOGC illustrated that IPD can save up to 30% on the cost of construction, and further cost savings of 2-10% can be achieved by employing integrated supply teams in single projects (American Institute of Architects, 2014).

In the UK, the RIBA Work Plan 2013 has been developed from RIBA Work Plan 2007. This framework offers a feedback loop to prompt the use of data from previous projects to inform strategies to improve project efficiency. The Work Plan enables relevant stakeholders to intensively work together from the early design stage, or design brief, to the close-out stage. The concept design stage encourages relevant professionals and stakeholders to engage in collaborative design via the arrangement of design team meetings and workshops (see Figure 2.17 in Chapter 2).

In Thailand, the traditional design approach used is similar to the design-bid-build method of the USA, and comprises concept design, schematic design, design development, construction document development, tender, and construction. However, design conflicts or problems still exist, and tend to occur in the construction phase due to need for rework, incomplete drawings, and pool communication (Charoenpornpattana, 2015; Makulsawatudom et al., 2004).

This review raised two research objectives, which are summarised as follows:

Research objective 1: "*To critically analyse current design team collaboration, identifying challenges and opportunities*."

Table 8.1 Summarises the key challenges and opportunities of current design team collaboration

No	Key	Content
1	Challenge	Efficiency of productivity, cost, and time.
	Opportunity	Concept design is a crucial phase. Engaging relevant disciplines in concept design increases the efficiency and productivity in solving design conflicts or problems before advancing to the next design phase.
2	Challenge	The AEC industry is fragmented and inefficient, leading to conflict, as each team is responsible for their own scope of practice and attempts to protect their individual interests.
	Opportunity	Development of integrated teams who work together, share responsibility, and who have a single goal and no competition amongst themselves, from early design to the end, results in high efficiency and productivity within a construction project.
3	Challenge	Collaboration is complex and difficult because the nature of collaboration requires the adaptation of mental structures called

No	Key	Content
		schemata in order to build knowledge, and share experience and information from other disciplines.
	Opportunity	Tools for collaboration should support team members to share experience and retrieve design information from other disciplines to build knowledge among team members.
4	Challenge	Communication among professionals is often referred to as a problem issue called 'over the wall' syndrome due to the fragmentation of the various disciplines involved. Naturally, one professional discipline is not knowledgeable about the representations of another's discipline, due to difficulty in communication or a lack of understanding, which leads to misunderstandings and errors.
	Opportunity	Problems in communication among different professions can be overcome by 'simplifying communication' and by the use of 'messy talk'. Informal communication can contribute to project success by optimising complex-problem solving.
5	Challenge	Lost information occurs during the collaboration between professionals involved in the design process. Professionals can usually exchange design information through video conferencing, audio talking, online chat and e-mail, but communication via these methods can be disarranged and full of digressions.
	Opportunity	Collaboration tools can integrate features of communication technology to support users in easily accessing, sharing, and retrieving the contents so that information from the problem-solving process can be structured for the exchange of design information.

Research objective 2: "*To identify existing tools and technology used for conceptual design team collaboration*."

Professionals in concept design team collaboration use tools to generate and develop design ideas from abstract to concrete, and to enable communication amongst members. Design activity requires processing within the brain in conjunction with the use of both analogue and digital tools, as summarised in Figure 8.2:

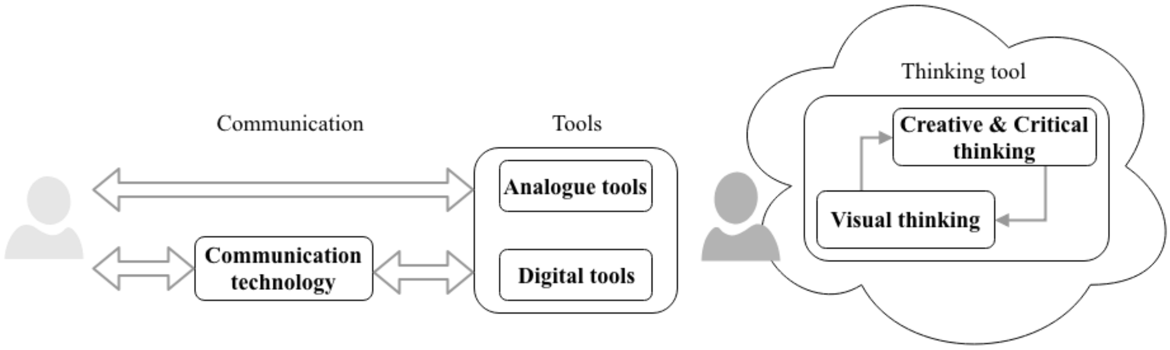


Figure 8.2 Diagram of Tools used in Collaboration
(Source: Researcher's own)

1. **Thinking tool:** Concept design requires creative and critical thinking through a process of visual thinking.
    - Creative and critical thinking plays a role in conceptual design by generating, reasoning, assessing, or judging design ideas. Critical thinking is defined as action within the mind to solve problems by analysing information and evaluating principles and knowledge, and relies upon rationality and decision-making. It is a linear process involving the adoption of conscious logic and rational thinking to form knowledge and understanding, or reach a decision. In contrast, creative thinking is imaginative and spontaneous, no longer linear in dimension, and more complex in its exploration of resources to find appropriate solutions in the synthesis of novel ideas. Design is defined as intuitive when creative thinking is involved.
    - Visual thinking is an important mediation between design information obtained using tools and the process of creative and critical thinking. The process of visual thinking is stimulated by external information and requires internal memory. Moreover, design information from external tools (analogue or digital tools) is loaded into mental visual imagery, which forms temporary pathways in the brain, enabling delivery to other functions, such as creative and critical thinking, and is deleted to clear a buffer in a short-lived cycle. Significantly, it requires the investment of enormous energy to maintain this process without interruption, to refresh the design information, and to protect it from fading from memory.

2. **Analogue tools:** Sketch and model-making are useful tools to support design in the concept stage. These tools are used in the design process in different ways due to their differing qualities; sketch is widely admired and fast, but model-making aids communication and exploration in design creativity during concept design.
    - Model making helps designers to easily explore form and scale, and offers a clearer perspective of three-dimensional images. It plays an important role in supporting the communication process between the professionals involved, by creating a sense of closeness and 3D reality in the physical world.
    - Due to its vagueness and the relationship between 2D and 3D, sketch is a powerful tool in enhancing designers' abilities to use and simplify complex information. It supports a designer's creative work in perceiving and translating complex ideas, which are then reduced to simplified design information during the thinking process. Sketching enables two-dimensional content to be loaded into the memory, and encourages immediate explorative thinking to support designers in maintaining their mental visual imagery. It provides fast and cognitively cost-free representation and feedback to the designer, by encouraging a cyclic 'dialogue' between the mind, the hand that holds the sketching tool, and the eyes that perceive the design information on the paper. The use of sketching as a tool is encouraged amongst designers, due to its ability to support the immediate passing of their thinking, and its cost-free cognition which does not obstruct their thinking process. Currently, sketching is admired as a good traditional tool, both for use in the design process and for communication.
3. **Digital technology:** BIM and CAD tools are used for collaboration among relevant stakeholders in the AEC industry. Although these tools have been used to increase productivity and for building creative ideas, digital tools are still difficult to use in supporting concept design because of their complexity, high demand on cognitive loads, and steep learning curve. These factors, in combination with the unfriendly user interface, become the main influences leading to restriction of 'creative exploration'.
    - The strength of BIM tools lies in their use within the early detailed design and construction stages. Other advantages of BIM are in virtual pre-assembly, error checking, on-site construction coordination, building maintenance, and interoperability. It has been encouraged with massive or parametric objects, to

enable other design teams to start to cooperate and gain access to the collaborative BIM environment.

- A CAD tool helps designers to visualise, synthesise and analyse designs, and to create alternative designs in order to increase productivity in terms of cost and time. The tool can be categorised under four usages; draft tool, modelling tool, concept design, and other uses, such as calculation or graphic presentation.

4. **Communication and technology:** In collaboration, different methods and notational forms are used for communication among professionals; for example, drawing, numbers, shorthand references for standard materials, and notes. Communication technology drives collaboration in the design process via both synchronisation and asynchronisation. Communication media is integrated with communication tools, such as sharing applications, online conferencing, instant messaging, social applications, email, and message boards, to support team collaboration in the design process. Although these tools are used to exchange design information during communication and collaboration opportunities, such as video conferencing, audio talking, online chat, and email, it is difficult to manage the communication content using these tools.

In Thailand, both analogue and digital tools are used for collaboration during the design process. Sketching tools are utilised to generate design ideas and communication amongst team members. Sketch is required to improve capability and collaboration. Digital technology is also adopted in the design process to support designers when presenting their concept design ideas, and assisting the draft team to prepare documents. Initially, designers use sketch to generate their design ideas, whilst digital tools are then adopted to continue the design process. The user interface function within a digital tool can support intuition and collaboration in concept design. Moreover, in terms of communication technology, relevant stakeholders use many channels of communication media, such as email, SMS, social media applications, and instant messaging for basic communication and collaboration. It is difficult to manage the contents of communication during collaboration and pictorial explanations in complex design.

8.3.2 The Architecture of a Digital Tool for Collaborative Conceptual Design

To define the archetype of a digital prototype for conceptual design collaboration, an understanding of varying approaches to the design process and collaboration, and the tools used in concept design, was required. To gain this understanding, an initial literature review was conducted; this was followed by case study research involving forty-three participants, all of whom were AEC professionals involved in collaboration in concept design. Participants within the case study were invited to complete a qualitative questionnaire to explore and describe current conceptual design collaboration in Thailand.

The research findings in Chapter 5 considered the requirements of the prototype model by analysing and condensing research participants' answers and suggestions. Participants indicated that the prototype model should have the following characteristics (see Figure 5.5):

1) Ease of use; this is required to support all users, such as relevant professionals, the owner, and/or other experts.
2) The prototype must be a repository for knowledge from communication during collaboration, so as to enable users to build knowledge from each other.
3) The prototype should possess tangible graphics and communication technology to help users in clearly understanding communication and collaboration.
4) It should support real-time collaboration.

8.3.3 Methodological Approach to Prototype Design and Development

Following the completion of the case study survey and the evaluation of the abductive research approach, the prototype design and development formed the next stage of the software design in this research. This final phase achieved the third and fourth research objectives as follows:

Research objective 3: "*To develop a methodological approach for the design and development of a digital prototype to improve conceptual design team collaboration in Thailand*."

According to the overview in this chapter and shown in Figure 8.1, the prototyping approach was chosen and modified to support the design and develop of the prototype and code in this research (as was explained in Figure 6.3 in Chapter 6). The prototyping approach considers the prototype requirements, prototype development, user testing and feedback, and the final product release. User testing and feedback is brought to the next case study evaluation phase and used to further develop the prototype specification.

By utilising an incremental iteration process in the research, this methodological approach to software design and development encourages the researcher to gradually design and develop by increasing the additional functionalities and features from small-scale tasks to complete tasks. Approximately every four weeks, the prototype was developed and updated in its functionalities and features. This approach assisted the researcher to gradually improve and update codes or change the direction of design and development during the process.

Research objective 4: "*To design and develop a digital prototype for improving conceptual design team collaboration in Thailand*."

The prototype requirement specification and concept design were explained within Chapter 6, whilst its relationship to the research objective was discussed in sections 6.4.1 and 6.4.2. By following the requirements elicited from the data collection, the concept design of the prototype was developed. These requirements led to the inclusion of the following features in the concept design:

1) Both multi-touch and digital pen interaction are provided to enable users to deal with easy tasks with both hands. Sketch is used to easily channel their intuition into data on the screen without disrupting their attention by dealing with problems and the associated thinking process. One hand can take the digital pen to sketch on the screen of the prototype, while the other hand is available to use the multi-touch interaction to deal with other tasks, such as zoom, pan, select, or to modify objects.
2) A collaborative sketch environment is provided to support users when working together in the same or at different places and times on portable devices. The prototype provides a shared space among users, who are connected by a Wi-Fi signal and the Internet. This enables relevant professionals to design concurrently when developing an abstract design idea.
3) Collaborative communication supports users to interact with each other via notes, discussion in the chosen area on the working page, and public communication within a project. The prototype allows users to sketch and communicate with each other on the working page, where sketched objects can become tangible graphics and combined with discussion. In addition, the sketch and discussion become a repository of knowledge accumulated from communication during collaboration.
4) A map of idea designs support users to create and work on alternative designs. Each page offers a space for collaboration and discussion, which contains the design ideas of each user. The map allows users to integrate other design ideas within the working page to encourage creative thinking (as discussed in Chapter 3, section 3.2.1.1) and critical thinking.

8.3.4 The results of the usability test

When the development of the prototype was complete, it was used in the evaluation process. A usability test, including performance measurements and a Software Usability Scale (SUS) questionnaire, was used to evaluate the prototype, as discussed in section 7.5, Chapter 7. The results of the usability test concluded that:

1) Effectiveness of prototype use is 0.90;
2) The learnability of the prototype is 79.97. Participants could easily learn to use the prototype and move from beginner to expert in a short time without a steep learning curve.

After participants finished the usability test task, they completed the SUS questionnaire to evaluate the prototype; the resulting SUS score was 75.21.

8.3.5 Recommendations for Adopting the Prototype for Collaborative Concept Design Team

Forming a focus group was one part of the evaluation process and used the six thinking hats technique to guide each group of participants. Details of this technique were provided in sections 7.3.2 and 7.3.3 in Chapter 7. In addition, the results of the focus group were also outlined in section 7.5, and met the fifth research objective below.

Research objective 5: "*To provide recommendations to improve conceptual design team collaboration in Thailand*."

1. Emotion (Red hat): Participants discussed how they felt on using the prototype
    - The prototype enhanced collaborative working amongst all relevant professionals and/or experts when working both in the same and different places, as if they were working on the same whiteboard on which everyone could easily sketch, post or chat.
    - A message function was required for communication although they were working together around the same table.
2. Judgement (Black hat): Discusses the potential problems
    - An easy graphic user interface was required instead of text buttons.
    - This version of the prototype needed to improve the picture insertion and be usable without connection to the Internet.
3. Benefit (Yellow hat): Discusses the potential advantages and how they could help

- The prototype assisted participants in conceptual design team collaboration when working on the same tablet.
- The prototype reduced the complexity of collaborative design as participants worked on the same, shared space. It enhanced their ability to solve problems and learn together.
- The prototype was able to assist relevant professionals in concept design to design concurrently and gather more than the current linear working system.
- The difficulties associated with collaboration and communication can be overcome, as the prototype connects all individuals with the same tool and offers a repository of design ideas and communication.
- The physical barriers to collaboration could be improved by reducing the need for meetings, which can be time-consuming.
- The prototype can solve the problems of communication by consolidating the design and communication elements, which increases the efficiency of collaboration and communication.

4. Ideas (Green hat): Discusses how to apply and develop the prototype
    - The prototype could become an instrument for AEC schools to support their training departments to improve collaborative design among professionals, lecturers, and students.
    - The prototype could be used as a brainstorming tool.
    - The prototype could be used for communication in team collaboration.
    - The prototype could be used to manage design projects, from concept design to construction, which requires a repository and design management tool for collaborative design teams.
    - Design ideas could be managed in the idea map feature of the prototype, which is used during the management of the design team.

These features of the prototype can be widely adopted in various ways, such as brainstorming, collaborative design, education and the storage of communication and collaboration. The prototype has been described in positive comments and has proven to be very useful for professionals in design team collaboration. This prototype should be promoted to encourage designers to work together from the beginning to the end.

8.3.6 Assessment of the Evaluation Process

After the prototype evaluation was complete, research participants were interviewed to assess the process. The process included two sub-methods, as follows:

1. Usability test:
    - It was illustrated that allowing the participants to be involved in 'hands-on' trials made it more interesting, easier, and more enjoyable when participants were both guided and autonomous.
    - Trialling alone promoted their individual intuition to learn and explore to use the prototype.
2. The focus group was adapted to use the six thinking hats technique;
    - The technique was promoted in that it helped participants to reduce pressure during engagement.
    - Participants felt that the technique assisted them to focus on the topic and concentrate on their ideas.
    - It provided a condensed way to reach decisions and share ideas in a discussion group without individual bias.
    - It demonstrated that this technique helped to generate and develop new ideas based on ideas shared within the group.
    - It demonstrated that this decreased negative attitudes due to discussions on all opinions using the nature of the technique.

8.4 Recommendations to improve conceptual design team collaboration in Thailand

The contents of this research were condensed to present the recommendations to improve concept design team collaboration; this followed the fifth research objective, as follows:

Research objective 5: "*To provide recommendations to improve conceptual design team collaboration in Thailand*."

1. The nature of Thai AEC industry is fragmented and inefficient. Enabling fragmented teams to work closely together in concept design offers an appropriate way to increase design efficiency.
2. All relevant disciplines should be encouraged to participate, share responsibility, and holistically solve design problem in concept design.

3. Open communication is crucial and should be considered to support relevant disciplines to achieve close collaboration and share knowledge and experience.
4. A collaborative design team should use, or adapt, appropriate tools and technologies, such as tablets, Cloud technology, and communication technology, to enable efficiency in conceptual design collaboration whether in co-locations, de-locations, or a mixture of the two.
5. Information communication technology should be appropriately adopted to manage the content of communication to build knowledge among relevant team members and support the retrieval of content from a knowledge repository.

Therefore, as the aim of the research was to investigate the use of electronic sketching to improve conceptual design team collaboration in Thailand, it can be concluded that this type of digital prototype could be used to increase productivity and the opportunities for concurrent design collaboration in conceptual design teams. This prototype could be used to reduce the number of meetings required, therefore saving time, and energy. In addition, all relevant designers are encouraged to design concurrently and collaboratively from the earliest level of abstract design ideas. Designers can connect with other disciplines to share and discuss their design, and solve problems whilst they refine their design ideas.

8.5 Contribution to knowledge

This research consists of original contributions to knowledge by developing a solution, methodological approaches for design and development, and prototype evaluation processes for team collaboration. The following define some contributions to knowledge:

- **The architecture:** The tool archetype for conceptual design team collaboration focuses on problem solving by conducting data collection and by recording the findings from relevant professionals within concept design. The problem areas of collaboration and tools are identified by relevant professionals and determined from the results gained through the research process. The models of the tool supported by these professionals are concluded to illustrate the current situation.
- **The evaluated architecture:** The architecture proposed as the first version of a digital prototype for concept design team collaboration was evaluated through the process developed for team evaluation. All results from the performance measures and recommendations were recorded and confirmed by the professionals who participated

in the case study evaluation research. Their recommendations became critical in defining the usefulness of the architecture when applied to conceptual design team collaboration.

- **Developed prototyping approach in research:** The prototyping approach adopted for the research was based upon the approaches of a Software Development Life Cycle (SDLC). This approach describes how best to develop the prototype to fit with the research methodology, linking the research methods to form a guide for any researcher who needs to develop software, either autonomously or within a small team.
- **Evaluation process for conceptual design team collaboration:** The usability test approach was applied to evaluate the software in its development cycle. The approach was modified to support multiple participants who evaluated the software prototype in the time given. The contribution shows the collaboration and adaptation involved in the application of the Six Thinking Hats technique within the focus group.

8.6 Future research

According to the prototype evaluation process, the research participants, being relevant professionals within conceptual design team collaboration, gave their recommendations for the application of the prototype. These recommendations are crucial in preparing the ground for potential future research in Thailand.

- Future research could brainstorm design problem-solving among professionals. Thai professionals could be invited to interview their peers about brainstorming, with some invited to the test process. The Six Thinking Hats technique could be integrated into the prototype to support the group evaluation of the brainstorming process.
- The prototype sought to support collaborative learning among students, lecturers, and professionals. Future research could be conducted to interview students, lecturers, and professionals on their use of the tool in educational activities within Thai architecture schools. The data collected could be integrated with, and used to improve, the model of conceptual design team collaboration.
- The prototype could be tested to solve problems in the Thai construction phase, with the potential that future research interview relevant professionals in the design and construction phases. The model of conceptual team collaboration could be used and examined in the construction phase between designers and contractors.

8.7 Final Reflection

This research was conducted in three phases: the survey, the prototype design and development, and the evaluation. Two of these phases needed the involvement of professionals for the data collection and prototype evaluation. The research methodology is reflected on, including what could be done differently if the research was conducted again, and researcher's experience on carrying out the work.

8.7.1 Reflections on the research methodology

In this research, the first research method used a qualitative questionnaire to collect data from relevant professionals in concept design. The time spent waiting for participants to respond and complete the questionnaire took too long. Some participants were busy and forgot to complete the questionnaire. In addition, some participants responded that they used too much time and energy writing their answers in the qualitative questionnaire.

To identify and describe problems and requirements for the prototype, the research process could have been improved by using interviews, either face-to-face or video calls, instead of a qualitative questionnaire to collect the data. In addition, a focus group was used to generate and collect ideas. The sampling size for the qualitative method was around forty participants for the interviews and ten participants for the focus group.

Ethical approval should be approved before the interim assessment (IA) so that the researcher can immediately conduct the process after the IA.

In the prototype design and development phase, the researcher was the developer who designed and developed the code to complete the prototype. If the research had been supported by a research fund, this would have aided the research. For further research, a small team, or 2-3 programmer assistants, should be employed. In this process, team discussions and its progress should be collected to evaluate the modified method. These team members should also be interviewed to gain their insights into the process.

For the final, prototype evaluation, phase, including the integrated usability test method, a focus group method using the Six Hats Thinking technique was adopted, and the process assessment adopted semi-structured interviews. The time taken for this stage was around three to four hours. The results of the process assessment were positive; however, the overall process was extended in length to provide breaks for participants. For future research, this phase should be extended in length and the phase should be divided into two separate sections. The first is the usability test method and another section should be the focus group and process assessment method. The process should be improved to support research participants as follows:

1. **The usability test:** Participants did not want a long demonstration and wanted to trial the prototype by themselves. For future research, the demonstration should only present the prototype features. Researchers should encourage participants to trial or play with the prototype by themselves.
2. **Time break:** A selection of snacks and drinks or a lunch box should be provided to the research participants. In addition, a break time of around 1-1.30 hours is advisable.
3. **Focus group:** Participants may be unfamiliar with the Six Hats Thinking technique. A mock-up using the technique should be provided to ensure that participants are more familiar with the technique. In addition, the process should not be rushed to change themes (hats), and the researcher should wait to ensure that the participants prompt the next theme under discussion.
4. **Process assessments:** Participants should be interviewed after completing the focus group on the same day.

8.7.2 Personal reflections on the research

These personal reflections present and share the practical experiences regarding the entire research. There are as followed:

1. **Academic skill**: The research methodology was designed and developed to serve the research aim and objectives. It increases academic skills, both through new knowledge and experiences, by conducting a research methodology that comprised three research methods. Firstly, these methods have their own function in responding to the research objectives, through the data collected, the exploration and description of the phenomena, and the evaluation of the prototype. The design and development phase bridged the survey case study phase and the evaluation case study phase. Secondly, the research method integrated sub-methods to follow the research objective. In this research, the evaluation case study was integrated with the usability test, focus group method, and assessment method.
2. **Dealing new platform and tool during design and development:** The architecture was designed and developed from the new plate form, computer language, and development tool. The researcher had to deal with a new environment of prototype design and development following the empirical requirement model and requirements

specification. It was necessary to learn a new tool and computer language, which created some difficulties for the researcher. When the researcher understood the foundations of the new environment for design and development, an action plan was loosely created to follow the modified prototyping model approach.

3. **Participants sampling:** The participant sampling involved a group of professionals who were involved in concept design. It was difficult to invite them to participate in the research. For the data collection, the researcher used a snowball strategy and tried to informally and formally communicate with potential participants. As the data was collected Thailand, the research participants were identified by the researcher. It was important to encourage the participants to understand the value their participation and the time they spent on participating in the research. In addition, the gathering of participants needed improvement; appointments were either cancelled or postponed when the professionals had to cover more important work responsibilities. The participants were required to inform the researcher and other participants if they were too busy due to unpredictable events.
4. **Providing a 'forgiveness' function in the prototype:** The developed prototype should be provided with a function to support user's mistakes in the evaluation process, as participants could easily make a mistake during the evaluation process. The prototype software prepared undo and redo functions to deal with errors and to improve mistaking activities. In addition, the prototype should have provided a recover function as it could shut itself down due to errors.

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Appendix 1
1st Ethical Approval from the University of Salford

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

21 September 2016

Dear Tirat,

RE: ETHICS APPLICATION ST16/131 – A digital prototype for collaborative conceptual design.

Based on the information you provided, I am pleased to inform you that your application ST 16/131 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management,
School of Built Environment
University of Salford
Maxwell Building, The Crescent
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Appendix 2
1st Participant Invitation Letter

Tirat Jaraskumjonkul
PhD research student
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United Kingdom, M5 4WT
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University of Salford MANCHESTER

A digital prototype for collaborative conceptual design.

Dear Madam/Sir,

My name is Tirat Jaraskumjonkul and currently studying PhD at the School of the Built Environment, The University of Salford in the UK under the supervision by Professor Vian Ahmed, and co-supervision by Professor Jason Underwood. The title of my doctoral research is "A digital prototype for collaborative conceptual design".**The main aim of the research is to:** To critically investigate and identify experiences of the multidisciplinary team and stakeholders involved in the current collaboration process in concept design stage of AEC industry project in the UK to develop a digital prototype tool to enhance real time collaboration and communication between the design team in the concept design stage.

This study will gather experiences and views of architects, building service structural engineers, cost consultant, lead project designer, construction lead (the members of the multidisciplinary and multifunctional teams working together at the concept design stage) within the context of the AEC industry projects in the UK.

Your cooperation is most essential as the successful completion of the case study could be beneficial information for developing a future digital tool which will be available to the AEC community to enhance real time collaboration and communication between the design team in the concept design stage. All responses to this questionnaire would be kept strictly confidential and will only be used for academic purposes only. Once an appropriate data collection will be completed and analysed, the original data will be shredded.

Unless requested, the data collected will appear anonymously in the final PhD thesis and other related publications such as local and international journal. To ensure anonymity, no personal details or details about the organisation will be disclosed.

Thank you.
Best regards,

Appendix 3

1st Research Participant Consent From

Title of Project: A digital prototype for collaborative conceptual design.

Ethics Ref No:

Name of Researcher: Tirat Jaraskumjonkul

Please tick the appropriate boxes	Yes	No
Taking Part		
• I confirm that I have read and understood the information sheet for the above study and what my contribution will be.		
• Email of research is shown so that I will have the opportunity to ask questions about the project.		
• I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.		
Use of the information I provide for this project only		
• I understand my personal details such as my name and email will not be revealed to people outside the project.		
• I understand that my words may be quoted in publications, reports, web pages, and other research outputs.		

Name of participant ……………………………………………

Signature
(Digital signature is available) ……………………………………………

Date: ……………………………………………

Name of researcher taking consent: Tirat Jaraskumjonkul

Researcher's e-mail address: T.Jaraskumjonkul@edu.salford.ac.uk

Appendix 4
1st Questionnaire Survey

Questionnaire Survey Instructions

* There are no right or wrong answers to the questions in this survey. Select the most appropriate answer for each question based on your view/experience.

* It is necessary in this study that all questions are answered, as the questionnaire is designed to achieve particular research objectives, and it is hoped not to offend respondents in any way. If there is question(s) that you are unwilling or unable to answer, you may skip to answer it and continue answering the remainder of the questionnaires.

* Remember that both your identity and that of the company you work for will remain strictly confidential.

1 Name and Family name:____

Your age group (Please, select your choice which is relevant)

18 to 24	
25 to 39	
40 to 60	
60 plus	

Your gender (Please, select your gender choice)

Male	
Female	

Email: ____

Your discipline

1. Architect
2. Building service and structural engineer
3. Cost consultant
4. Lead designer project
5. Construction lead
6. Other…………………...

2 Which is your role within the design team you are working in?
(Please, select your choice which is relevant.)

1. Senior
2. Junior

3. Internship
4. Others………..

How long have you been in your role?

1. 1-5 years
2. 6-10 years
3. 11-15 years
4. 20-25 years
5. More than 26 years

How long have you worked in the profession?

1. 1-10 years
2. 11-20 years
3. 21-30 years
4. 31-40 years
5. More than 41 years

3 What kinds of projects do you engage in concept design?
(Please, select your choice which is relevant.)

1. Residential
2. Health facilities
3. Academic
4. Commercial-retail
5. High right building
6. Complex building

What size of project

1. Small building
2. Medium building
3. Large building

4 Should conceptual and schematic design be a collaborative design process to enable work across the multidisciplinary and multifunctional team? Do you have any comments?

____

____

5 How do you collaborate design projects in concept and schematic design process?

Describe how do you collaborate design projects in concept and schematic design process?

____

____

6 Usually, there are professionals who engage to work together in design process such as architect, building service and structural engineer, cost consultant, lead designer project and construction leads.

Which other stakeholders should be engaged in collaboration of concept design and schematic design stages? Why?

____
____

7 How many people engage in collaborative design at the concept design stage for each project?
Small building: ________________
Medium building: _______________
Large building: ________________

8 How many ideas do you develop in concept design?
(Please, select your choice which is relevant.)

1. Only 1
2. 2-3
3. 4-5
4. 6-More

9 What are the problems facing collaboration in concept and schematic design process?

____
____

10 Do you agree that the ICT tool for collaborative design should enhance participation for specialists' co-location and "desynchronisation" requirement for information exchange in the concept and schematic design?

____
____

11 Do you think that there are any barriers stopping collaboration in concept and schematic design stages? How could the barrier be removed?

____
____

12 Do you agree that both misunderstanding and interpreting information creates problems in communication in collaborative design due to different experiences and backgrounds of participants for concept and schematic design process? How do you solve the problem?

____
____

13 Do you think that all multidisciplinary teams should have a director to monitor all contents of communication in team to prevent any conflict? How do you solve the conflict problem?

____
____

14 Besides yourself and colleagues building knowledge, understanding other disciplines is also important to enable collaboration among those multi disciplines from different backgrounds and with different experiences.

Do you agree with this statement? How do you achieve this your projects?

____

____

15 Please, tick level of appropriate tool (where 5 is extremely good and 0 not suitable at all), and which tool is it appropriate to assist in creating and developing new design ideas in concept and schematic design process?

Scale	0	1	2	3	4	5	No idea
Sketch; based on paper							
2d CAD software; 2d AutoCAD							
3d CAD software; 3ds Max, FormZ, Rhino, SketchUp,FormIt360, 3d AutoCAD.							
BIM software; Revit, ArchiCAD							

16 Do you use any computer software for concept design?
Yes or No If Yes….
Does the computer software has the capability to be used to support you in concept and schematic design (Please describe)?

____

____

17 Some argue that sketch is an admired tool to capture ideas in concept design – and it cannot be substituted by computer software.
Do you agree with this statement and could you describe your thoughts?

____

____

18 What aspects of the computer software; BIM&CAD tool, be improved to support designer's critical and creative thinking for developing concept design. Why?

____

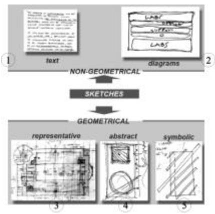
____

19 What aspects of the traditional tool; sketch based on paper and pencil, should be improved to support designers for developing the concept design? Why?

____

____

20



According to the picture above, what types of sketch do you use to create concept design and schematic design?

1. 1st type: Text

2. 2nd type: Diagram
3. 3rd type: Representative
4. 4th type: Symbolic
5. Other:____________

21 According to the previous question, do you think what you will use in communication or collaboration with your colleagues? Why?

____

____

22 Is it important to preserve the contents of discussion among participants in concept and schematic design? Why?

____

____

23 How do you manage contents of design information from collaborative design such as previous discussion, or other notes? Are there any problems?

____

____

24 Someone argues that sketch was used to share ideas during the process of collaborative at the concept and schematic design stages.

If it will be developed for collaboration in concept design, what aspects of the sketch (will be developed as digital sketch) can be improved to enhance designers' ideas?

____

Appendix 5
Objectives of Qualitative questionnaire

General information part
To identify the characteristics of the multi disciplines and stakeholders and the composition of the multidisciplinary and multifunctional teams working together at the concept design stage

1 Name and family

NAME:____

Your age group(Please, select your choice which is relevant)

18 to 24	
25 to 39	
40 to 60	
60 plus	

Your gender (Please, select your gender choice)

Male	
Female	

Email:_______________________________________

Your discipline

1. Architect
2. Building service and structural engineer
3. Cost consultant
4. Lead designer project
5. Construction lead
6. Other…………………...

.

2 Which is your role within the design team you are working in?

(Please, select your choice which is relevant.)

1. Senior
2. Junior
3. Internship
4. Others………..

How long have you been in your role?

1. 1-5 years
2. 6-10 years
3. 11-15 years
4. 20-25 years
5. More than 26 years

How long have you worked in the profession?

1. 1-10 years
2. 11-20 years
3. 21-30 years
4. 31-40 years

More than 41 years

What kinds of projects do you engage in concept design?
3 (Please, select your choice which is relevant.)

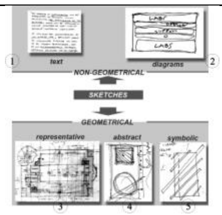
1. Residential
2. Health facilities
3. Academic
4. Commercial-retail
5. High right building
6. Complex building

What size of project

1. Small building
2. Medium building
3. Large building

No.	Objectives	Questions	
1	To identify procedure and practice of the current existing collaboration process among multidisciplinary team at the concept design stage	4	Should conceptual and schematic design be a collaborative design process to enable work across the multidisciplinary and multifunctional team? Do you have any comments?
		5	How do you collaborate design projects in concept and schematic design process? Describe how do you collaborate design projects in concept and schematic design process?
		6	Usually, there are professionals who engage to work together in design process such as architect, building service and structural engineer, cost consultant, lead designer project and construction leads. Which other stakeholders should be engaged in collaboration of concept design and schematic design stages? Why?
		7	How many people engage in collaborative design at the concept and schematic design stages for each project? 1. Small building: ________________ 2. Medium building: ______________ 3. Large building: ________________
		8	How many ideas do you develop in concept design? 1. Only 1 2. 2-3 3. 4-5 4. 6-More
2	To identify any problems currently experienced in communication and collaboration at the concept design stage	9	What are the problems facing collaboration in concept and schematic design process?
		11	Do you think that there are any barriers stopping collaboration in concept design stage? How could the barrier be removed?
		12	Do you agree that both misunderstanding and interpreting information creates problems in communication in collaborative design due to different experiences and backgrounds of participants for concept design process? How do you solve the problem?
		13	Do you think that all multidisciplinary teams should have a director to monitor all contents of communication in team to prevent any conflict? How do you solve the conflict problem?
		14	Besides yourself and colleagues building knowledge, understanding other disciplines is also important to enable collaboration among those multi disciplines from different backgrounds and with different experiences.

<table>
<tr><th>No.</th><th>Objectives</th><th colspan="2">Questions</th></tr>
<tr><td></td><td></td><td></td><td>Do you agree with this statement?
How do you achieve this your projects?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">To identify experiences of problems of using current tools for collaboration in concept design stage</td><td>15</td><td>Please, tick level of appropriate tool (where 5 is extremely good and 0 not suitable at all), and which tool is it appropriate to assist in creating and developing new design ideas in concept design process?
<table>
<tr><th>Scale</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>No idea</th></tr>
<tr><td>Sketch; based on paper</td><td></td><td></td><td>x</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2d CAD software; 2d AutoCAD</td><td></td><td></td><td></td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>3d CAD software; 3ds Max, FormZ, Rhino, SketchUp,FormIt360, 3d AutoCAD.</td><td></td><td></td><td></td><td></td><td>x</td><td></td><td></td></tr>
<tr><td>BIM software; Revit, ArchiCAD</td><td></td><td></td><td></td><td></td><td></td><td></td><td>x</td></tr>
</table></td></tr>
<tr><td>16</td><td>Do you use any computer software for concept design?
Yes or No If Yes….
Does the computer software has the capability to be used to support you in concept and schematic design (Please describe)?</td></tr>
<tr><td>17</td><td>Some argue that sketch is an admired tool to capture ideas in concept design – and it cannot be substituted by computer software.
Do you agree with this statement and could you describe your thoughts?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">To allow user participation and identify factors which may assist in resolving current problems experienced of using the current tools for collaboration/ working together</td><td>18</td><td>What aspects of the computer software; BIM&CAD tool, be improved to support designer’s critical and creative thinking for developing concept design. Why?</td></tr>
<tr><td>19</td><td>What aspects of the traditional tool; sketch based on paper and pencil, should be improved to support designers for developing concept design? Why?</td></tr>
<tr><td colspan="4"></td></tr>
</table>

No.	Objectives	Questions	
5	To identify use sketch in Thailand	20	 According to the picture above, what types of sketch do you use to create concept design and schematic design?
		21	According to the previous question, do you think what you will use in communication or collaboration with your colleagues? Why?
6	To identify user requirement for retrieval of information from the process of communication and collaboration	22	Is it important to preserve the contents of discussion among participants in concept design? Why?
		23	How do you manage/store contents of design information from collaborative or individual design at concept and schematic design such as previous discussion, sketch, or other notes? Are there any problems?
7	To collect user requirements for developing communication and collaboration tools (if they can identify)	10	Do you agree that the ICT tool for collaborative design should enhance participation for specialists' co-location and "desynchronisation" requirement for information exchange in the concept and schematic design?
		24	Someone argues that sketch was used to share ideas during the process of collaborative at the concept design stage. If it will be developed for collaboration in concept design, what aspects of the sketch (will be developed as digital sketch) can be improved to enhance designers' ideas?

Appendix 6
2nd Ethical Approval from the University of Salford

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

24 May 2018

Dear Tirat Jaraskumjonkul,

RE: ETHICS APPLICATION STR1718-27 : A digital prototype for collaborative conceptual design

Based on the information you provided, I am pleased to inform you that your application STR1718-27 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Dr Anthony Higham
Chair of the Science & Technology Research Ethics Panel

Appendix 7
2nd Participant Invitation Letter

.....
PhD research student
Room 504, School of Built Environment
5th Floor, Maxwell Building,
The Crescent, University of Salford, Salford
United Kingdom, M5 4WT
Tel: +44(0) 161 295 7305
Email: ...

University of Salford MANCHESTER

A digital prototype for collaborative conceptual design.

Dear Madam/Sir,

My name is ... and currently studying PhD at the School of the Built Environment, The University of Salford in the UK under the supervision by Dr. Mark Shelbourn, and co-supervision by Professor Jason Underwood. The title of my doctoral research is "A digital prototype for collaborative conceptual design". The main aim of the research is to: To investigate how electronic sketching could improve conceptual design team collaboration in Thailand. The electronic sketching is a digital prototype developed to enhance real time collaboration and communication in this research.

This study will gather experiences and views of professionals which may be architect, building service or structural engineers, cost consultant, lead project designer, construction lead within the context of the AEC industry projects in Thailand.

Your cooperation is most essential as the successful completion of prototype evaluation could be beneficial information for developing a future digital tool which will be available to the AEC community to enhance real time collaboration and communication between the design team in the concept design and schematic design. All responses to the evaluation process of prototype would be kept strictly confidential and will only be used for academic purposes only. Once a process will be completed and analysed, the original data will be shredded.

Unless requested, the data collected will appear anonymously in the final PhD thesis and other related publications such as local and international journal. To ensure anonymity, no personal details or details about the organisation will be disclosed.

Thank you.

Best regards,

Appendix 8
2nd Research Participant Consent Form

Title of Project: A digital prototype for collaborative conceptual design.

Ethics Ref No:

Name of Researcher: ...

Please tick the appropriate boxes	Yes	No
Taking Part		
I confirm that I have read and understood the information sheet for the above study and what my contribution will be.		
Email of research is shown so that I will have the opportunity to ask questions about the project.		
I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.		
Use of the information I provide for this project only		
I understand my personal details such as my name and email will not be revealed to people outside the project.		
I understand that my words may be quoted in publications, reports, web pages, and other research outputs.		

Name of participant ……………………………………………

Signature

(Digital signature is available) ……………………………………………

Date: ……………………………………………

Name of researcher taking consent: ...

Appendix 9
Participant Information Sheet

Research Title: A digital prototype for collaborative conceptual design.

I would like to invite you to take part in a research study. You need to understand rationales why the research is being done and what it would involve for you. Please take time to read the following information carefully. You could email to ask questions if anything you read is not clear or would like more information. Take time to decide whether or not to take part.

This study is a part of PhD research; the research will focus on developing a digital prototype for collaborative design among designers; architects, engineers, and relevant stakeholders, in architectural concept design. The evaluation needs recommendation of participant to use the prototype in practice at concept design and schematic design. The outcomes will be useful and important for developing tool of collaborative design and disseminating to AEC community in the future.

What is the purpose of the study?

Develop a digital prototype which will assist all designers to work together in developing from abstract to concrete ideas at concept design and schematic design in Thailand. Thus, this study is process of prototype evaluation for collaboration and communication.

Why have I been invited?

You are closely relevant in concept design and schematic design in terms of professional practice in architect, engineering, cost consultant, lead designer and project construction lead. Your recommendations will be crucial parts for this study to reveal the agenda improved.

Do I have to take part?

It is up to you to decide. We describe the background and objectives of the study and go through the information sheet, which we provide them to you. We then would like to ask you to sign a consent form to show you agreed to take part. You are free to withdraw before the day of the evaluation prototype, without giving a reason.

What will happen to me if I take part?

1. All information is introduced and briefed in term of test procedure, equipment, place of test, and specific instruction. All activities will be recorded in the room by a digital camera.
2. A presentation of using prototype will be demonstrated to participants. After demonstration, they will be encouraged to ask what they need to know.
3. All participants will be encouraged to play the prototype each other.
4. Participants will be asked to do the questionnaire of Software Usability Scale (SUS). It is a hard copy which will be stored in safe and secure place with limited access like me and my supervisor.
5. All participants will be asked to put on a small camera for recording using prototype. Collaboration and communication tasks will be completed and recorded by the small camera.
6. Focus group uses parallel thinking to encourage all participants to describe what they think. The six thinking hats technique is used and colour hats will be prepared and asked them to put on between talking each other.
7. Some participants will be asked to interview by face by face in terms of this process in another day.
8. The session of evaluation process will take around 3 hours.
9. All electronic data will be password protected. All data will be backed up on could drive and stored in another safe place in case of losing and piece of data.
10. Your all answers are beneficial for the study. Your answers will be treated as qualitative data and will be analysed through one of the analysis methods.

What are the possible disadvantages and risks of taking part?

There are not any disadvantages or risks in this study.

What are the possible benefits of taking part?

We cannot promise the study will help you but the information we get from the study will help to increase the understanding of current performance of collaborative design and tools for concept design process. In addition, the needs of designers will be also revealed in terms of collaborative design tool which are important for developing the tool for collaboration and communication.

What if there is a problem?

If you have a concern about any aspect of this study, please contact the researcher by email who will do their best to answer your questions.

Will my taking part in the study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential, and any information about you which leaves the university will have your name and address removed so that you cannot be recognised.

What will happen if I don't carry on with the study?

You can withdraw from the study but keep in contact with us to let us create a link in the academic communications. Information collected may still be used. Your information such as questionnaire, or data from interview that can still be identified as yours will be destroyed if you wish.

What will happen to the results of the research study?

All the results will be used to validate the initial digital prototype of this research. Part of the result will be published. You will not be identified in any report/publication unless you have given your consent.

Who is organising or sponsoring the research?

Salford University

Contact details:	Ph.D. Student School of the Built Environment University of Salford 4th Floor, Maxwell Building The Crescent Salford, Greater Manchester M5 4WT
Researcher Name:	...
Phone No:	...
E-mail:	...

Appendix 10
2nd Questionnaires

Research Topic: A digital prototype for collaborative conceptual design

Overview of the Research Study

This survey is based on an ongoing PhD research study. The aim of this research is to develop a digital prototype to support collaboration among multidisciplinary professionals at concept design and schematic design in Thailand.

Questionnaire Survey Instructions

* There are no right or wrong answers to the questions in this survey. Select the most appropriate answer for each question based on your view/experience.

* It is necessary in this study that all questions are answered, as the questionnaire is designed to achieve particular research objectives, and it is hoped not to offend respondents in any way. If there is question(s) that you are unwilling or unable to answer, you may skip to answer it and continue answering the remainder of the questionnaires.

* Remember that both your identity and that of the company you work for will remain strictly confidential.

Q1. – Gender

Male ☐ Female ☐

Q2. – Age

____

Q3. – Discipline

____

The SUS questionnaire will be used in session of prototype evaluation.

No.		Strongly disagree			Strongly agree	
		1	2	-	4	5
1.	I think that I would like to use this system frequently.			Not selected		
2.	I found the system unnecessarily complex					
3.	I thought the system was easy to use					
4.	I think that I would need the support of a technical person to be able to use this system					
5.	I found the various functions in this system were well integrated					
6.	I thought there was too much inconsistency in this system					
7.	I would imagine that most people would learn to use this system very quickly					
8.	I found the system very cumbersome to use					
9.	I felt very confident using the system					
10.	I needed to learn a lot of things before I could get going with this system					

Appendix 11
Focus Group Guide

QUESTIONS IN THE FORCUS GROUP

Q1: "How do you think you would feel if you use current tools for colocation collaboration, delocation collaboration, and mix process of colocation and delocation collaboration?"

Q2: "How do you think you would feel if you use this prototype for concept design in design team collaboration?"

Q3: "What are problems in terms of collaboration and communication at concept design in Thailand (colocation/ delocation/ both coloation and delocation)?"

Q4: "What are problem of current tool if your team works together in case of colocation/ delocation/ both coloation and delocation"

Q5: "What are the weaknesses of current tools for collaboration and communication that we need to improve?"

Q6: "For collaboration and communication in concept design, what are weaknesses of the prototype are?"

Q7: "What are its advantages if the prototype would be used for design team collaboration in concept design or design?"

Q8: "How can advantages of using the prototype improve design team collaboration?"

Q9: "What do you take this prototype in AEC practice?"

Q10: "How do you use this prototype to improve problems of design in practice?"

Q11: "How can the prototype improve design team collaboration at concept design?"

Q12: "What are your recommendations to use this prototype to improve design team collaboration?"

Appendix 12
An Example of Focus Group

Red hate: Focus on feelings

RQ1: How do you feel when you are using the current tool to design a concept design in different place (De Location)?

J: It's slow. Today, it is analogue. After finished sketching, first person, architect have to summarize it. When an architect thinks, it may have limits for other parts. When we got a model, and the rest of team continue doing it. It turns out that they have to follow my idea. If we can do a brainstorming in a first place, the work is better than I work by myself. And they might feel like they just follow only. No passion, something like that. It's not motivated. But we focus on work, we've a time limit to control us. So, they follow me, they have no right to argued with me much. They had to follow which they might have better ideas to do but not in a good rhythm to do. Because of different locations. It's impossible to do a brainstorming at the same time.

K: My idea is similar to Ji. It may cause a delay. But I want to add that one thought maybe one point of view but with sharing, others can add a bit here, and there to fill in that work.

Researcher: As far as you use a current tool, do you have any problems to work with others who is not here?

K: I would say from my experience. I started by myself. It's not in a team as Ji to share jobs. Who sketch, who design, who do the draft. I may do like one person's job from the beginning till the end.

JM: Pretty much the same. It's not different much. A current tool is just for a designed, so far I use. I have to call for a meeting. Then redesign, it causes a delay to work.

J: Sometimes we disagree with other, but we came after them.

JM: I barely face this. Mostly they discuss and send the task to me. The constructions have to go through the design or owner first. I barely meet them as well.

Researcher: Do you meet them during calculate structure or design concept?

JM: No, just manage work.

RQ2: and what do you think of this prototype?

JM: It's fast. It's faster than a current tool. It can see the image clearer.

K: As far as I use, if I got this to work, everyone sees the ideas together. I feel like we are a team work more.

J: I am excited. It is a tool that even though we have an Internet, conference video call but it's not a mix like this. We draw lines, pictures and other can mention its dimension. Try this way- if they speak after the time passed, it's too late. But if we discuss since the first day, we have our own reason. We communicated although we are in different locations. We share ideas, which is better. We tell pros and cons then accept them. I mean the work, is from a brainstorming so it should be better than a one man work that let others solve the problem afterward.

Black hat: Focus on experience, logical thinking, reason, criticize

BQ1: What are the problems caused by communication at the present when your team works in a different place (De-location)? What are they?

J: Miscommunication. We understand one thing. Just a word, work together. We talked and we thought he understand the same, but he understands the other way. This is one problem. The second one, we separate the task clearly in Thailand. If it involves with shapes, it's architect's job. Truly, it includes system, air conditioning, fire session but scope is a clear cut. An architect doesn't have any knowledge like my previous work that involve with fire protection or smoke protection. But when it comes into shape. An engineer would say that he is only a system supporter. He doesn't do this, but he should. This small thing becomes a problem – who will do it.

K: Working together, I think it's not only a designer team. It includes an owner to have his concept or his requirements perceptibly. It helps designers, like architects, interiors or other part mistaken the concept. It might cause the problem since the beginning.

JM: Due to the structure and architect. It will not be consistent. If he came later, we have to discuss the plan with him- make it consistence. What I met, we didn't do or understand the same page. Now we are redo the plan and cost for owner. The owner concerns about the cost when we offer. He doesn't like it so we have to do like the old plan.

BQ2: What are the problems from using current tool while your teams are working in different places (De-location)?

J: Send via email is a problem. Simple problem is that program with different version, can't open. Then working style is different. Like the office here, each one is in order. But if it's an interior, everything is like a bomb. Previous work is like CAD for both engineer and architect. The system is similarly. Xref is the most stable. If it's an interior, an interior will export everything. File is a mess. Finally, an engineer continues work and has a problem. This is just a beginning.

A tool like email – got error. Nothing more. About timing, when we sent the data but in a bad timing, so it got delayed until it got solved. This is the tool we are using. It takes energy out. The second person is waiting for the first one. The second one edit, then the first one edit. It is wasting time.

K: For delay, and complicate working. It's like edit and reedit.

Researcher: Now which tool do you use with long-distance co-workers?

K: Normally email, Line to contact customers.

Researcher: Does it have any problems?

K: Maybe about time. It's inconvenient to respond. He might not be able to answer. Sometimes contractors got annoyed.

JM: When I worked with a contractor at the front site, he told, and I sketched. Then I worked it in CAD like he sketched. I had to ask him again. Sometimes the picture is unclear in Line. Sometimes we're not sure so we have to go back and ask. He wrote details and it's better – already wasting time. Most problems are from human. Some don't understand how to use the program. The current tool is just ok.

K: This is another important point. K used to face at front site. Incorrect installed or we want to add more owner's need. We have to add extra things and sketch. It's tough. Sketch, then take picture and send. But this one, I sketch and see it. Doesn't need to repeat.

BQ3: What are the weaknesses of communication tool and co-working at the present that you want to improve?

K: It makes work complicate. many steps. It's not done. The current tools like application, sketching, I have to capture and send.

J: Even sent, it doesn't mean that it's done. The other side may or may not understand. We kept going until we are on the same page. It took times. The weak point is it can't be done within one shot.

K: We may focus here but others may focus on something else of this picture. But this one, it has a mark to show.

J: If it's finished in one application, it's ok. But this isn't. We use Line – just to communicate, AutoCAD is drawing the plan, but he couldn't draw without our email. The weakness is if we would have something that can do everything. If we finish the plan, everyone agrees and send to others without changing the application.

Yellow hate: Focus on positive thinking.

YQ1: What are the advantages if this digital prototype was used in the design process as a team?

JM: We can solve at the right point. We can edit anywhere, we can do it. It helps us working faster.

K: It makes the process less complex. The work is a clarity because we will focus everything in an idea. Not only in sketching or in the messages. It helps us work in team.

Researcher: Let's change the flag. This is a problem. Previously, you listed a problem that unclear working, how is it?

K: If we use this prototype, its benefit is that less complex working. But today is a complicated working. It has to use many applications before we send to others. Maybe some- with responsibilities. When we use this one, it answers propositions well. If the jobs are crossing, you can use this one to edit with others.

J: It reduces the overlaps and time saving. Another problem is that re-editing. But this one will help it finished in the beginning. Not like started building by one department, then another one saw the mistake and have to edit. This one would save time.

YQ2: How does the advantage of this prototype improve a teamwork?

K: Like I answered in the first question about complexity. This answer is agreeable with the first one about timing. There is a complexity, it involves timing. So for a second question, it helps about timing. It's faster, not slow, no delay in decision making. Any complexity can be clear right away.

J: It's like we think together in the same direction since the first day. It's like we can have a meeting all the time. In fact, it's not. Then this one is good because we don't have to be together for a meeting. We can have a meeting in a different location and share ideas since the first day. And we can notice the project's limitations, its causes, and what the limitations are. Everyone would know as same as we do about the limitations – how to solve them. This program reduces the working problem – not only time but also redo the work.

Green hat: Focus on new idea/innovation

GQ1: As in the professional practice of architecture, engineering and construction (AEC: Architecture, Engineer, Construction), What will you do with this prototype?

K: Maybe it's about a concept design. When we finish it, we can merge the file or picture to continue in the process and keep going.

Researcher: According to your answer, what do you think? Can an engineer use this one after we finish a concept design? Can we apply with something else?

JM: Maybe with a structure design like the steal in the beam … how to put it, something like that. Beside the concept design.

K: It is something that can apply with, beside a concept design? When the concept is done, next one is a process like planning design or electricity system- can be used in this one. Engineer or electricity or constructing structure – this can solve them at the same time without us using CAD. Some device may have a problem opening that file version. We can work full and may complete within that meeting.

J: I think it is ok too. It can be used every step – from concept to construction. Because of the construction. It always changes. Its errors are from constructors or structure design. This can solve the problem with everyone's agreements at the same time. For instance, we have a limited space. But the design is not working so the front man may revise its structure to provide more spaces. He can ask an architect if he does it, will it have any impacts. If it's like, is an engineer ok with it? It's done. Now, what we are doing, if it's not as a plan. There are many documents sending to us to adjust. Every time, an engineer or an architect have to go there to get it done. With this prototype, three people can discuss right here. An architect focuses on the beauty. In case, it's not beautiful, can you make it like this? An engineer focuses on its strength. A constructor focuses on its simple of construction. It is like the problem is speeding and don't have a site meeting. Like they said about their problems which caused after a construction has begun. Then the architect jumped in. With this prototype, it has a meeting. If an architect designed like this, maybe he can't because it takes the force. It has beams. If an architect doesn't want any beams here, then they have to move it. I think this one can help well. Like this sample, an architect did. We didn't concern about inside space like an interior do. An interior may want a space like double floor or something. An architect has to check if it's possible zoning and discuss with an engineer. Will it cause any problem or request more space there? It can help designing. Although the designed finished, three sections have to work together.

GQ2: How can you use this prototype to improve your professional practice?

How is the work of architecture, engineering and construction like in Thailand?

K: I work in designing area. Most project is involved with hospitals. Working step is as usual. Brief information from customers and turn into plan, check plan, edit and edit. The problem is often from customer's requirements. They don't know what they want but ask us to do it first. When other careers jump in, like interior, found out that it's not what they want or want more. He will redo all. On the other hand, the owner has no idea of their desire and keep us doing the models until they notice. Architecture must work under pressures to make a blueprint. Maybe because of its complexity. But some projects, contractor can create a blueprint on his own. Unless, it's too complex, the contractor won't do it.

Researcher: In fact, we need to focus on the beginning design, such as programming, concept design and design & development.

J: Yes, if the programming is clear since the beginning, it is good. But mostly, it isn't clear here. If it is the same project, he copies from his competitor's and make it better for him.

Researcher: And who does the programming?

J: Mostly, architects. If it's engineer, come when things fit perfectly. But interior didn't join during programming. If possible, they can, it would be great. They could understand that this space is what I want; the architect will set a zone. They can discuss in construction perspective. Is it possible or it isn't? If they want a double space, they have to work together since the beginning. In Thailand, it's not like that, hardly.

Researcher: Architecture schools do not teach and delve into programming.

J: Do not wait ... like to use skills to do repeatedly.

Is it similar in the interior area?

K: There are changing. When interiors got assigned a building frame. Though we use the same zone or function or maybe changing something new. It may affect the light channel or building image that architect has designed.

J: It's like repeating work twice.

K: And for engineer, how is the overall?

JM: When we got the plan, we can build general structure, but later on, architect who got hired after starting, usually change the first design structure. It changes quite a lot.

Researcher: What's happened?

JM: At first, owner hired us to do both inside and outside. But when the owner know his needs, he started to hire architect. He chose to hire right position for each job. But in this case, it started with structure first. The architect came too late, nearly it's done and there are many changes which we have built a lot.

J: He tried to reduce costs by using design and built (Turn Key).

JM: Yes, that's about the structure and the strength. We have to recalculate. It's hard here and got accelerated. So, it is difficult.

K: The owner might be confused what he wants at first and he probably didn't know about this process.

J: Yes, he changed often.

J: Nowadays is more complex than the past. We have a lot of work to do. Previously we finished designing a building. That's it. Now is not the same. We have to work a lot more. But the compensation did not increase.

Researcher: When we work in co-location style, same table, how should we communicate when everyone works on their own?

J: Beside chatting, I want to have notes and chat and we can sketch at the same time.

K: I agree to use notes or chat to improve communication, to store necessary data. And sometimes, one talk but disturb another's work.

J: Previously, we had to call a week or two weeks. Or when one party is done then we hold a meeting. This prototype will be able to talk and work together. And there will be another meeting to confirm.

GQ3: Can Digital Prototypes improve or correct the problems of the design team together during Concept design and Schematic design?

K: I can summarize in the basic design, such as Concept or Schematic. When you sketch in several pages. Then you merge them in the same page or files with in same link. It can be seen as a large scope in the same place.

Researcher: The problem is that it will spread. This tool will link them together.

J: Because some are not the same view. An engineer might see one, an architect focuses on another or an interior look on something else. Then they merge these three points to see a point. They notice what would happen if they want it like this since the first day. These get everyone together from start. He mentioned to do like this, to take a long span or that. Is it possible or impossible? Does it have any limitations? It's about a right design with possible scope. Normally, an engineer is waiting there until we got things done and check with the plan. Sometimes we forgot about the cradles. If we use this, an engineer can tell an architect from the start. To tell limitations about design. Which one is possible or impossible? If we can accept, both Concept and Schematic can pass without solving problems later. It is like reducing conflicts. It's not exactly a conflict but probably couldn't see all side. I mean, when we design, we focus on spaces, or plate. Then he joins and puts beam there and there. What we thought of, it got decreased. But if we know that we want this long span, we have to lose this space since then. The conflicts maybe less. It is not a conflict but can't see all angles. Everyone focuses on their professions. If we brainstorm, we see the problems and know the direction. Therefore, there is no redesign for both Concept and Schematic.

Researcher: As an engineer, JM, would you contradict or mention a problem since the beginning?

JM: I would. I have to. If you design this, the structure would be like this. I have to tell him to change or change the structure according to the design.

Blue hat: Brainstorming From 5 hats,

Q1: Can you suggest this digital prototype to solve problems and design together as a team?

JM: It's quite convenient and direct communication. It's easy to work, much more than using Line or other applications.

K: It can be used, not only with AEC. It can be used even with graphic design.

Researcher: This one is actually in the yellow hat; positive thinking.

K: Even with advertisement, they can use. A creative designer can use too because they have to explain with image, storyboard, maybe a roughly sketch.

Researcher: If they discuss something else, talk with a client or others.

K: We may deal with a technician, we can sketch a design with him or sketch a draft to show a client. From this zone to that zone roughly to with customers – as interior style. But for me, I see a wider view for many occupations to use this prototype. It can with various career, including students to present a schematic design. The students will be convenient this day. They have a communication tool. They would enjoy working more. Compare with me, when I was a student. I didn't have anything like this. I had to carry all equipment and it is baggy. This one is convenient, and every career can use to present their ideas.

JM: I recommend every step. I recommend since starting the concept. It's like every hat said. It should have every section – owner, engineer, interior- to brainstorm from a start. Maybe the owner has no idea but join with this. He knew the idea and told us if it's not what he wanted. He could tell us if he wanted like this. It may not be the same direction, but we can adjust it more concrete. Everyone shares their ideas- what should or should not. Each person has his own point of view. It's not as widely as others but working together, can see them all. And we can have a same agreement so there are less problems. Like, I only do my job, I didn't give the idea, so I got nothing. So, everyone wants to have this, this is a result. It's not like you edited, you fixed it. I didn't think so I don't fix it. This will save cost, time and other things. If you can develop this prototype, not only for IOS. It should work. It is fascinating.

Researcher: K mentioned using in Education. If I invite you to be a lecturer using this tool. Will it have any benefits? I mean the students use this tool and so you do too.

J: It doesn't have to be like this or as checking.

Researcher: Both ways, even with de-location.

J: As checking, it works well. I was invited to talk about this once. They didn't understand much but they have to do a project after that and check by themselves. They didn't want to disturb me. But with this one, it's not a record. When you finish, you send to me. I can explain the students. It's saving resources. I don't have to fly. I don't have to be in a same place to explain. It's good for teaching too.

Appendix 13
Interview Guide

INTERVIEW GUIDE

Q1: How is over view of all the process?

Q2: How is your feeling to be encouraged to play the prototype's interface after demonstration?

Q3: How is the each task of playing the prototype?

Q4: How is your feeling to engage with the focus group which uses this technique of the six thinking hats?

Q5: You think how the parallel thinking in the six thinking hats is?

Q6: What are disadvantages for the six thinking hats technique used in the focus group?

Q7: What are advantages for the six thinking hats technique?

Q8: Do you have any suggests in terms of future evaluation of digital prototype?

Appendix 14
An Example of Interview

Q1: How is the overall process?

K: I think it is innovative to know this application. Today we tested and learned it briefly from a demonstration. After I tried it, I know it could be an answer in what careers. It is a good answer to working problems.

Researcher: About 3 to 4 hours, is it too long or too short? Or shall I add more better tracks ?

K: In case that the application has more features, you may add up but the duration is expanding too. We may divide into parts. Like this part, it takes 2 days for a meeting or cut it shorter. Or explain roughly its instructions for problems in specific areas such as engineering, and architecture. Each group may have various aspects to try out. You can explain overview what we can try.

Researcher: Do you want to take a longer period?

K: I really want to. Either more hours or shorter hours but I want to know all information. To know what it can do. I heard that there is a picture importing function.

Researcher: If the time takes longer, is it ok? Or divide into morning and afternoon session?

K: Maybe morning and afternoon session.

Researcher: If I divide into morning and afternoon session, there are 6 hours. How about I invite to test the prototype about 6 hours? How do you feel?

K: About a day with a break.

Q2: How do you feel to get supported to test this prototype and be a part of it after prototype demonstration?

K: I feel excited and enjoy. I have a new toy to try. It involves with our career directly. Because I normally turn on my computer, the program and work or sketch with pen, papers only. But if I have this, I can do with my smartphone or iPad. It makes more comfortable. I understand that sometimes we work, rest. But when we work outside, we probably bump into something interesting, we can sketch it with this application like interior design or other details. I think this one is ok with my work. With another one, I’m having problems with work, we have to discuss at front site. With this one, we can take picture outside and send into group to share it – whether this detail is ok with our plan. I am happy with this one.

Researcher: Was the lecture boring?

K: Yes, it was. Because I only listened to. Like we listen to a teacher teaching something and we didn’t play with him. If we could play while you were teaching us each point, I could remember better. It would be a fun learning.

Researcher: Do you remember after test it?

K: I remember roughly that we have to start with this one first. What this bottom is for linking others to see. We input this picture for grouping. Due to the duration and get familiar with the tool in the first time, I may remember. If it is a tool in an application, I think it’s more convenient.

Q3: how was it to get encouraged to test in the various sections with this prototype?

K: I think it is ok to use it. We can note and mark in it to edit or add something. In working case, I suppose sending just a picture and write wording for next picture. They might not see the point that we asked them to fix. This one is a focus. Instead of circle it, we could point it out where to fix it.

Q4: How do you feel to join a group interview that using six thinking hats techniques?

K: I think it shows opinions in orders like 1st, 2nd, and 3rd answer in each content. They are in important orders. This is a benefit in six thinking hats. It can branch in each color aspect clearly.

Researcher: Do you feel it is too detailed?

K: Yes, I do. Because I answer and it covers all. But with more details, it reminds us to realize that it has more details. Like I answer overall for one question. When it is specific, I notice that I might skip this part.

Q5: What do you think of parallel thinking in six thinking hats?

K: Parallel thinking is a sharing opinion. Everyone has various ideas. For those who create program, they can get various ideas to answer or continue from that idea.

Researcher: In the future, does this application should have this technique in it? Like six thinking hats discussion.

K: Probably a few colors are better to discuss and share opinions.

Q6: What is a weakness of using six thinking hats technique to collect a group data?

K: There are many various ideas. They just flow but still in the frame of six thinking hats. It has its theme. There are more advantages than disadvantages. The weak point is that has too detailed about time. But it has more benefit than weakness. It can go into details that we might forgot to think of. The weak point is about timing. It took too much time. It isn't concise.

Researcher: Can you explain "too detailed"?

K: I'd say "more detailed". We can go in depth in each part, each color because someone may answer quite narrow but with sharing ideas, we can continue and have more depths.

Researcher: What do you think if I am as a program conductor and I think this is another point of another color, then I change the hat color and back to a different color?

K: It should be in each color a time. Although the answers might jump around but if you brake "that is in this loop." It should be in each loop.

Q7: And what are the advantages of using this technique?

K: After I use this one, we can tell others that this application answer questions in most career. Every career has a creativity. Even we talk about online vendors. I think they have to discuss with the companies or their representatives to produce or design products. They can use this application to work. If this application is done, most occupations can use it. The advantage is that it answers questions all the time like Line, Facebook, IG. Everyone uses them. This one answers even with students.

Researcher: Any the advantages of using six thinking hats to collect a group data?

K: Everyone has his rights to share opinions. This is an advantage. It opens mind to see how far we can push it to the top.

Q8: Do you have any recommendations about this digital evaluation process in the future?

K: A process that can teach using program. We learn it without opening the program. It is like a story telling. Supposing, the prototype has nodes to create image, change colors, import, group and individual work. It explains briefly and let us test along with. It may cut down the time. The clip may be in a minute to watch and learn. It should be fast. We can try while you are teaching. It will be faster. It may not reach 6 hours.

Researcher: And how about working in group?

K: It's a duration. It depends how fast you can type. With manual, it is easy, so it is faster. But the one with A, B and the A, B, C, conversation should be an overall conversation first. Because person A or person C will notice person A's process or have to wait orders from person B or C, like a dialogue.

Researcher: Are 5 steps ok? Shall I add anything else or should we focus on timing?

K: Focus at timing. Like we are advertising them to know its specialties and play along with. Or tell briefly in that clip about its functions, its features then try it. That would be faster.

Researcher: Do you have any suggestions for parallel thinking?

K: It depends on a person who answer or give suggestions. Each person spend time wisely because they think a bit then answer.

Researcher: The timing set at 20 minutes to build your structure idea. Is the time enough? Is there anything else or do you want to use a real hat instead of flag?

K: Timing is enough. I think everyone focus at the same point. If it is a hat, everyone doesn't see it. This light up the interview more fun. It supports the application more joyful, not stressful and not nervous.