CONCEPTUAL DESIGN PROCESS IMPROVEMENT FOR DRAINAGE SYSTEM USING PROJECT MANAGEMENT

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ปัญหาหลักในอุตสาหกรรมด้านการออกแบบ วิศวกรรม และการก่อสร้าง คือ เรื่องของเวลา ต้นทุนและ คุณภาพ การออกแบบโครงการอาคารอุตสาหกรรมมักมีความยุ่งยาก โดยเฉพาะอย่างยิ่งในด้านการบวนการทางระบบ mechanical และขึ้นตอนการออกแบบระบบท่อ ในช่วงกระบวนการออกแบบเชิงความคิด เนื่องจากมีผู้เกียวข้องในโครงการค่อนข้างมาก

บริษัทที่เป็นกรณีศึกษาซึ่งเป็นผู้จัดจำหน่ายเฉพาะทางด้านโซลูชั่นท่ออุตสาหกรรมในประเทศไทยได้รายงานในประเด็นของการออกแบบใหม่เกี่ยวกับการจัดการโครงการที่ไม่ดีของกระบวนการออกแบบเชิงแนวคิดในโครงการก่อสร้างซึ่งส่งผลกระทบต่อประสิทธิภาพในการทำงานและความพึงพอใจของลูกค้า ดังนั้นการวิจัยครั้งนี้จึงมีวัตถุประสงค์เพื่อปรับปรุงกระบวนการออกแบบเชิงแนวคิดโดยใช้แนวคิดในการจัดการโครงการเพื่อลดจำนวนการออกแบบใหม่ในขั้นตอนการออกแบบเชิงแนวคิดสำหรับโครงการออกแบบการระบายน้ำฝน กระบวนการออกแบบเชิงแนวคิดใหม่นี้ได้ถูกนำเสนอใน 4 ขั้นตอนคือการเริ่มต้น การระบุ การแปลง และข้อกำหนดทางเทคนิค ขั้นตอนเหล่านี้ได้รับการระบุไว้อย่างชัดเจนว่าเป็นกระบวนการป้อนข้อมูล (ด้วยแผนการจัดการโครงการ เครื่องมือและเทคนิคต่างๆ เช่น รายการตรวจสอบ แผนผังต้นไม้ ระบบโมเดล 3D และการตัดสินของผู้เชี่ยวชาญ) และผลที่ได้รับ

ทั้งนี้ ได้มีการทดสอบกับโครงการออกแบบสำหรับอาคารโรงงานและคลังสินค้าจำนวน 30 โครงการ ผลการวิจัยพบว่า จำนวนครั้งของการออกแบบใหม่ทั้งหมด (N) ลดลง จาก 102 ครั้ง เป็น 24 ครั้ง (จาก 30 โครงการ) ตาม KPI ที่น่าพึงพอใจของบริษัท นอกจากนี้ ยังสามารถลดต้นทุนในการแก้ไขแบบจาก 1,326,000 บาท เป็น 31,200 บาท และช่วยลดระยะเวลาในการออกแบบ จาก 327 วัน เป็น 212 วัน ดังนั้นแนวทางที่นำเสนอจึงได้รับการพิสูจน์แล้วว่าเป็นไปได้จริงและได้รับการปฏิบัติอย่างเต็มที่โดยบริษัท

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The major concern in the architecture, engineering, and construction (AEC) industry is time, cost, and quality. The design for industrial building project usually complex, particularly in a field of mechanical and piping process due to the large involvement of project stakeholders. The case company, which is the specialist supplier of industrial piping solution in Thailand, reported the issue of redesigns regarding to their poor project management of conceptual design process in construction project that effect to their work performance and customer satisfaction. Thus, the purpose of this study was to improve the process of conceptual design using project management concept to reduce the number of redesign in the conceptual design phase for storm drainage design projects. The new conceptual design process was introduced in 4 stages-Initialization, Identification, Translation, and Specification. These stages were clearly defined their input, process (with project management plans, tools and techniques such as checklist, tree diagram, 3D model system and expert judgment), and output.

This was validated with 30 pilot projects of storm drainage design in factories and warehouses. The results revealed that, the total number of redesign was reduced from 102 to 24 under the satisfied of company's KPI. In addition, the total cost of redesign was decreased form THB 1,326,000 to THB 31,200. Furthermore, the total design time from the start to finish the specification output was reduced from 327 days to 212 days. Therefore, the proposed solution was proved to be practical and fully implemented by the company.

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Chapter 1 Introduction

1.1 Introduction

The major concern in the architecture, engineering and construction (AEC) industries is the issue of time, cost and quality. The Conceptual Design phase is about the creation of solutions in order to meet the specific design specifications (Hsu & Woon, 1998). The design for industrial building projects is usually complex due to the heavy involvement of stakeholders eg. owner, designer, consultant, contractor, and specialist suppliers, particularly in a field of mechanical and piping (Gil et al., 2001).

Over the past two decades, research in construction has focused on the benefits of the suppliers collaborating through all the project phases (Sødal, 2014) in an effort to increase the project time and quality performance (Song et al., 2009). This is because suppliers in the construction industry have become more specialist as a result of more complexity of the construction projects (Baccarini, 1996; Quinn, 2000). The early collaboration in the creation of design teams by the stakeholders at an early phase will allow the design of the building project to minimize risk from the outset (Sødal, 2014). There is increased research of supplier involvement at the conceptual design stage of construction in other counties such in UK (McIvor & Humphreys, 2004), Korea (Song et al., 2009) Hong Kong (Lau et al., 2010), and Malysia (Nawi et al., 2014), however, most specialist supplier involvement in conceptual design seems to be addressed in terms of project perspective (Song et al., 2009; Gil et al., 2001) since conceptual design is a complex process (Song et al., 2009) eg. in planning and management (Gil et al., 2001). The improvement in conceptual design process, redesign and project development that affected the specialist supplier's performance in Thailand has not been investigated. In addition, the specific field of conceptual design for drainage system have never been focused.

Project management is an important method that aims to accomplish an objective of the project. Bibby (2003) mentioned that managing the design process by using project management has been implemented in many industries, including construction. Project management has been found to be an important contributor

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towards the completion of early design process or conceptual design process in construction project (Abdul-Kadir et al., 1995).

The current researches have played an important of using project management to meeting all stakeholder needs in design phase to reduce reworks and impacts at entire process (Gray & Hughes, 2007; Bibby, 2003). The industrial building project are involved to large stakeholders making more complex with planning and management (Gil et al., 2001). In industrial building project, the building service design such drainage system is usually carried out by suppliers. Design supplier companies view the conceptual design process as the strategies that need to be competitive for the design approval and also to reach the client requirements. From this view, the supplier companies should consider a management plans to control the design process and integrate the project management tools and techniques to refine the client requirements.

A project plan is an attribute within project management achieved by managing and controlling the design process. Bibby (2003) mentioned that a project plan is essential to improve the design process for effective design outputs and this can be carried out by the Project Manager or Design Manager. Baldwin et al., 1994). Gray et al. (1994) and Gray & Hughes (2007) have suggested the planning strategies to overcome the complex design process can include developing brief documents such as a brief procedure or report. Luecke (2004) also mentioned the importance of resource planning during the project process. Where the roles and responsibilities are defined for the entire project team throughout the design process (Kagioglou, 1998). Many literature sources were used to develop the different types of design plans such as Brainstorming, Meeting, Decision Metric or Analysis based on the appropriate design characteristics to assist the manager for planning and control of the design process (Cross & Roy, 1989; Crumrine et al., 2005; Varvasovszky & Brugha, 2000; Ormerod, 2005; Yu et al., 2006; Yu et al., 2005). Roberts (2014) stated that the successful planning of conceptual design should include the development of project charter. Mustaro & Rossi (2013) further mentioned that developing the project charter can help the manager to overcome the scope change problems. Besner & Hobbs (2008) also confirmed that approximately 12% of construction projects have used a project charter for a successful design planning and management during the initiation phase.

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The project team can gain a lot of support by utilizing well know Project Management Tools and Techniques. Their integration into the workflows can be a decisive element for success to achieve the required results for the client requirements. (PMI, 2013). The appropriate management tools and techniques that may support the system design include: drainage design in conceptual design process. Goral (2007) indicated that the risks in conceptual design process can be found and controlled early by using Checklists before the designer starts to create. Gu & London (2010) and Azhar (2011) mentioned that a 3D based system is used to cope with client requirements. Rondini et al. (2016) indicated that a Tree Diagram can been applied in the product service system design for the earlier defined client objectives. Gregory et al. (2006) mentioned that the Expert judgment technique is used to evaluate and make the decision, for example; how to communicate with project stakeholders.

Since the conceptual design process of storm drainage systems involves many project stakeholders systematic management from supplier companies should be deliberated in order to improve the operation design project performance.

1.2 Company Background

The case study company was founded in Thailand in 2002 and is a leading supplier of industrial piping solutions in building projects. The company manufactures and supplies innovative piping products, such as Polyethylene Pipe Systems, Glass Reinforced Plastics (GRP) Pipe Systems, Fire Protection Pipe Systems, and PP-R Pipe Systems as shown in **Figure 1**, to meet the various needs in the construction industry. Since 2010, the company has focused more on the service sector in order to gain traction in the architecture, engineering and construction (AEC) market by providing designs, material supply and installation of roof drainage system solutions. This will be the case study of this research.

Figure 1. Company's Product
Source: Case Study Company, 2017

1.2.1 Current Organisation

Currently, there are six main departments within the company: Engineering, Central Sales, Central Accounts, Central HR, Central Marketing and the Warehouse, as shown in **Figure 2**. The design of the drainage systems is almost exclusively conducted by the Engineering Department and the Sales Department. As per **Figure 3**, the company provides the design, material supply, supervision and installation of roof drainage systems. The design process includes 3 main stages, the conceptual design stage, secondly the detail design stage and finally the as-built stage.

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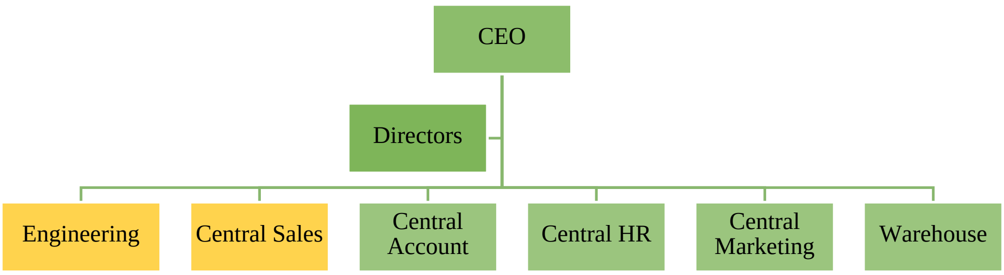

Figure 2. Organisation Chart
Source: Case Study Company, 2017

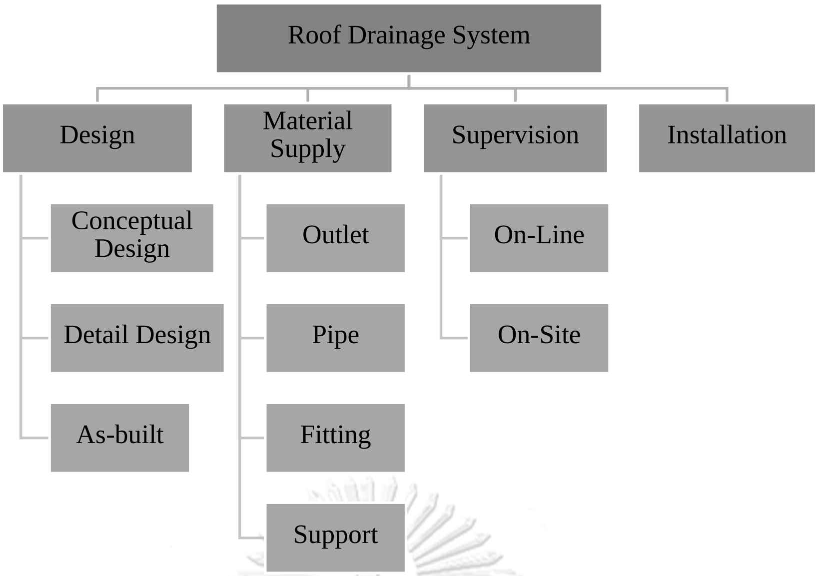

Figure 3. A generic product and service structure for roof drainage system
Source: Case Study Company, 2017

Figure 4 illustrates the percentage of projects involving various building types. The Factory and Warehouse category had the highest amount of design projects.

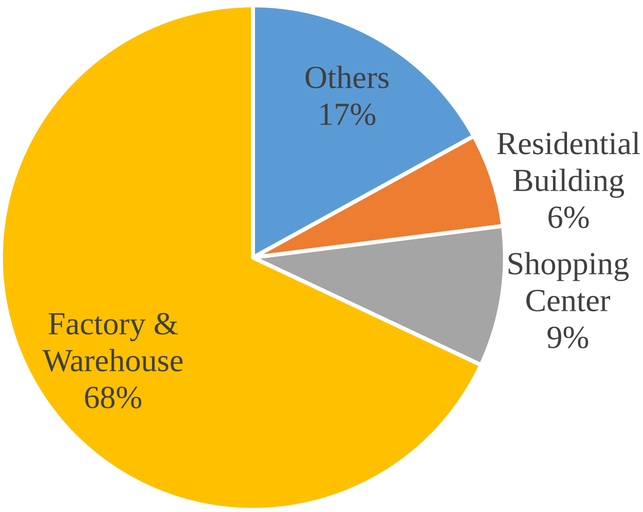

Figure 4. The percentage of design projects in different building types
Source: Case Study Company, 2017

The designs were operated under the current human resources of the case study company as indicated in **Table 1**. However, the operational design process of the case study company can be classified as a project-related activity, the scope of the conceptual design is handled by the Engineering and Sales Departments. The project team organisation for the conceptual design stage involves the staff in the organisation as shown in **Figure 5**.

Table 1. Human resources of the company for design projects

Position	Number of Resource
Project Manager	1
Design Manager	1
Sales Manager	1
Senior Design Engineers	3
Design Engineers	3
Draftsmen	3
Senior Sales Supervisors	6
Sales Supervisors	22
Total	40

Source: Case Study Company, 2017

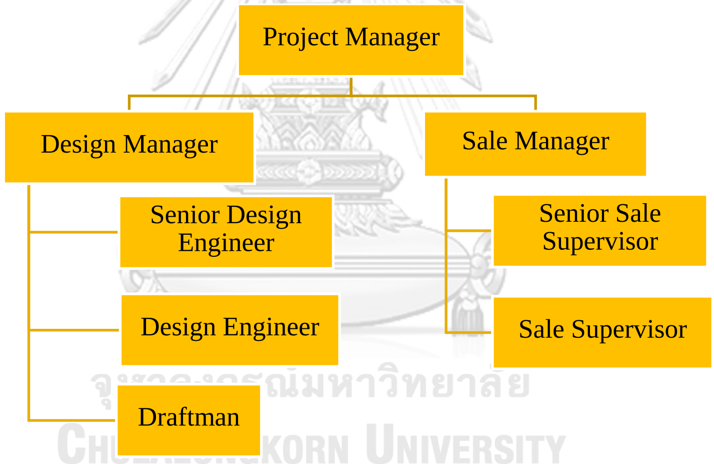

Figure 5. Project team organisation for the conceptual design stage
Source: Case Study Company, 2017

1.2.2 Introduction of Drainage Systems

There are two types of roof drainage systems available in the market being conventional gravity systems and siphonic roof drainage systems. Both system types consist of roof outlets, a piping system and the rainwater collection gutters.

The conventional drainage system relies on gravity or the slope of the piping system. This results in low flow velocities within the system and requires a relatively large and costly pipe diameter and enormous underground works. In contrast, a siphonic roof drainage system utilises the energy from the height of the building to create negative pressure inside the pipes and allow the system to run full-bore during rainstorms, which allows the rainwater to be rapidly removed from the roof with higher flow velocities, cheaper smaller pipe diameters, and fewer underground works, as shown in **Figure 6**. However, siphonic roof drainage systems are usually created by a specialist firm in rainwater management.

The case study company has particular expertise in siphonic roof drainage system design, supervision, and installation. The specialist design team's strength lies in providing design, technical advice and custom solutions for each project and its specifications.

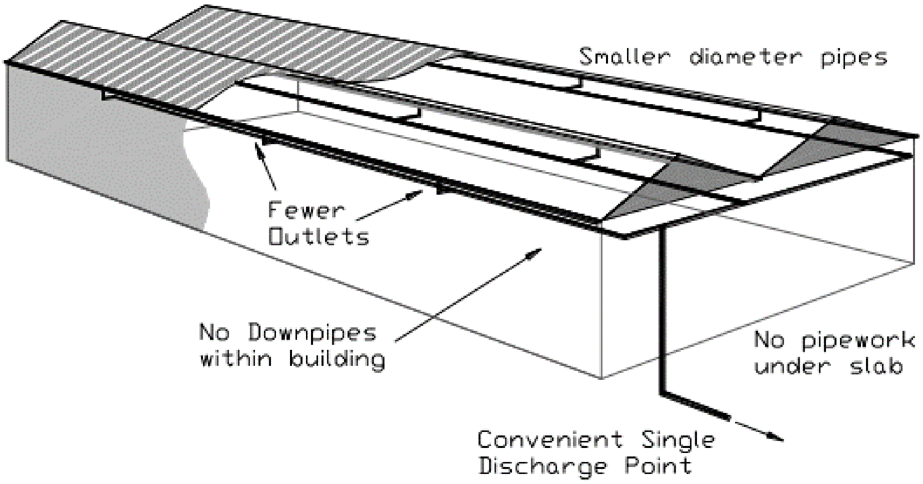

Figure 6. Example of a Siphonic Roof Drainage System (Lucke et al., 2007)

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1.2.3 Range of Design Features

The case study company currently provides three main typical types of design features, namely the Single Outlet System, the Multi-Outlet System, and the Primary & Secondary System. **Table 2** compares and contrasts the characteristics of the design concepts that the case study company can provide to clients.

Table 2. Comparison of Design Feature

System Features	Single Outlet System	Multi-Outlet System	Primary & Secondary System
Maximum length between outlets	30 m.	25 m.	25 - 30 m.
Maximum capacity per outlet	60 l/s	25 l/s	25 - 60 l/s
System Cost	Low	High	Premium
Total Project Cost Reduction	Low	High	Medium
Number of Downpipe	Many	Few	Variable
Design Flexibility	Low	High	High
Safety	Standard	Standard	Premium

Source: Case Study Company, 2017

However, a high level of flexibility in the designs results in more complexity in the design process. This research focused on the conceptual design process of the siphonic roof drainage design projects, where the design depends on the defined design criteria of the client requirements, such as the scope, level of protection, piping material, site conditions and space conditions including the consideration of the project constraints for approval criteria that are based on the budget, solutions and safety. The conventional way to manage the design process of the Case Study company is as follows.

1.2.4 Conceptual Design Process of the Case Study Company

The Conceptual Design Process is both challenging and complex. The objective of this process for the company is to gain acceptance from the customers in the pre-bidding stage. This type of acceptance is defined as the approval of the storm drainage design concept and specifications based on the client's requirements. The functional view of the conceptual design process for a roof drainage system is shown in **Figure 7**.

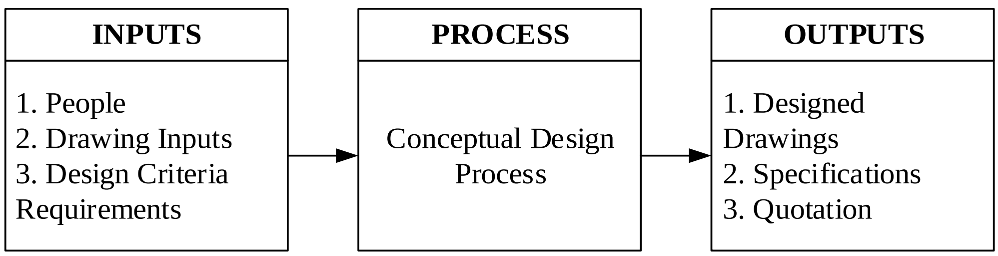

Figure 7. The functional view of the conceptual design process for supplier
Source: Case Study Company, 2017

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Normally, the conceptual design process of the Case Study Company is divided into six main stages: Client Requirements, Checking the Data, the Design Concept, Materials Estimation, Quotation, and Approval of the Design Specification. The process activities can be set out in the form of the Input-Process-Output model as shown in **Figure 8**.

To produce the conceptual design **outputs**: the Design Specifications and Quotation, the conventional process activity begins with the interaction between the Clients and the Sales Engineers. The project information, the necessary drawing inputs and the requirements of the client's project are requested through the project briefing by the Sales Department. After that, those data are transferred to the Design Department by the Sales Engineer. Then, the Design Department responds by checking the input data and the requirements, such as the CAD drawings, the design rainfall intensity needed for flood protection, the specific system route lines and the available locations of the discharge points. Next, referred on the information received from Sales, the ideas and design concept solutions of the project is discussed and arranged within the Design Department. This includes the Design Engineers preparing the CAD drawings, manually calculating the catchment area and flow rate of the roof plan, and analysing and making the decisions based on the available data and information that has previously been received from Sales, as well as the consideration of the system's standard requirements and the designers' perspectives. At this point in the process, the concept solution can be generated. Following this, the system layouts can be shown in the CAD drawings. Moving to the material estimation, the pipe size diameters that are specified during this stage are done through the Analytical Design Program for generating the bills of materials (BoM). Finally, a set of design spcification and the BoM are transferred to the Project Manager so that it is possible to quote a project price with the description of the scope of work. At the end, all conceptual design outputs are delivered and presented to the clients by the Sales Department for the approval of the design concept.

However, the conventional conceptual design process has caused both operations management and quality problems as a result of the high number of redesigns, which is a major problem for the design team. The detailed information regarding this issue is described in **Section 1.3.**

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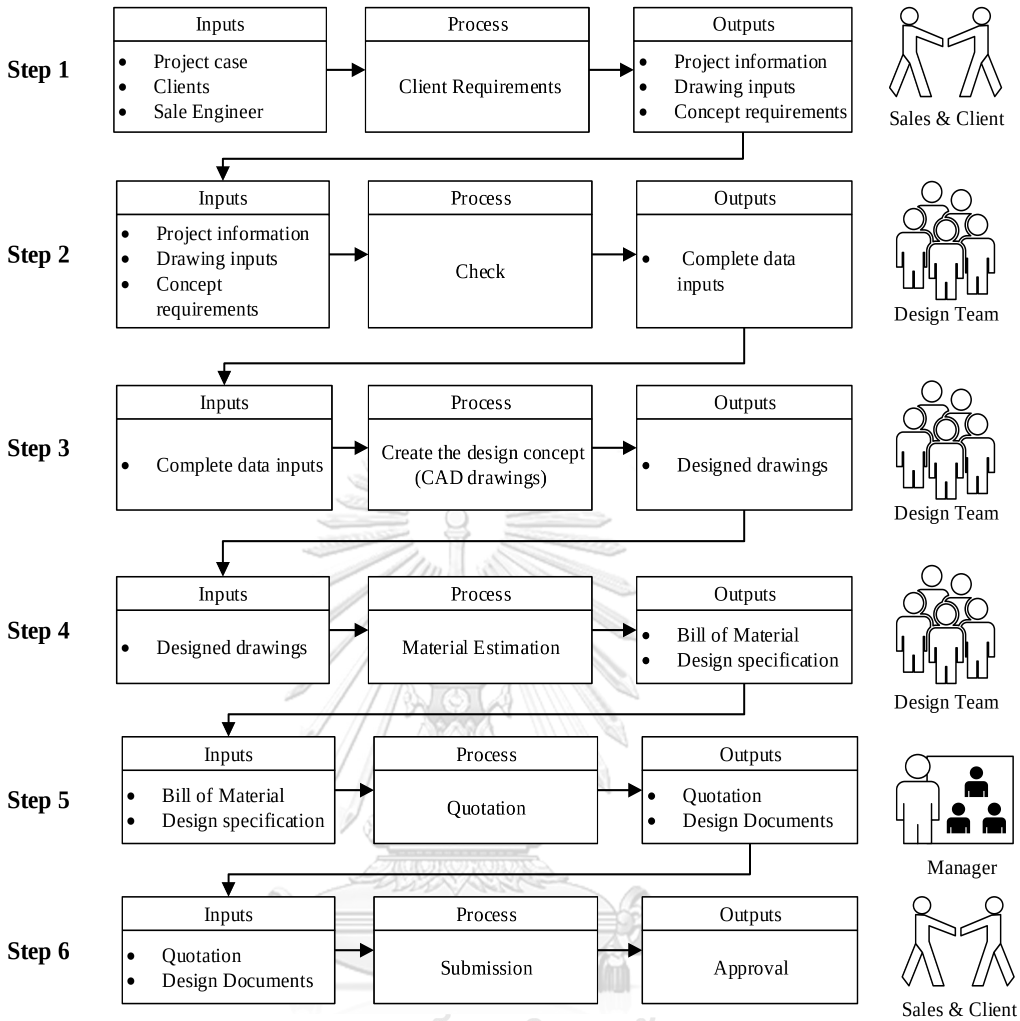

Figure 8. Conventional Conceptual Design Process
Source: Case Study Company, 2017

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1.3 Statement of the Problem

Regarding the conventional design process as described in **Section 1.2.4**, the Sales Department have previously received complaints from major customers about mistakes in identifying the design criteria requirements, such as incorrect scope, pipe materials, calculation parameters, etc. These then impacted the building project schedule. The historical data from 2011 to 2016 included; the number of projects, the number of redesigns and redesign ratio in conceptual design phase. The redesign ratio was calculated according to the following equation:

$$\text{Redesign ratio} = \frac{\text{Total number of redesign (N)}}{\text{Total number of project (N)}} \quad (1.1)$$

Figure 9 indicates that the amount of design projects has risen steadily since 2014 to 2016 from 54 to 125 projects, and there were the corresponding increasing rejections from customers. This lead to increased redesigns (reworks) in the period. The ratio of redesign per project was in the range of 2.1 to 3.4.

A number of redesigns can be defined as a part of the cycle of process activities ranging from the beginning to the end of the conceptual design process. Redesign problem occurred more frequently project by project and have an impact on all of the activities within the conceptual design process. According to the increase in the number of redesigns in **Figure 9**, it can be implied that the design process is not conducted in an effective way, which impacts the operating costs, project schedules and level of customer satisfaction.

According to **Figure 4**, the highest amount of design projects classifying by the type of building is in Factory and Warehouse building which accounts for 68% of total projects. The major size of a project of this category designed by the company is between 20,000 to 35,000 sq.m. **Figure 10** shows the amount of redesigns of project size M (20,000-35,000 sq.m) for factory and warehouse buildings from 2011 to 2016. This data represents a high ratio of redesign per project ranging from 2.9 to 4.2 which then contribute to the increase in operating cost and time at conceptual design process.

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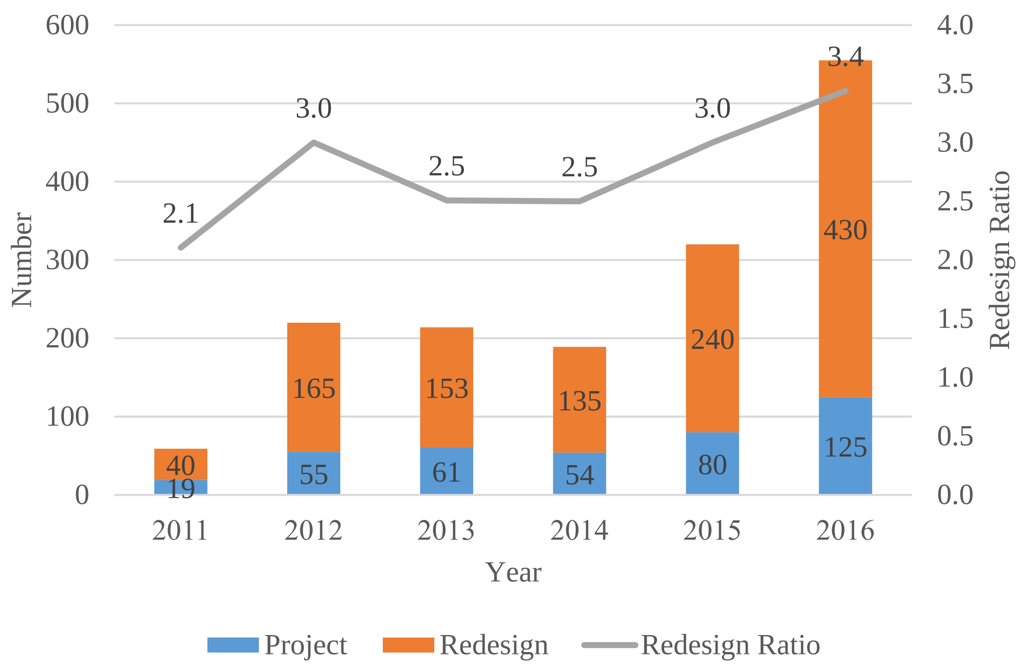

Figure 9. Redesign record from 2011 to 2016 for all building type
Source: Case Study Company, 2017

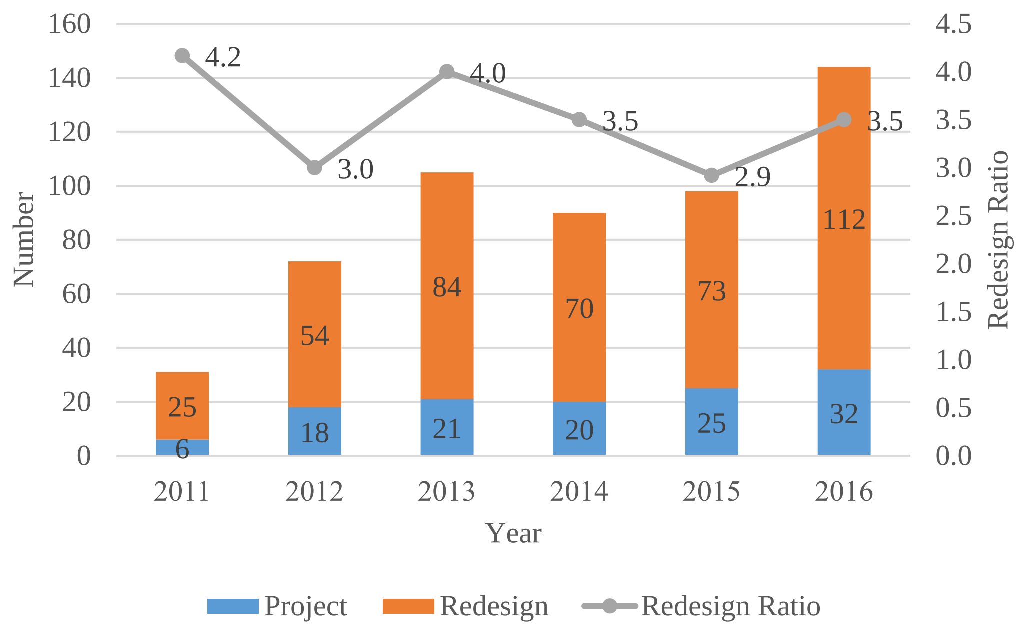

Figure 10. Design record from 2011 to 2016 for factory and warehouse building
Source: Case Study Company, 2017

However, a reduction of redesign is required for design service suppliers to maintain a competitive position for approvals and reduce the impact such the operating design cost. So, to decrease the number of redesign in the conceptual design process, the director has set the Key Performance Indicator (KPI) for redesign reduction, so that the number of redesign (*N*) needed to achieve the approval of the design criteria requirements from the customers must be within two redesigns ($N \leq 2$), as shown in **Table 3**.

Table 3. Key performance indicator of redesign reduction for the company

KPI	Target
Number of redesign (*N*)	$N \leq 2$

Source: Case Study Company, 2017

Table 4 shows the previous number of redesigns and the estimate redesign cost. From the previous 122 projects of factory and warehouse buildings of project size M undertaken from 2011 to 2016. The estimate cost of redesign per revision was THB13,000. The actual cost of 122 project was THB 1,586,000. There were 78 projects that failed to meet the company's KPI, which generated an additional amount of redesign cost of THB 3,848,000 during the period.

Table 4. Redesign cost

N	Project	Estimate Redesign Cost (THB)
$N \leq 2$	44	1,105,000
$N = 3$	33	1,287,000
$N = 4$	27	1,404,000
$N \geq 5$	18	1,638,000
Total	122	5,434,000

Source: Case Study Company, 2017

1.3.1 Identifying the problems

During the conventional design process, the errors, mistakes and incorrect items cannot usually be found until the design outputs have already been submitted to the clients. The reasons for disapproval, which lead to the primary causes of redesign, were recorded by the design team. As a result, the primary causes of redesign were compiled from the recorded design data of the 77 projects undertaken from 2014 to 2016, as seen in **Table 5**. Pareto chart analysis from Craft and Leake (2002) was used to identify which reasons for disapproval from the customers were the most frequently causes of redesigns. The results of the analysis shown in **Figure 11** indicate that “Incorrect scope of design”, “Incorrect concept requirements” and “Design not optimising target budget” were the top three most frequent reasons for disapproval, making up a total of 80% of the redesigns; with 35% being from the incorrect scope of design, 30% being due to the incorrect concept requirements, and 15% resulting from the design not meeting the target budget. However, in order to reduce the number of redesigns, every item needs to be considered, except item D since this is an uncontrollable factor generated by the main architect.

Table 5. Redesign reasons by customers from 2014 to 2016

Causes of Redesigns	Frequencies	% Frequencies
(A) Incorrect scope of design	88	35%
(B) Incorrect concept requirements	77	30%
(C) Design not meeting target budget	38	15%
(D) Design change by main architect	20	8%
(E) Incorrect design parameters	18	7%
(F) Human error	14	5%
Total	255	100%

Source: Case Study Company, 2017

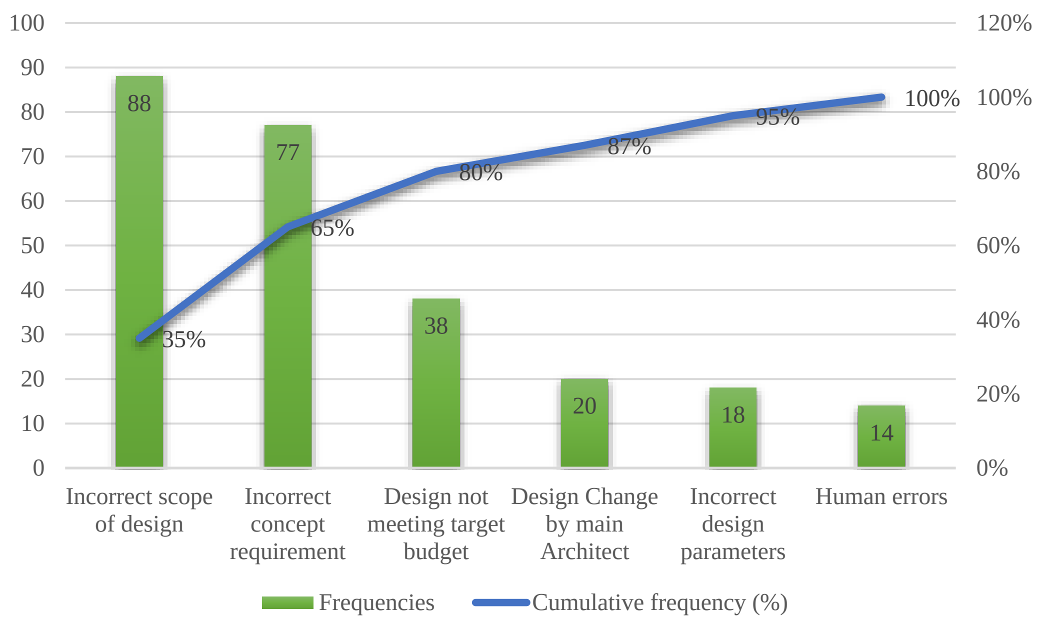

Figure 11. Pareto Chart Analysis of causes of redesign

The need for redesign can be initiated by the clients and the Sales Manager, Drainage Designer, or Project Manager within the project team. Failure and mistakes usually occur early on near the beginning of the process, which has an impact on the lifecycle of the conceptual phase. The detailed descriptions of redesigns for the company's roof drainage design during the conceptual design phase are summarised in **Table 6** below.

Table 6. Detailed descriptions of redesigns in the conceptual design process

Cause of redesign	Process Occur	Detailed Description
(A) Incorrect scope	Step 1-2	- Failure to identify piping specifications - Lack of clarity regarding the discharge points, e.g. connections to manholes, storm tanks, or a conventional drainage system. - Failure to identify the scope of design, such as the number of roofs to be covered in the design - Failure to identify the scope of work, such as painting work, underground work, etc. - Missing necessary input information
(B) Incorrect concept requirements	Step 1	- Change of location of downpipes - Change of route lines - Change of locations of outlets - Incorrect pipe diameter requirements - Incorrect system concept requirements
(C) Design not meeting project budget	Step 3-5	- Over budget due to over-design - Revision of quotation due to design change
(D) Design drawings changed by main architect	Step 3-5	- Design drawings changes, such as roof plan changes or roof slope changes
(E) Incorrect Design Parameters	Step 1	- Incorrect rainfall intensity rate - Incorrect pipe specifications - Incorrect calculations
(F) Human Error	Step 3-5	- Drawing errors - Calculation errors - Document errors - Not enough care and attention

Source: Case Study Company, 2017

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1.3.2 The root causes of problems for the case study company

The fault tree diagram applied from Goldberg et al. (1994) was used to analyse the root causes of the majority of the problems (80%) that were shown from the Pareto Chart Analysis as having an impact on the redesigns. **Figure 12** indicates the three sub-problems of the redesigns associated with poor project management. The detailed analysis is as follow:

1. Incorrect scope of design

   Defining the scope is one of the most important parts in the early design process. The company has poorly clarified the scope of design due to the inadequacy of the design briefs. In addition, the scope requirements are not recorded in any document because of the lack of project planning and control.

2. Incorrect concept requirements

   Clients do not fully understand which concept should be the appropriate solution based on their project constraints. This is also caused by the poor briefings, as the conventional design brief sessions only involve the interaction between sales and the client. Moreover, there is a lack of systematic concept selection guidelines and a prioritising system that are needed to refine the design concept requirements of the project participants, which is caused by the lack of effective tools and techniques of the case study company.

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3. The designs not meeting the target budget

   Due to the missing information generated from the poor design briefings and the lack of optimising analysis in the process, which were caused by the poor project planning and control, the designs do not meet the project budget requirements.

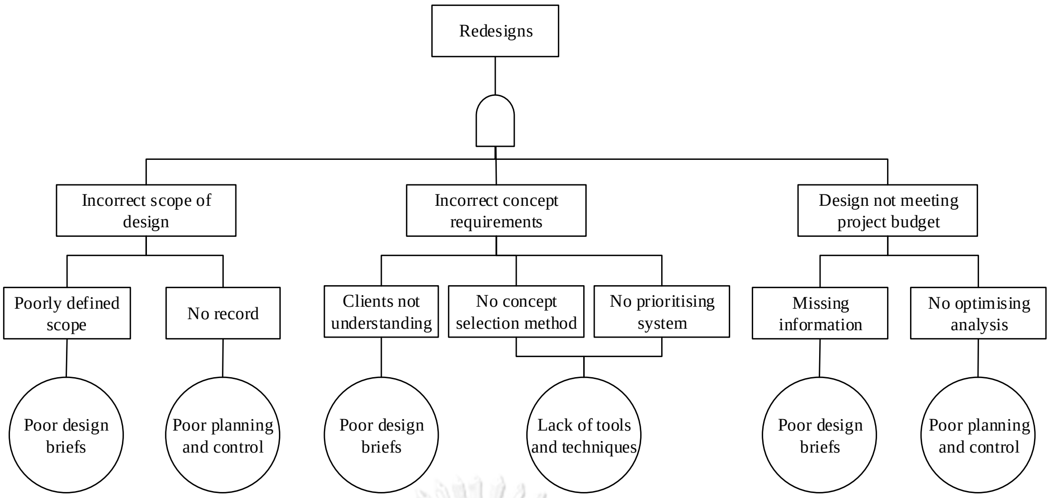

Figure 12 Fault Tree Diagram for causes of redesigns

The summary of the main causes of redesigns associated with **poor project managemen**t that is illustrated in **Figure 12** can be identified as:

1. **Poor briefings**
2. **Poor project planning and control**
3. **Lack of tools and techniques to define client requirements**

Underling on the poor project management problems, design briefing is a major element of project planning (Yu et al., 2006; Yu et al., 2005). A poor briefing can indicate a case of poor project planning. Planning and control is also a significant process in project management. In addition, the application of tools and techniques is an important factor to manage and control the process in order to accomplish the client's project requirements (PMI, 2013).

1.4 Research Question

According to the explanation of project management and what could support the success of project in **Section 1.1**. The systematic project management was considered to be an appropriate method improve the poor management problem for the case study company. So that, the framework of research question can be interpreted as in **Figure 13**.

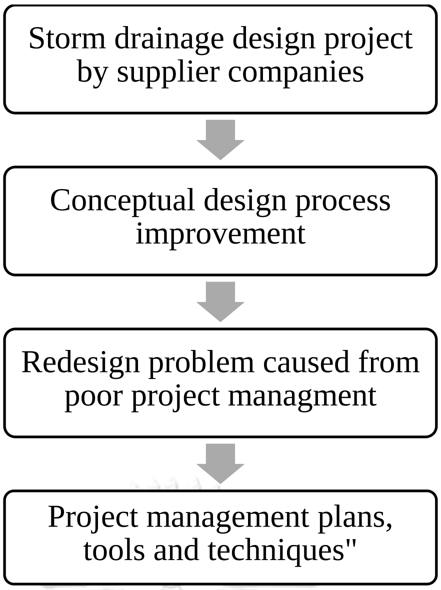

Figure 13. The framework of research question

Based on the framework in **Figure 13**, **the research question to be answered is**: *"How to reduce the number of redesigns in conceptual design process for storm drainage design projects from the perspective of supplier companies?"*

1.5 Research Objective

The research objective is *"To reduce the number of redesign though conceptual design process improvement for storm drainage design projects by using project management."*

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1.6 Assumption of the Research

The project management system is developed for conceptual design process improvement which is assumed to be a practical method to reduce the number of redesigns for the case study company.

1.7 Scope of the Research

To achieve this objective, the project management methodology was applied for the conceptual design process improvement. The scope of conceptual design process improvement can be summarized as follow.

Case Study:	Piping Company
Improvement Process:	Conceptual Design Process
Drainage System:	Siphonic Roof Drainage Systems
Method:	Project management
Validation:	Thirty-projects pilot implementation for Warehouse and Manufacturing Buildings
Type of Project:	Design-Bid-Built
Project Size:	Roof area between 20,000-35,000 m^2
Limitation:	The redesign according to the design change made by the main project architect, such as a roof plan change or a roof slope change, is considered as an uncontrollable factor that is not accounted for in the company's KPI.
Country:	Thailand

1.8 Expected Outcomes

1. The storm drainage management tools and techniques will assist the designer to optimally refine the design concept and client requirements.
2. The operation design management systems will be improved when the new conceptual design process is implemented
3. The number of redesigns will be reduced.
4. The customer satisfaction will be improved when the company can decrease the number of redesigns needed for approval.

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1.9 Summary of Research Process

The steps of research process can be summarized in **Figure 14**.

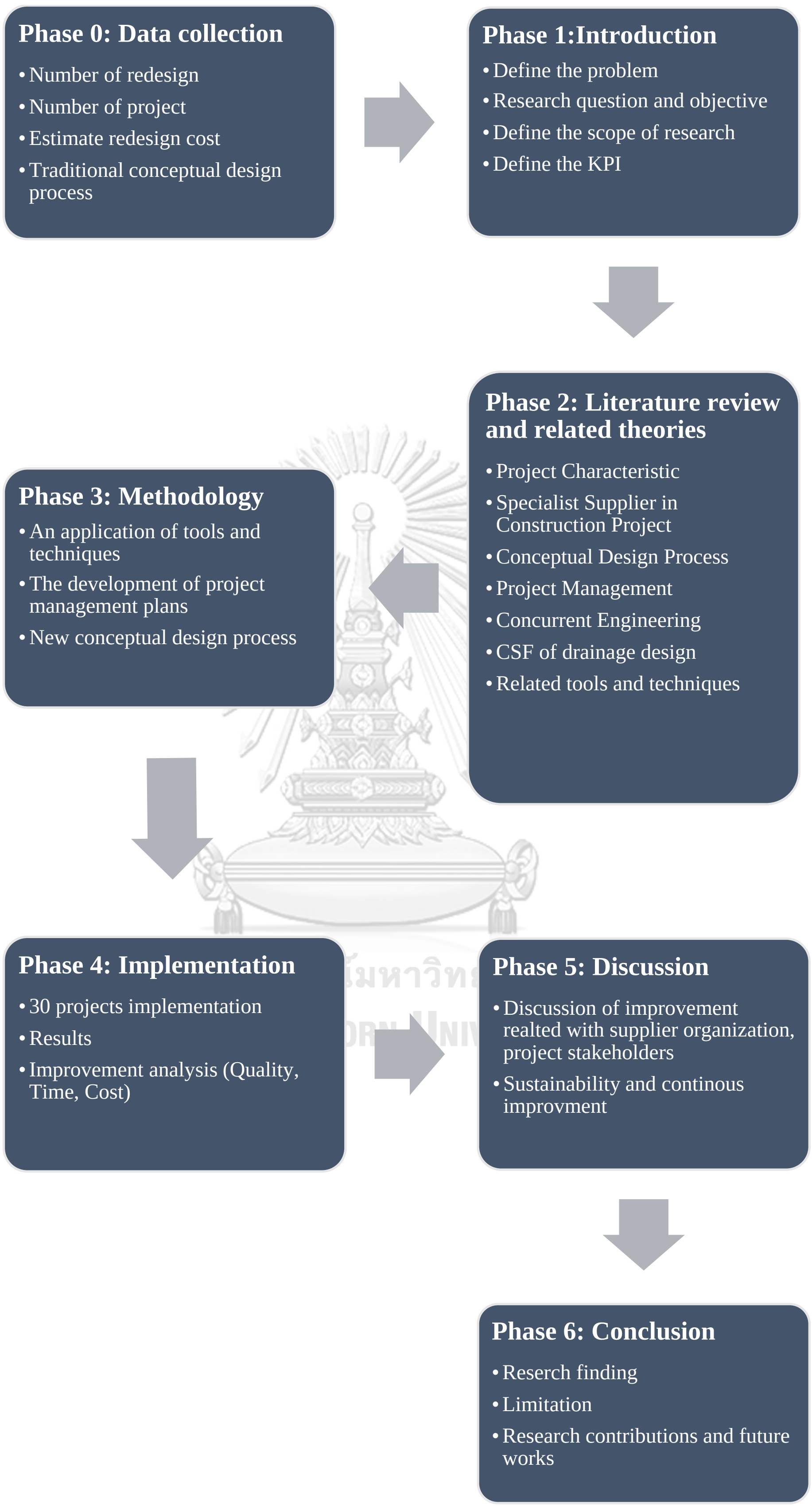

Figure 14. Summary of Research Process

Chapter 2 Related Theories and Literature Review

According to the identified problems in Chapter 1, this chapter represents the background information of literature review and the related theories in this research. The information include (1) project characteristic (2) understanding specialist supplier in construction project (3) overview of the design process that relates with specialist supplier (4) the conceptual design process (5) project management (6) Concurrent Engineering (7) Project management in the concurrent engineering environment for conceptual design process includes: project participants, project plan, design brief and project charter (8) Critical success factors (CSFs) for approval in the drainage design (9) related tools and techniques to apply in the drainage design and (10) the summary of related theories and literature review.

2.1 Project Characteristic

The definition of a project, according to PMG (2003), has been given that a project is a unique task for a specific duration, where within the set boundaries of cost, material and resources, a singular goal has to be accomplished. Tuman (1983) said that a project has a particular purpose or objective and involves people in the organisation for dealing with risks. This specific objective can be defined as identifying a specific time for project completion and having a set of quality or performance expectations (Pinto & Slevin, 1988). Gittinger (1972) also defined a project as a set of complex activities concerning how to obtain benefits with limited resources.

In summarise, the characteristics of a construction project can be divided into 5 dimensions as follows:

- Unique in nature: Projects are depend on the project constraints and requirements, which require a different set of activities or solutions to manage
- Limited timescale: Projects have a limited time line from the start to the end of the project
- Limited budget approval: Every project has a limited payment for approval based on the client requirements

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- Limited resources: The agreement of required resources such designs and specifications are needed in order to start the project
- Risk involvement: Risks are usually involved in managing the project

The characteristics of a project can be viewed through the project life cycle, which normally consists of a project phase or sub-phase within the project life cycle. The phase definition can be described in many ways depending on the specific industry or different types of products or services (Prabhakar, 2009). According to the project life cycle for a constructed facility shown in **Figure 15**, the conceptual design of a roof drainage system in a construction project is generated during the design phase of the construction process. Generally, the process output in this phase is the design specification. For an industrial building project such as warehouses and factories, this part usually involves many professional organisations such as consultants, financial teams, specialist suppliers, engineers and architects based on a particular design in a building (Hendrickson & Au, 1989).

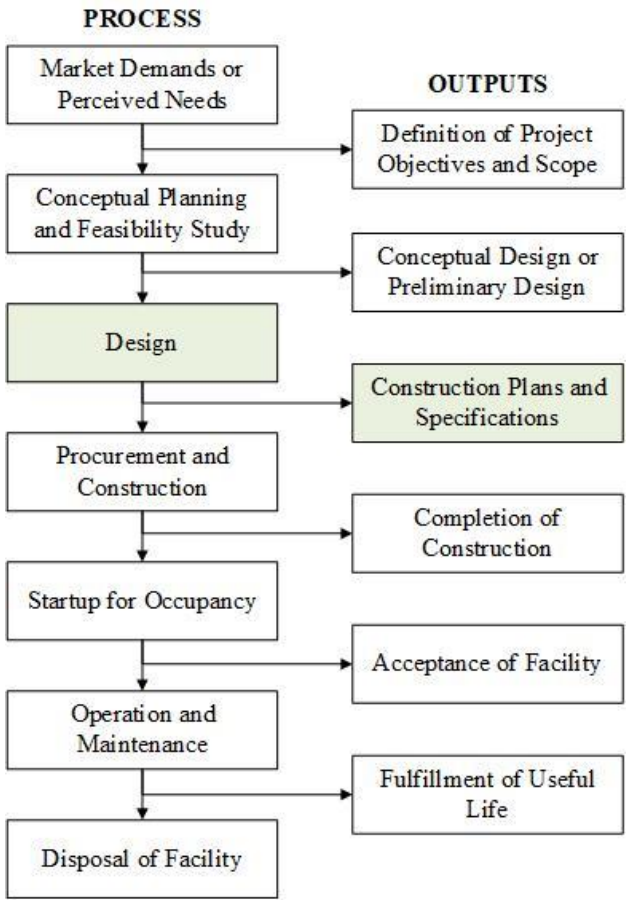

Figure 15. A Project Life Cycle of industrial building (Hendrickson & Au, 1989)

2.2 Understanding specialist supplier in construction project

The key characteristics of specialist supplier works according to Yik et al. (2006) are included; (1) Provide the knowledge and skills to the clients, (2) Provide the special methods or equipment for work process, (3) Supply the products, and (4) License its products or services to other organisations. Yik et al. (2006) also future mentioned that the design of the construction project could not be completed without the integration of specialist suppler (Yik et al., 2006). The some examples of industrial building systems that might involve the specialist supplier are:

- Energy supply (eg. Gas, Electricity, Solar System)
- Fire detection and protection system
- HVAC system (Heating, Ventilation and Air Conditioning)
- ICT network
- Lifts
- Security and alarm system
- Water and drainage system

According to Briscoe et al. (2001) a typical network of construction supplier involving in the industrial building project is shown in **Figure 16**. By the main Architects and Engineers Design Building need to cooperate with the suppliers for material supply and technically knowledge during the design process to produce the design and specification to the main contractor. The specific field to be focused in this paper is in the area of siphonic roof drainage system as mentioned in **Chapter 1**.

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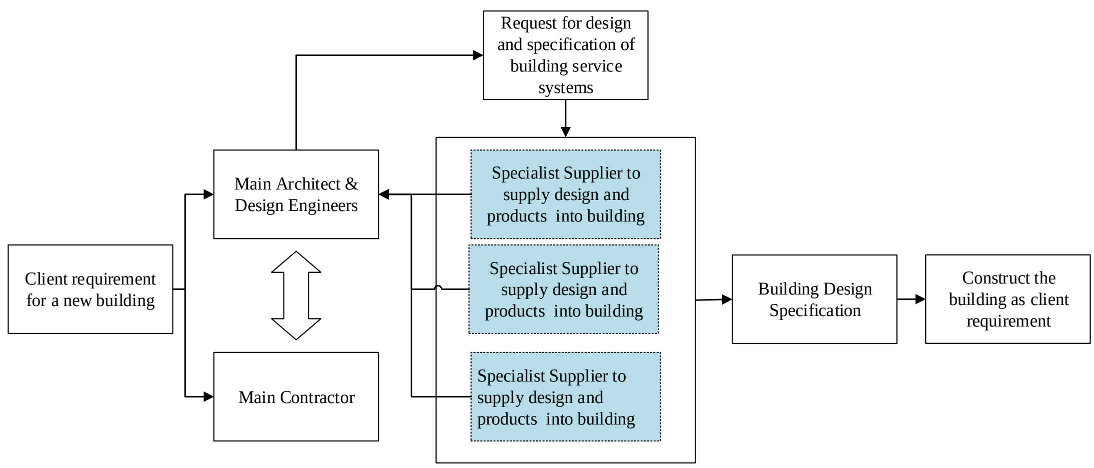

Figure 16. A typical network of specialist supplier in the industrial building project Adapted from Briscoe et al. (2001)

2.3 Overview of the Design Process that relates with specialist supplier

The engineering design process in construction building consists of different phases or stages. The life cycle of the design process based on the perspective of the specialist design supplier, who provides the goods and design services for the main project, can be divided into 3 main stages throughout the construction project including (1) Conceptual design, (2) Detailed design or Shop Drawing, and (3) As-built Drawing.

2.3.1 Conceptual Design

A conceptual design can be described as a set of requirements from customers at an early design stage that has been translated into a concept selection (Akay et al., 2011). Birkhofer et al. (2005) identified conceptual design as a clarifying process, which is the first step before embodiment design. Tatum & Korman (1999) defined a conceptual design as a set of schematic design drawings that reflect the owner's vision. In this work, the author would like to specify the conceptual design as the strategies where clearly have a competitive advantage for the design approval and also meet the client requirements.

2.3.2 Detailed Design or Shop Drawing

A detailed design is the next stage after the conceptual design. Tatum & Korman (1999) further identified the detailed design as a stage of submission to a contractor for approval and installation. This phase may be severely affected caused by reworks or redesigns if the concept is not planned well. The detailed design of the case study is normally generated after the procurement process, which includes the details of piping route lines and the Shop Drawing (Isometric Drawing) for installation.

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2.3.3 As-Built Drawing

Finally, the As-Built drawing is produced at the final phase of design process, which is usually done by the contractor or supplier responsible for the installation work. The As-Built data is collected from the actual installation (Liu et al., 2012), identifying what was constructed in the building. In other word, the As-Built drawing is a record of the final design in the building project.

The number of redesigns or modifications is often generated along the life cycle of the design process. Many researches have highlighted that this is because of poor decision making in the early design stage, which tends to be a major impact on the project performance of time, quality and cost (Ali, 2010). Not clarifying client requirements was ranked as the most influencing factor of redesign, which often happens when there is poor process execution during the conceptual design phase (Osmani et al., 2008).

2.4 The Conceptual Design Process

2.4.1 Definition of conceptual design process

At the earliest design stages, it is critical to pin point the processes involved, to have work steps defined and identified – it is also known as conceptual design process (Birkhofer et al., 2005; Akay et al., 2011). Jansson and Smith (1991) described it as the idea creation and idea selection process for the specific needs and constraints, which may consume a small part of the total design process, but have a significant impact on the overall design process. The conceptual design process of the case study company can be described as a pre-contract process subject to alignment between functional systems and client requirements for the system specifications, starting from collecting the client's project information to the approval of design specification.

2.4.2 General issues in the conceptual design process related to specialist suppliers

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As mentioned that, the design for industrial building are complex, particularly in a field of mechanical and piping process. Listed below are the issues of the conceptual design process that are related to specialist suppliers in industrial building projects.

- High initial costs of projects (Rahman & Omar, 2006)
- Difficulties in planning due to the nature of the construction industry (Kamar et al., 2012)
- Poor planning (Hashim et al., 2011)
- Lack of project team integration (Nawi et al., 2011)
- Insufficient information conveyed to the project team (Nawi et al., 2011)

- No guidelines or standard design in early design phase (Kamar et al., 2007)

The case study company had redesign issues that can be defined as the poor quality of the design outputs. The main root cause of frequent redesigns was poor project management, as the cause and effect analysis identified in **Section 1.3.2**. These redesign issues are also related to the above mentioned specialist supplier issues, such as poor planning, lack of project team integration, which contribute to the impact of the supplier organisations.

2.4.3 Impact of specialist suppliers on conceptual design works

Considering the impacts of specialist suppliers on the conceptual design works in construction projects related to the issues listed above, Hassim et al. (2009) indicated that poor project planning during the pre-construction or conceptual design phase will decrease the productivity of the supplier and also affect the project duration, cost and quality as well as the level of customer satisfaction. These factors could also lead to higher operational costs and the decision of rejection or disapproval by customers (Yik et al., 2006). The reason for this situation is often inadequate identification of the client's needs and requirements during the early design stage (Goral, 2007). Thus, specialist suppliers should have a proper management role in the conceptual design phase in order to minimise these impacts on the project.

2.4.4 Nature of the conceptual design in Thai industrial building projects

In addition to the issues and impacts of the specialist suppliers, another major factor is the nature of the conceptual design process in industrial building projects, which usually involves a wide variety of project stakeholders such as the owners, designers, consultants and specialist suppliers (Ali, 2010). As a result, this phase is usually a difficult task to manage due to the dynamic and complex nature of the process and because, in the early stage, the information is highly dependent on the client's requirements (Wang et al., 2002). Therefore, a clear understanding of client requirements is importance for every supplier firm. However, supplier organisations usually have a low level of involvement with the main project stakeholders in clearing the needs in design, which contributes to the requests for redesign in the conceptual design process. In fact, the possible ways to improve the conceptual design process of specialist suppliers have rarely been discussed in the Thai construction industry. Therefore, improving the conceptual design process is necessary in order to make the design outputs more attractive and competitive. The related researches on the improvement of the conceptual design process are summarised in **Section 2.4.5**.

2.4.5 Related publications about conceptual design process improvement

Process improvement can be described as the improvement of an existing process or activity within the functional boundaries of an organisation (Macdonald, 1995). Conceptual design process improvement is the focused area of this paper, which consists of a multi-step form specialist design supplier in dealing with main construction project participants to generate the design specifications for approval.

	Area of improvement				
Improvement tools	C	A	P	R	I
Interactive coordination	—	—	Yes	Yes	Yes
Intranet	—	—	—	—	Yes
Checklists before design	—	Yes	Yes	—	—
Checklists after design	—	Yes	Yes	—	—
Quality function deployment	Yes	—	—	—	—
Value stream mapping	—	—	—	Yes	Yes
Training	—	—	—	Yes	—

Note: C=client, A=administration, P=project, R=resources, and I=information.

Figure 17. Design process improvement tools (Freire & Alarcón, 2002)

Freire & Alarcón (2002) proposed Lean Methodology in their research for the elimination of waste and non-value adding tasks during the design process of a construction project. This is done by using 4 stages of improvement methodologies, namely Diagnosis & Evaluation, Change Implementation, Control and Standardisation. Freire & Alarcón (2002) also suggested the application of improvement tools based on the areas of improvement as shown in **Figure 17**. The implementation results were able to reduce the product unit errors by 44%, waiting time by 53%, decrease non-value adding activities by 31% and improve 31% of the productivity. However, the specific phase in design and the specific field of design in the construction project was not mentioned in their research.

The study from Wang et al. (2002) mentioned that collaborative design during the conceptual design phase is a future trend for design improvement to deal with complex activities such as face-to-face meetings. In reality understanding, understanding the project stakeholder requirements at the early design phase is difficult as in a project could have different views of interest by each participant (Lepak et al., 2007). Haddadi et al. (2016) evaluated a concept, which has a structured shell for the construction of a new designs undertaking. The objective of this structured shell lies in recognizing and understanding the owner's and users' needs and implementing these into useful building blocks. These should then identify the design creation, evaluate it and implement it into a usable solution. Thus being in an early stage able to oversee the expected value and the success of each phase of the project. However, that research only proposed a conceptual framework for early construction phase. The specific field in construction projects has not yet been clarified. Further research also required the application of tools for each step of best value approach, such a framework has never been implemented in real project case studies.

Wong & Li (2008) stated that every specific field of design has different elements of criteria in nature. Drainage systems are a part of the service system in an industrial building project (Wong & Li 2008). There are many types of drainage systems in construction projects, such as roof drainage systems, road drainage systems, and site drainage systems. The area of focus for this research is the conceptual design process of siphonic roof drainage system, as the author mentioned in **Chapter 1**.

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The study from Jugdev & Moller (2006) represented that, in the past, project management has been highly applied in the implementation phase, concerning work allocation, work load balance and resource management. Nowadays, the scope of improvement using PM has been widely expanded to the early phase (Conception, Initialisation) and closing stage (Utilisation, Close Down), as shown in **Figure 18**.

According to Emmitt & Ruikar (2013) design management is about managing the information and people. The design management guideline according to the RIBA plan of work as shown in **Table 7** has separated the stage in construction into 7 stages, by every stage has different viewpoints and outputs to be focused. The conceptual design of drainage system developed by the specialist is related to the pre-construction phase of the industrial builidng project (RIBA, 2013). Where the design specifications and material of buildings is defined before moving the construction phase.

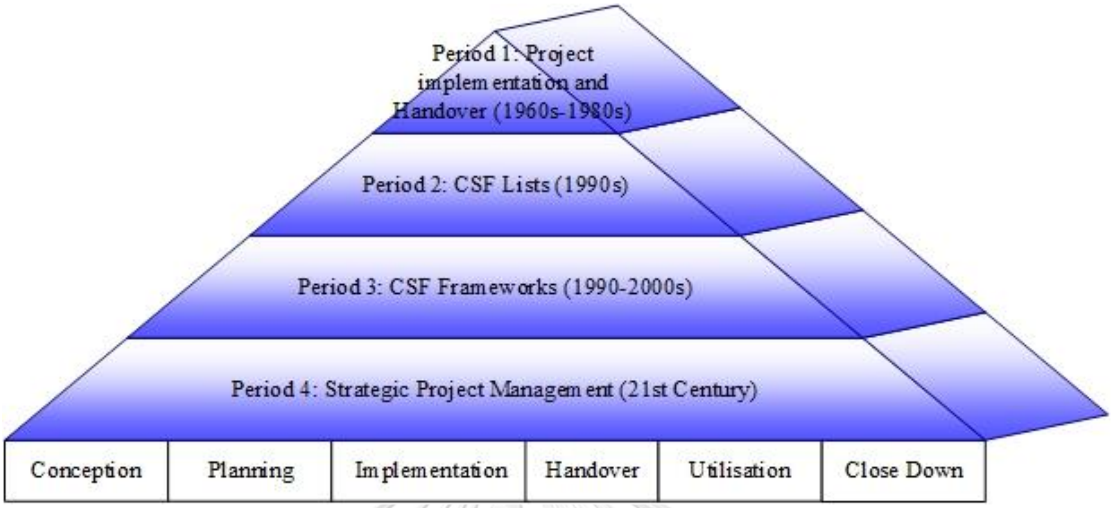

Figure 18.The revolution of project management
Adapted from (Jugdev & Moller, 2006)

However, there was insufficient information about conceptual design process improvement for roof drainage systems, this particular field have rarely been discussed in project management topic. While the related public papers are highly focused on the operating performance and theory of the system (Wright et al., 2002; Wright et al., 2006; Arthur & Swaffield, 2001; Lucke & Beecham, 2009), Mailhot & Duchesne (2009) studied the design criteria of drainage system to determine the risk level and system performance are acceptable for the building lifetime, there is a lack of information about design process and management during the conceptual phase. The closest information is about the design standard from BS (British Standards Institution, 2000), which includes the calculation method, design guideline, and system specification. However, the detailed process during the conceptual design is not mentioned. The author would like to fill the knowledge management gap of specialist supplier firm to manage the design process under the design requirements from project stakeholders. The conceptual design process should be represented in multi-steps within the phase. The support tools, techniques and project management plans used to produce the output of each step are required to assist the Project Manager in managing the conceptual design project for a more effective design outcome. Improving the conceptual design process by using project management will be the method of

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improvement for this study. The definition and principle of project management will be described as follow.

Table 7. RIBA plan of work, Adapted from (RIBA, 2013)

Preparation	**A**	Appraisal	**Stage 1**	**Preparation**
	B	Design Brief		
Design	**C**	Concept	**Stage 2**	**Concept Design**
	D	Design Development	**Stage 3**	**Developed Design**
	E	Technical Design	**Stage 4**	**Technical Design**
Pre-Construction	**F**	Production Information		
	G	Tender Documentation	**Stage 5**	**Specialist Design (Conceptual Design of Drainage System)**
	H	Tender Action		
Construction	**J**	Mobilisation	**Stage 6**	**Construction**
	K	Construction to Practical Completion		
Use	**L**	Post Practical Completion	**Stage 7**	**Use & Aftercare**

2.5 Project Management (PM)

2.5.1 Definition

Project Management (PM) has been applied as a method for achieving project success over the past 40 years (Jugdev & Moller, 2006). It is a timeless method that can be used in a project-based organisation and the operating processes of any construction project. According to PMI (2013), Project Management can be defined as “the application of knowledge, skill, tools and techniques to project activities in order to meet the project requirement". Brown (2007) also supported that PM is "the set of management techniques" to be applied for enabling project goals. Regarding the study from Jugdev & Moller (2006), PM tends to highly involve selecting, defining and prioritizing to ensure optimal output for managing project success. Van der Merwe & Bussin (2006) explained that PM is "the process of managing, allocating and timing resources" that are subject to achieving objectives by integrating resource capability management. Nikumbh & Pimplikar (2014) also mentioned that PM is the art of delivering effective communication and material resources along the project life cycle, where the modern management techniques should be integrated in order to achieve the project constraints of scope, time, cost, quality and client requirements. In this paper, the PM of a drainage system is based on the view of a drainage specialist organisation that is a specialist design supplier for an industrial building project. Thus, PM can be defined as the ability to communicate with project participants to achieve the criteria requirements under project constraints for specification approval.

2.5.2 Principle of project management in construction

Hendrickson & Au (1989), have illustrated the function of PM in a construction project into 4 main phases as follows:

1. Specification: Clarification of objectives, scope, budget, quality, performance requirement, and people involved
2. Maximisation: Create the optimal method of resource utilisation in terms of people, materials and equipment in order to complete the project plan
3. Implementation: Implement the operating process by using a proper plan, decision-making support, work procedure, and controlling system through the entire process
4. Development: Create an effective method of communication for conflict reduction between participants

Adriennes (2014) emphasized that PM can be done thought the basic project life cycle from the beginning to the completion, which can be divided into 4 main phases.

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1. Initiation: Identifying the project needs and requirements, and consideration of the feasibility and delivery of the solution for concept approval.
2. Planning: Once the project is approved, a project team will prepare a schedule and project plans for the completion based on the scope of work.
3. Execution: Transformation of the plans into action, and management of the work activities with the consideration of time, cost and quality.
4. Close out: Delivery or handover of the project to the clients.

Referring to the conceptual design process of the case study company shown in **Figure 8** can be considered as **belonging to the project initiation phase**, as the company refers to the project initiation phase as the conceptual design phase. Previously, the project manager was only concerned about delivering the conceptual design outputs within the deadline, but overlooked which parts of the project management process during the conceptual design phase should be managed. Consequently, more redesigns were generated when submitting the conceptual design outputs to customers.

2.6 Concurrent Engineering (CE)

CE is the element of project management. CE has become a key method of design management in product development system with the target of meeting the customer requirement regarded on time, cost and quality (Winner et al., 1988).

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CE has been applied in the construction process for performance improvement of the construction project life cycle (Kamara et al., 2001). In order to achieve that target goal within the construction industry, Kamara et al. (2002) have mentioned that communication and information management were the critical factors for the area of improvement in construction. Basically, the adoption of CE in design process are subjected to delight the client needs with a varieties of tools and resources (Kamara et al., 2002; Egan, 1998). This due to the CE process has allowed more collaboration within the construction supply chain by having team integration as shown in **Figure 19**. However, there were insufficient evident to justify that CE implementation has been fully integrated in construction processes (Mohamad, 1999). The publications from Bogus et al. (2005) have mentioned the benefits and the implementation of CE in construction design process that the design delivery time had been improved by using CE. Kamara et al. (2001) also used CE in early briefing stage of design process to clarify the customer requirement. However, Hambali (2009) suggested that redesigning the entire processes is not necessary for the implementation of the CE.

In order to improve the conceptual design process in a construction project created by the specialist supplier, the consideration of project management program with the integrated concurrent engineering environment at conceptual design process to be used in this research can be illustrated as in **Section 2.7, 2.8 and 2.9**.

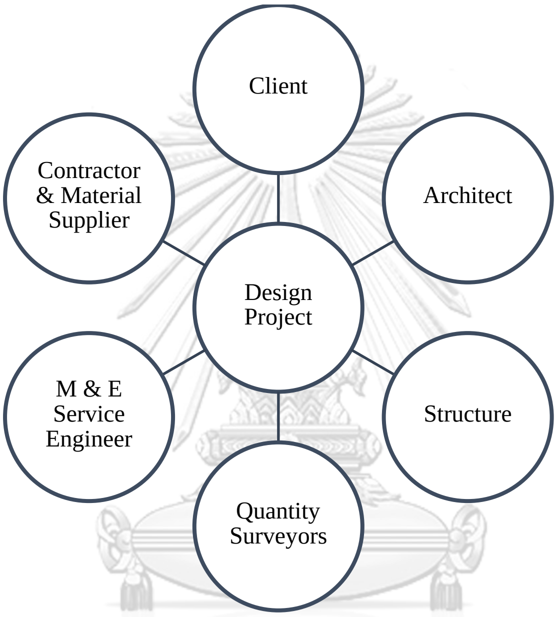

Figure 19. The Example of Integrated Team in Concurrent Engineering (Evbuomwan et al., 1998)

2.7 Project Management in the Concurrent Engineering Environment for Conceptual Design Process

In this section, the author considered the conceptual drainage design process as a project management process. The general **inputs** of this phase include drawings from the client, refined piping materials, constraints and client requirements. The **outputs** are the design drawings, specifications and quotation for the system. The items to be considered by the drainage project manager for managing the drainage design project in the **conceptual design phase (initiation phase)** to improve the project performance are as follows.

2.7.1 Project Participants

Project participants during the conceptual design of drainage systems can depend on the form or shape of the building, such as a Design-Bid-Build (DBB) Project or Design and Build (DB) Project. However, the main participants' roles and responsibilities in the conceptual design phase of a drainage system in an industrial building project can be described as follows.

The Owner/Owner's Representative is the person or company who owns the property. It is important to clarify their needs and objectives since they are mainly responsible for the decision making and need to be informed about the design and construction progress (Goral, 2007). Owner involvement is an important key for project success in a construction project (Petersen & Murphree, 2004).

A Project Consultant is assigned by the owner. Their roles and responsibilities are related to various activities along the project life cycle, including managing the project under the project constraints of time, cost and quality. By mainly coordinating with the management teams of the project, both within and outside project participants, providing guideline, planning, monitoring supervising and using their skills and knowledge to review and make sure that the project is on the right track (Sarda & Dewalkar, 2016). Therefore, all design, and specification, must be approved by the project consultancy.

The Project Designer is responsible for creating the design concepts, drawings and specifications of the building project. The designer plays an important role in traditional DBB projects during the design process, where design and construction elements are provided separately. This method is quite time consuming compared with a DB project (Goral, 2007). However, this type of construction project is still the most widely used in Thai construction.

The Design-Built Contractor is a contractor firm that provides both design and construction services to the owner. Thus, they normally participate during the design phase in a construction project. Providing the design concept, cooperating with the consultancy and project owner for various activities in the design and construction, the contractor has high influencing power in the project (Goral, 2007).

The Drainage Specialist Supplier is an external design supplier with expertise in siphonic rainwater management systems, providing design specifications to the project designer or design-built contractor during the conceptual design process of its business services. Referring to **Figure 20**, a drainage specialist supplier firm usually cooperates with the project designer for a DBB project. On the other hand, the interaction comes from design & built contractor and working directly with the contractor for a DB project during the conceptual design process for design solution, specifications, drawings and materials supplier and a sub-contractor of the main contractor in a construction project (Case Study Company, 2017).

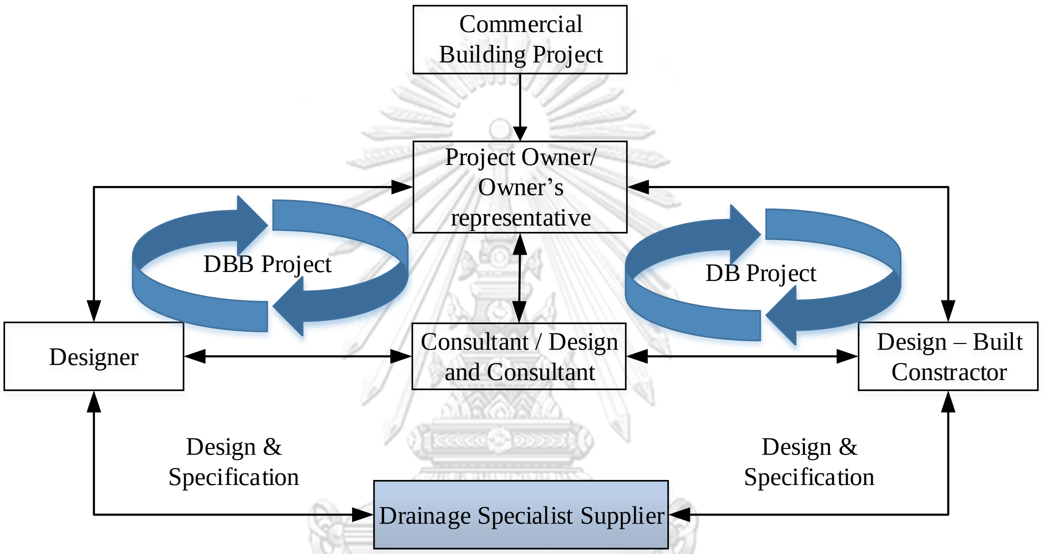

Figure 20. Project participant and relationship among the conceptual design phase Adapted from (Goral, 2007)

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2.7.2 Project Plans

According to PMBOK, a project plan or project management plan is a document that provides detailed instructions for how to achieve the project goal (PMI, 2013). The project plans to manage the conceptual design phase of the drainage system can be outlined as follows.

2.7.2.1 Project Human Resource Management Plan

To be able to start the design project, project team planning within the organisation is an essential part because the process activities can be done through the actions of people. Luecke (2004) highlighted the important elements of resource management in a project, where clear understanding of people’s roles within an organisation was the key factor in managing a project, which should include the (1) project manager, (2) project leader and (3) team members.

RASCI matrix is an effective method to clarify team roles and responsibilities for a project related activities (Crumrine et al., 2005). The example of RASCI chart is represented in **Table 8**.

Key output: Clarify team roles and responsibilities

Table 8. Example of RASCI matrix

	Project Manager	**Design Manager**	**Design Engineer**	**….**	**Sales Engineer**
Stage 1	R/A	C			I
Stage 2	C	A	R		I
Stage 3	C	A	R		I
Stage 4	R/A	C	C		I/S

Adapted from (Crumrine et al., 2005)

2.7.2.2 Project Stakeholder Management Plan

According to the typical participants in a construction project as described in **Section 2.7.1**, Ward and Chapman (2003) stated that the project stakeholder is the major concern for identifying project objectives that reflect the design requirements and the priorities in the design concept. Clear understanding of the project objective and priorities can be carried out in the format of a project stakeholder analysis matrix (Varvasovszky & Brugha, 2000). An example of the stakeholder analysis matrix is shown in **Table 9**.

Key outputs: Project Stakeholder analysis matrix

Table 9. The Example of Stakeholder Analysis Matrix

Organization	Project Stakeholder	Focus issue	Influence/ Power	Communication Plan
Company A				
Company B				
Company C				

Adapted from Varvasovszky & Brugha (2000)

2.7.2.3 Project Scope Management Plan

Referring to the problem statement in **Chapter 1**, the scope of design is one of the critical issues during the pre-design stage that cause redesigns within a process. The scope of design for a roof drainage system in this paper means (1) which area should be covered, (2) the design parameter and (3) and what condition that should be included or excluded in the system design and service. The scope of work (project) for a supplier is subject to agreement by the project's representative. Khan (2006) mentioned that a clear scope definition is required during project initiation. To determine the scope definition of each project, consideration of project constraints need to be included. Ormerod (2005) mentioned that identifying the scope requirements of the design can be done through the briefing process which will be descried in **Section 2.7.3.**

Key output: Scope identified

2.7.2.4 Project Requirement Management Plan

The responsible project team needs to clarify the requirements of each building project with the project clients. By understanding what clients need, Doloi (2011) stated that effectively meeting with the project stakeholder should be a possible way to enhance the client requirements in the construction industry. The requirements for design specification development can be divided into 2 main categories: (1) Functional system requirement and (2) Client requirement (Song, 2017). The client's requirements, along with the conceptual design process, should be collected, analysed, tracked, reported and agreed upon by the authorisation and stay in scope (Jiao et al., 2006). The way to capture the client requirements can be done through design brief which will be described in **Section 2.7.3.**

Key output: Requirement identified

2.7.2.5 Project Communication Management Plan

Sturges Jr et al. (1993) stated that conceptual design process begins with "Question" and ends with "detailed specification", the communication among the project participants and within the organisation is important to create the efficient outcome. A case study company requires a communication planning to avoid the missing information to generate the design outputs. The basic communication such as status reporting or updating should be included in managing the communication within the process (Chapman, 2001). The conventional communication planning was lack of monitoring and control since most information transfer via phone conversation not in a recorded document. Moreover, there was no systematic baseline to ensure that those information are frequently updated in a timely project manners. The communication plan will be shown in **Chapter 3**.

Key output: Communication plan and update

2.7.2.6 Project Risk Management Plan

According to Mailhot & Duchesne (2009) risk in drainage design is related to the criteria requirements which impact on the system's performance (or the acceptable level of risk in the system), and the incorrect concept requirements of design output. Which can be the reason for disapproval at the end of the project phase. The common risks in the design process are from unclarified design scopes and requirements (Chapman, 2001). The application of tools and techniques will help a project manager to identify the risks which will be explained in **Section 2.9**. Moreover, systematic planning and control at the early design stage will allow suppliers to minimize the risks within the process to reduce the possibility of a change request or design mistake. During the initiation design phase, the using of a project charter can help the organization decrease the risks since the project manager can review all necessary design information before submission to the client (Chapman, 2001). Project risk assessment and mitigation plans of this research were described in **Section 3.11**.

Key output: Project Charter, Mitigation Plan

2.7.3 Design Brief

Briefing can be defined as a stage of design planning or architectural planning process in construction project (Yu et al., 2006; Yu et al., 2005). As mentioned in **Section 2.7.2.4**, briefing has become an important stage in design process to manage the more demanding and requirements from clients (Blyth, 2000). The client requirement, design criteria, functional design concept, scope and specification can be generated by the Design Brief through sketch drawing (Ormerod, 2005).

The participants of design brief are generally included the Project Manager, Project Stakeholders and design expert or specialist in some area of building design. The process of Briefing in construction is considered as a complex and dynamic (Yu et al., 2006). The elements of briefing should be included the clear statement of client requirements, the project constraints for the client acceptance or approval (Chatzi, 2012). The different viewpoints of briefing from Ahmad et al., (2011) are related to the process of capturing the needs, problems identification and planning to manage that problems, which could be the effective method to identify the client requirement at early design stage, to avoid the rework at downstream design activities. Macmillan et al, 2001 said that the problems that have occured during the conceptual design phase is the wrong people involved in initial briefing seassions, the lack of detail steps to be reached for concept proposal, and the worng expectation that all requirements can be satified equally.

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Why design brief should be implemented in organization?

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Design brief was the critical process of the case company that impact to the whole design process. The author identified that the element of poor project planning and management was the poor briefings: the lack of detail steps in briefings, the low involvement of drainage engineer in briefing season, which lead to ineffective communication flow of the design process. Therefore, the design brief session should be implemented in this research and the collaborative briefing team and briefing procedure are required for better operation design process management.

2.7.4 Project Charter

Project Charter is a summary document of project's goals, objectives, and scope of works/projects (PMI, 2013) that used to secure stakeholder approval during the conceptual design phase. In other word, the project charter is a summary information from the project plan. According to Hayes (2000) project charter contains the main 7 items which includes (1) Project goal, (2) Requirements, (3) Scope, (4) Constraints, (5) Milestone, (6) Risks, (7) Project stakeholders.

Project charter has widely applied in many project management in various industries. The previous researches that had been using the project charter, for example, Mustaro & Rossi (2013) have applied a project charter to manage the academic research project to overcome the scope requirement. Roberts (2014) also developed project charter for managing the IT project based on the project constrains of budget and time. This can implied that use of project charter is similar to general project management, but the context is different depending on purpose and type of project. According to the servey result from Besner & Hobbs (2008), 12.3 % of engineering and construction projects have use the PM tools, including the project charter.

Why project charter should be implemented in organization?

Since the case study company is a project-based organization, project charter should be suited with the work characteristic of design project. In order to minimize the change request from customers. Therefore, the application of project charter should be suitable in area of drainage design or other building service systems that subjected to redesign reduction.

2.8 Critical Success Factors (CSFs) for Approval in the Drainage Design

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Completing the drainage design process is not easy, especially the conceptual design phase of building project, it is vibrant, dynamic and crative (MacMillan et al., 2002). Its concern with many requirements from a variety of project stakeholders. Therefore, understanding the Critical Success Factors (CSFs) of drainage system in construction project is necessary, which can have a positive impact to the project outcomes (Cooke-Davies, T, 2002).

The related research from Wong & Li (2008), have identified the CSFs for the selection of drainage systems in building projects. The resulted data from Wong & Li (2006) and Wong & Li (2008) indicated that the cost effectiveness; low system cost or life cycle cost reduction (Clements-Croome, 2001; AIIB, 2001; Myers, 1996), the work efficiency; enable to perfome according to the client requirement such as safe requirement (AIIB, 2001; Kreider, 2000), the user confort; such as flow rate requirement (AIIB, 2001; AIIB, 2004), and the technology related; the design solution to support the architectural design or modernization of system (AIIB, 2001). While, the most significant factors were the cost effectiveness and the work effectivness.

Value is also one of the driven factor in design process, the value can be identified in many ways (Salvatierra-Garrido et al., 2012), the value creation for the building project is focused in this paper. So, value of the design of roof drainage system for building project can be something that improve the project such as project cost reduction, value creation at conceptual design phase is hard to manage but its worth for planning at early stage to minimize the complex at downsteam process (Knotten et al., 2015).

In addition, Banihashemi et al (2017) said that CSFs should be integrated into the construction project management practices. For, the positive influence to the project stakeholders (Robichaud & Anatatmula, 2010) in managing the project at early stage. This research was focused on the 3 main project stakeholders (Project designer, Project Consultant and Project Owner). The related CSFs for the design of roof drainage design project propose in this research were summarized in **Table 10**.

Table 10. CSFs Framework of the design of drainage system

CSFs for the design of siphonic roof drainage system	Description	Key to achieve
Cost Effectiveness	Focus on the lowest cost of roof drainage system	Achieving essential function design and client’s requirement
High Safety in Design	Focus on the highest safety for the building	Achieving luxury function design and client’s requirement
Adding value for building project	Focus on the value creation of overall project functions to reduce the total project cost such as civil work reduction	Achieving essential function design as well as improve the project and meeting client’s requirement

Adapted from (Wong & Li, 2006; Wong & Li, 2008; Knotten et al., 2015)

2.9 Related Tools & Techniques

Without the tools and techniques to support, the Project Manager and Project Team can be struggled to manage the operation process smoothly. Tools & techniques to support the design activities during the conceptual design phase. However, various filed of design or process can be required different type of tools and techniques to be used. The appropriate support tools & techniques for roof drainage system during the conceptual design process are listed as below.

2.9.1 Checklist

The project information and acquire data at the early design stage can be done by using the checklist (Fernández-Sánchez & Rodríguez-López, 2010; Firesmith, 2007). Goral (2007) indicated that using checklist at conceptual design stage can help to evaluate the risks before the design start to produce. The reason for selecting checklist is to minimize the complexity of data collection task. Moreover, this could be the reference record from customers for a statement of project information and scope and material specification. And also, to avoid the missing necessary drawing inputs transfer to design team.

2.9.2 3D-Based System

A virtual modeling, is an emerging technology that have increasingly used widely in construction industry (Gu & London, 2010). Appling the 3D model at early conceptual design process has a positive resulted in managing the design projects, the information and design criteria requirement can be easily communicated, a scope of design can be simply identified. In addition, the customer's trust and understanding can be improved through using 3D technology (Gu & London, 2010; Azhar, 2011). Since, the traditional way to communicate with client was the critical problem of the company case study. The reason for selecting 3D based-system is to enhance the communication between the design team and project stakeholders.

2.9.3 CSF Tree diagram

The Tree diagram which is used to analyze the objective statement from broad objective into the deeply level of detail (Besterfield, 2012). Rondini et al. (2016) have applied this tools for PSS design at early development phase which recevied a good result in the industrial context. The Tree diagram is proposed in this research to support the design thinking which identify the customer's needs based on CSF dimensions from client's board objective into the deeply detail of drainage system specifications.

2.9.4 Expert Judgment

Expert Judgment is one of the effective technique for project management in conceptual design phase. The data analysis for example; risk identification, stakeholder analysis, can be justified by the experts on the project such as Project Manager (Fernández-Sánchez & Rodríguez-López, 2010; Zeng et al., 2007). Nieto-Morote et al. (2011) used this techniques to deal with subjective judgment such as; risk identification and weigh analysis in construction project. However, this could generate the negative result if the expertise had less knowledge and poor decision making. Expertise for this case study is referred to the experience Project Manager and Sales Manager, who had over 15 years' experience in construction industry. So, it should be a suitable technique to identify the background information of project stakeholder and generate the appropriate way for the communication plan and management.

2.10 Summary of Related Theories and Literature Review

Based on the above review, the project initiation management framework proposed in conceptual design process for the design of roof drainage system are shown in **Figure 21.**

Redesigns reduction during the conceptual design process haven't been played enough effort in the construction industry (Osmani et al., 2008; Osmani et al., 2006), very few attempts have addressed the important of design practices on waste minimization during the design process (Coventry & Guthrie, 1998). The recent effort from Yap et al. (2016) have developed the conceptual framework for managing the design change reduction in design process, the specific phase was not focused.

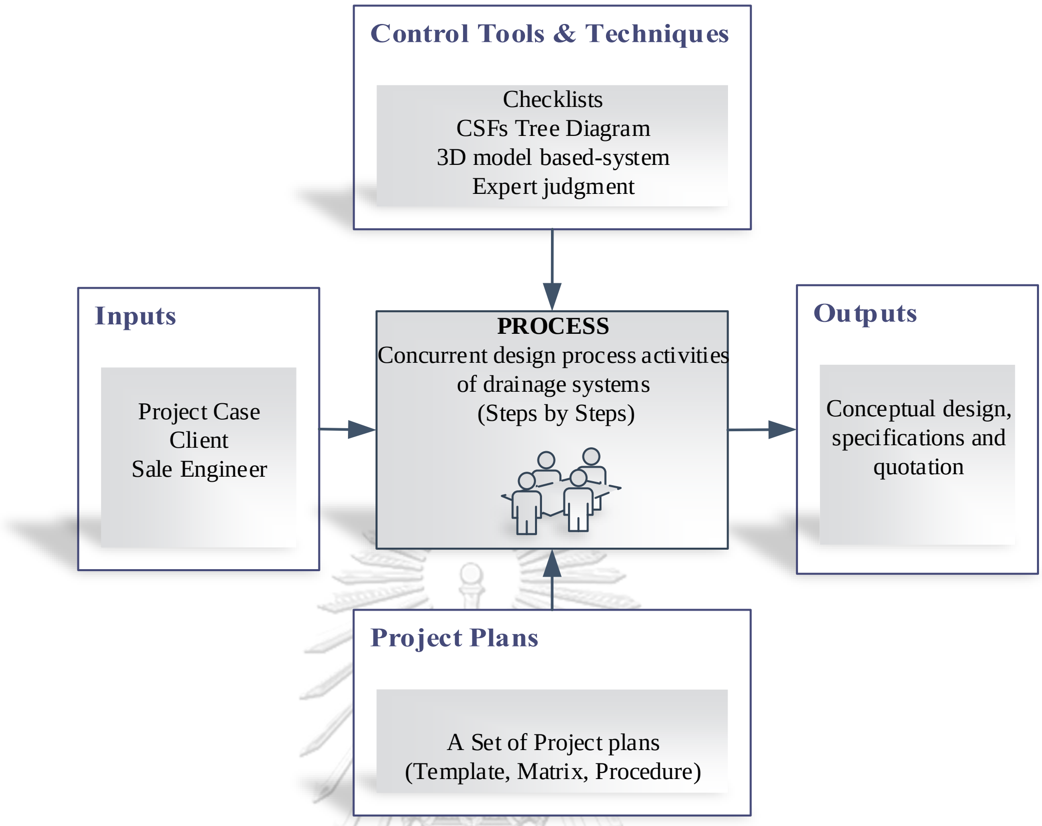

Figure 21. Project Initiation Management Framework of Drainage Design

High number of redesigns in conceptual design process can be reflected the high cost, time, the quality of design output and the customer satisfaction. The author believe that every stage of design process has different objective to be focuses. The design at conceptual design phase is mainly subjected to the requirement from project stakeholder (Project owner, Project designer and Project consultant) Redesigns reduction during the conceptual design phase is the important part that need to manage effectively for achieving the success design approval.

Therefore, redesign reduction at conceptual design process of roof drainage system was the aim of this study to assist the drainage supplier during the early design phase. The summary success criteria for design approval at conceptual design phase can be summarized in **Figure 22**.

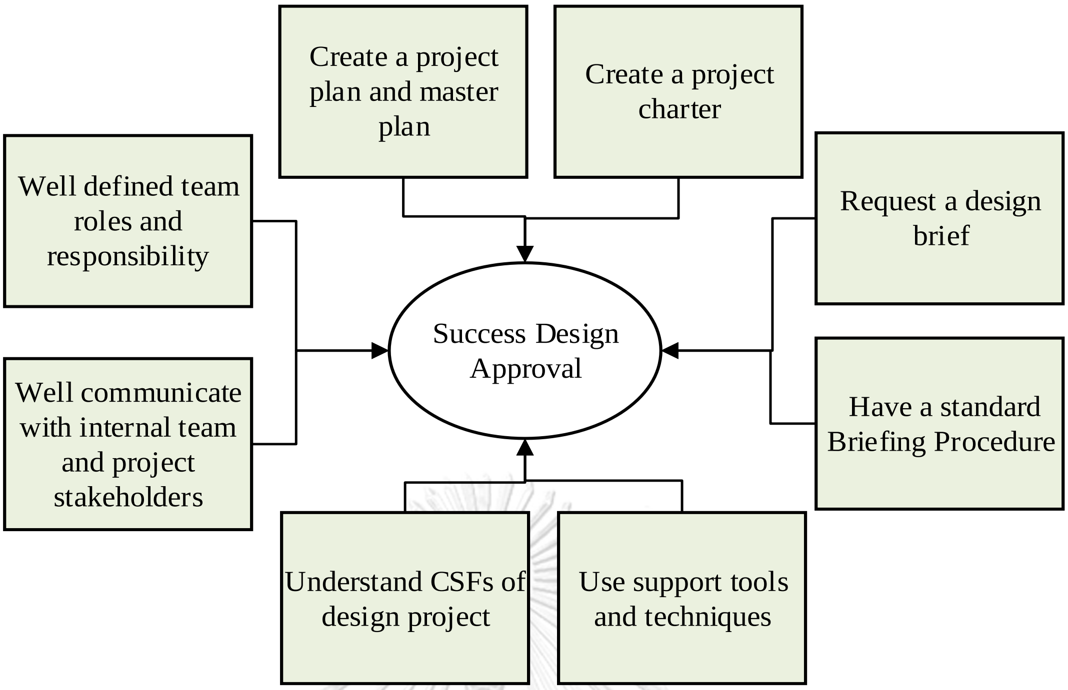

Figure 22. Success criteria for design approval at conceptual design phase

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Chapter 3 Research Methodology

This research methodology aimed to improve the conceptual design process for drainage systems based on the problem identified in **Chapter 1** and the related theories and literature review in **Chapter 2**. This chapter describes how the methodology of this project was carried out including research question, research method, research design, stages of new conceptual design process (Initialisation, Identification, Translation and Specification), the comparison of proposed process with traditional process, validation plan, project risk assessment and mitigation plans and the summary of the research methodology.

3.1 Formulation of the research question

As the research question mentioned in **section 1.4** that *"How to reduce the number of redesigns in conceptual design process for storm drainage design projects from the perspective of supplier companies?"* This research question was formulated based on the problem of the traditional conceptual design process which was currently caused by a poor project management of the case study company, resulted in high number of redesigns and client disapprovals.

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3.2 Research method

The proposed methods for conceptual design process improvement in the case study included the project management methodology which covered; concurrent conceptual design process, the development of Project Plans, as well as an application of design tools and techniques to assist the project manager and other team members in conceptual design process of storm drainage system.

The proposed methods were outlined into 4 main stages including Initialisation, Identification, Translation and Specification as shown in Figure 23.

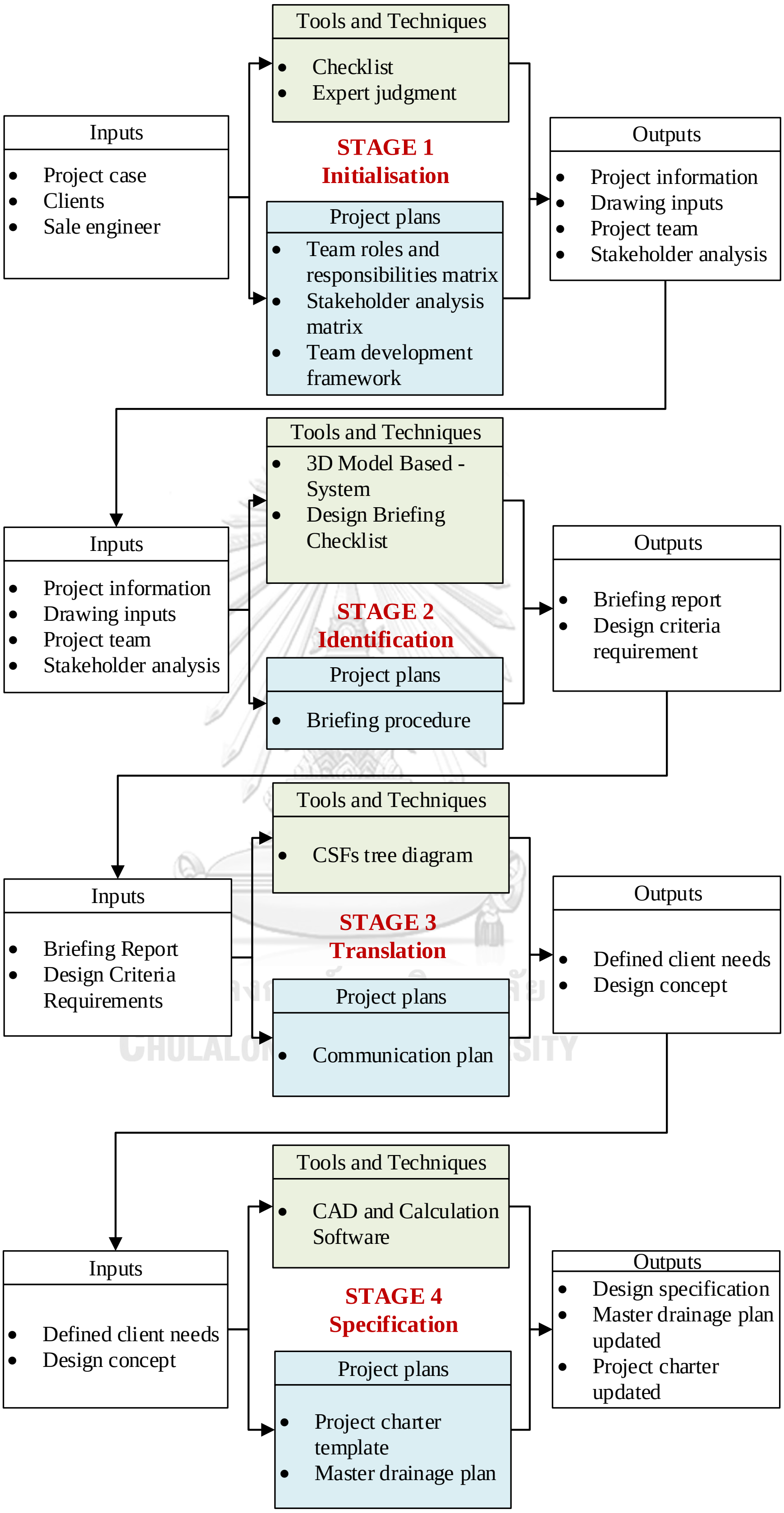

Figure 23. Proposed Methodology

3.3 Research design

The research design of this paper was developed according to the research method through Initialization, Identification, Translation and Specification as shown in **Figure 24**.

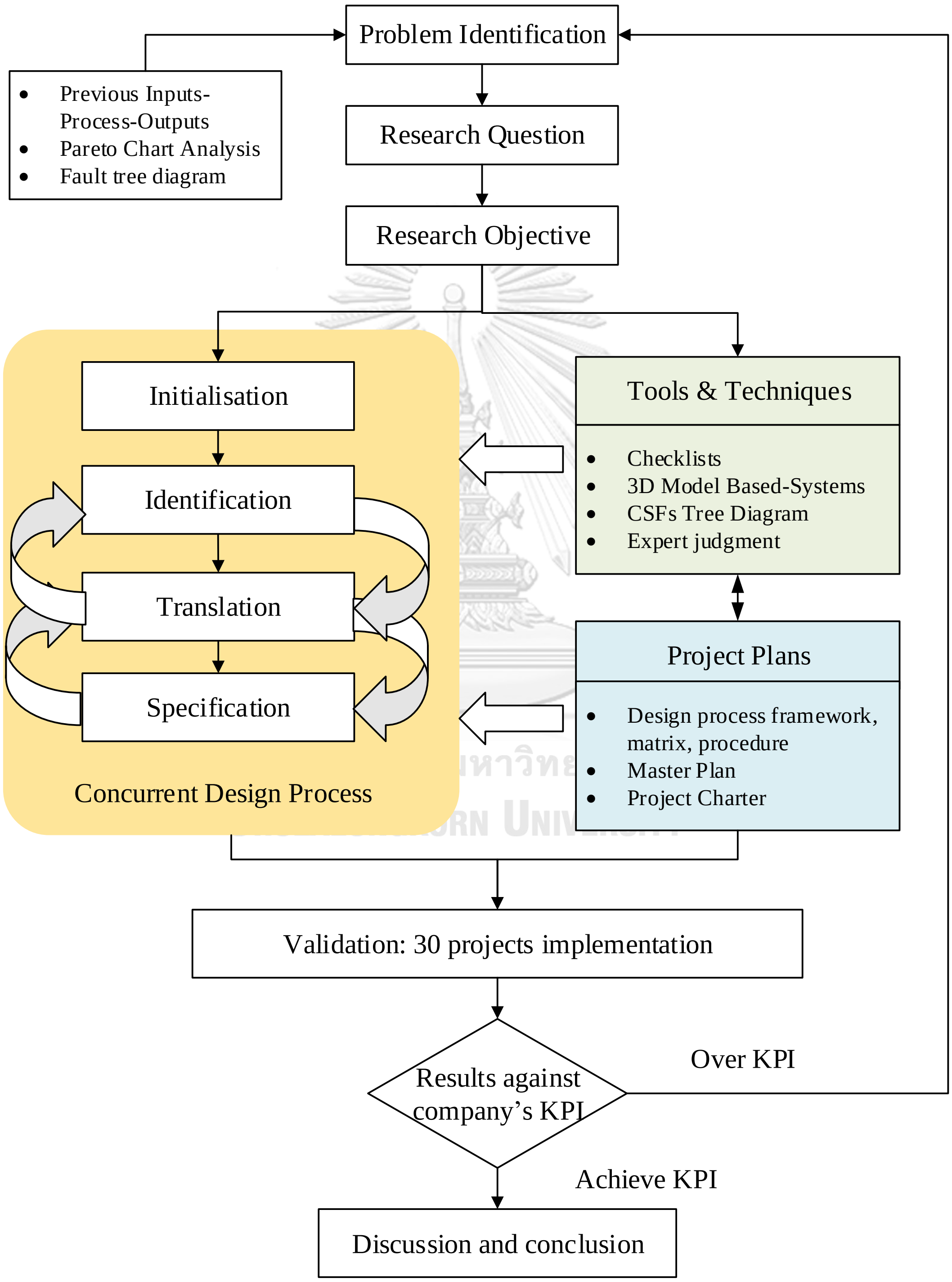

Figure 24. Research Design

3.4 Initialisation Stage

3.4.1 Data collection

The poor planning and management in the early design phase has caused design waste from being redesigned and resubmitted during the process. The data collection was the first activity of the conceptual design process, which aimed to collect the design data and general information for the project from the client. It can be carried out via phone call, email or face-to-face meeting by sale engineer. Since the previous process was ineffective, the design team usually missed some necessary information and drawing input, resulting in long waiting time and design mistakes. As such, a project checklist (Fernández-Sánchez & Rodríguez-López, 2010; Firesmith, 2007) was the most appropriate tool chosen for data collection because checking off a design item was an easy and quick method to avoid missing information during communication between the sales engineer and clients. The detailed checklist is shown in **Figure 25**. The element of data collection for design inputs included:

- Information about project stakeholders
- Request for drawing inputs
- Scope of design (which building? how many roofs?)
- Identify the design parameter for calculation (Rainfall intensity rate)
- Piping specification (HDPE, PVC etc.)

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PROJECT CHECKLIST

1. Data collection

Project Information*	Project Participants*	Drawing Input*
☐ Project Name : ___________	☐ Sale : __________________	☐ Roof Plan*
☐ Location : ______________	☐ Owner : ________________	☐ Section*
☐ Request Date : ___________	☐ Designer : ______________	☐ Site Drainage
☐ Due Date : ______________	☐ Consultant : _____________	

2. Scope of design, feasibility of design and the limitation of building

Scope of Design*	The height from gutter to discharge point is greater than 3 m.?*	Are there no limitation of building that could impact to the roof drainage system?*
☐ Roof ☐ Terrace	☐ Yes	☐ Yes
☐ Canopy ☐ Garden	☐ No (this project is not feasible for Siphonic system)	☐ No (Please specify)

3. Design parameter and concept requirements

Select Design RFI*	Select Piping Material*	☐ Primary System*	☐ Addition System
☐ 150 mm/hr	☐ HDPE	☐ Stack	☐ Overflow System
☐ 200 mm/hr	☐ UPVC	☐ Siphonic (Multi-Outlets)	☐ Secondary System
☐ 250 mm/hr	☐ GI	☐ Stack & Siphonic	
☐ Other ______	☐ Other ___________	☐ Depend on designer	

4. Piping system requirements

Position of downpipe	Maximum pipe diameter	Piping route line
☐ Anywhere, depend on designer	☐ Any size, depend on designer	☐ Anywhere, depend on designer
☐ Specify in drawing	☐ Max. dia require _____ mm.	☐ Specify in drawing

5. Service requirement

Need gutter size recommendation?	Service option preference
☐ Yes	☐ Design & Supply Mat. ☐ Turnkey
☐ No	☐ Design, Supply Mat. And Supervision

6. Additional Comments

Figure 25. Project Checklist

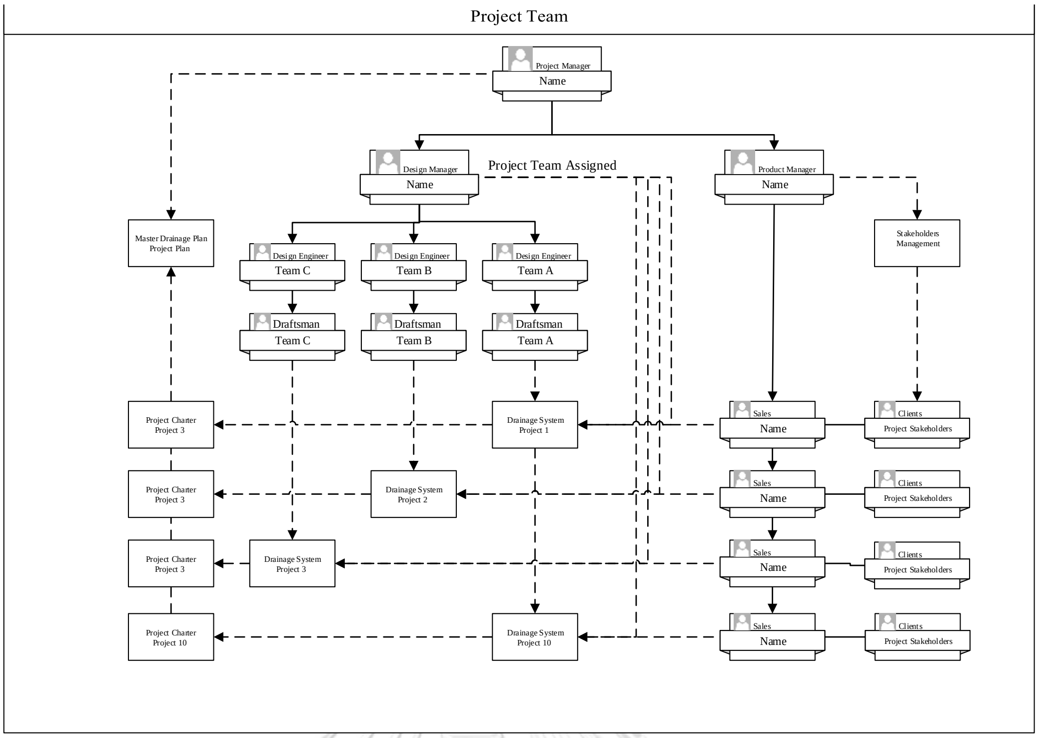

Figure 26. Project Team Development

3.4.2 Create a Project Team

In order to get effective documentation concerning drainage systems, efficient resource planning and management is required. Once the project information has been received, the project team can be classified by the design manager at this stage and the team development framework is shown in **Figure 26**. The project team for storm drainage systems include a project manager, design manager, sales manager, sales engineer, design engineer and draftsmen. The RASCI method was used to develop the roles and responsibilities matrix of drainage supplier organisation as shown in **Table 11**.

The application of RASCI method for conceptual design process is as follows:

- Responsible: The person who responsible for accomplish the task.
- Accountable: The person who responsible overseeing how the task is done, and done correctly.
- Supportive: The person who responsible for supporting the task such as technical support.
- Consulted: The person who provide the advice and knowledge such as design knowledge.

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- Informed: The person who responsible for updating the work status or the agreement that were made in each stage.

Table 11. Team roles and responsibilities matrix

Activites R - Responsible , A - Accountable, S - Support, C - Consulted, I - Informed	Actors Project Manager	Design Manager	Sale Manager	Design engineer	Sale Engineer	Draftsmen	Client
Stage 1: Initialisation							
Data collection and complete the checklist			A	C	R/I		I
Create a project team	R/A/I	C					
Stakeholder analysis	R/A	C	C		I		
Stage 2: Identification							
Drawing study	C	A		R	I	S	
Request for a meeting		A		C	R/I		
Design brief	A	C		R	I		I
Report				R	I		
Stage 3: Translation							
Translation requirements into the design				R			
Design concept development				R			
Concept selection and confirmation		C		A	I		R
Stage 4: Specification							
Issue the design specification	C	A	C	R	I	S	
Issue the quotation	R/A	C	C	I	I		
Issue the project charter	R/A	C	C	I	I		
Document submission for approval	A	C	C		R/I		
Status updating	A	C	C	I	R/I		
Approval	A	C	C	I	I		R

Stakeholder analysis in **Table 12**, which is created by the sale manager based on project information from the sales engineer as well as discussion and approval by the project manager. The purpose of the stakeholder analysis is to identify the influence level and key focus from project stakeholders about the design project. The analysis

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results can be generated through the Expert Judgment method (Fernández-Sánchez & Rodríguez-López, 2010; Zeng et al., 2007). Accordingly, appropriate stakeholder communication management can be decided at the initialisation stage.

Table 12. Stakeholder Analysis Matrix of Drainage System

Stakeholder Organization	Project Stakeholder	Focus issue	Influence/Power	Communication Plan
Company A	Owner			
Company B	Designer			
Company C	Consultant			

3.5 Identification Stage

3.5.1 Study the drawing

When the project team was formulated, the design engineer needed to study the drawings and calculate the rainwater runoff based on the BS standard (British Standards Institution, 2000). After that, the hand sketched drawings could be formulated.

3.5.2 Collaborative Design Brief

Regarding the poor design brief in a traditional process, it causes the formation of an inadequate level of technique knowledge from the sales engineer to deal with clients. The project designer requires detailed technique information for their project building. According to the concurrent engineering concept, an effective design brief for roof drainage systems was proposed in this research by involving the project stakeholder and design team in the design brief to explore the needs and solutions for drainage systems.

The design brief team consists of the storm drainage team, including a design manager, design engineer, sale manager, sales engineer, and the clients; the project designer, project consultant and owner. In order to process the Design Brief smoothly, effective design tools are required, to enhance client understanding about the drainage systems. 3D model based-system was proposed in this research to enhance the communication among the design team and project stakeholders. The sample 3D model based-system is shown in **Figure 27**.

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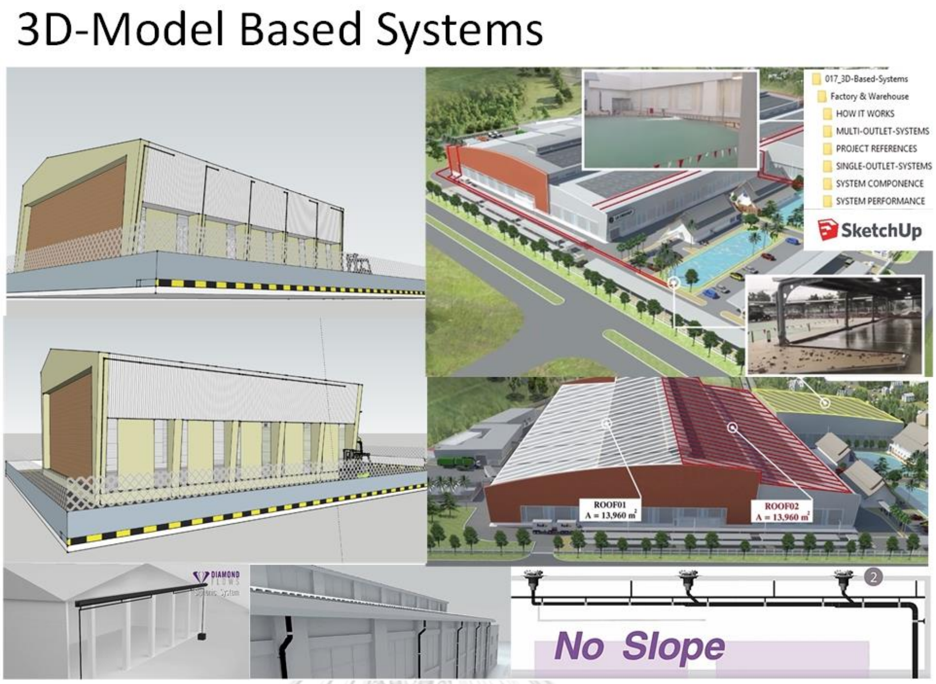

Figure 27. 3D Model-Based System

- **Task 1: Introduction**
  - Introduce the project team
  - the products & services and system performance
- **Task 2: Drawing Review**
  - Clarify drawing revision to be discussed; Roof Plan, Floor Plan, Section, and Site Drainage
- **Task 3: Scope Clarification**
  - Clarify the scope of design
- **Task 4: Requirement**
  - Clarify the concept requirements
- **Task 5: Project Condition**
  - Identify the project site condition; space and location
- **Task 6: Risk Consideration**
  - E.g. the impact from tree, operation and maintenance, warranty
- **Task 7: Solution Discussed**
  - Discuss on various solutions that the company can provide using 3D model based scenario
- **Task 8: Expected Results & Closing**
  - Summary the expected results, due date for submission and closing
- **Task 9: Record**
  - Issue the brief report and sent to the participants

Figure 28. Briefing Procedure

The detailed brief procedure is illustrated in **Figure 28**. Design briefing checklist is related with the brief procedure. In addition, the design briefing checklist need to be completed during the briefing session on each project and sent to the design manager (See **Table 13**). At the final task of the Design Brief, the design team will create a briefing report with the design criteria and condition requirements to work in the next design stage.

Table 13. Design Briefing Checklist

DESIGN BRIEFING CHECKLIST		
Design briefing content	Provided	Remarks
Task 1. Introduction - Introduce the project team - Product & Service - System performance	☐	
Task 2. Drawing Review - Drawing revision - Roof Plan - Section - Floor Plan - Site Drainage	☐	
Task 3. Scope Clarification - Roof area, Number of building - Aboveground - Underground	☐	
Task 4. Requirement - Design rainfall intensity rate (mm/hr) - Piping spec. (HDPE, PVC, etc) - Piping route line	☐	
Task 5. Project Condition - Spacing under gutter - Gutter size - Shaft location - Storm tank location	☐	
Task 6. Risk Consideration - Safety factor - Overflow system - Warranty	☐	
Task 7. Solution Discussed based on the design services: - Single-outlet system - Multi-outlets system - Primary-secondary system	☐	
Task 8. Expected Results & Closing - Due date for submission	☐	
Task 9. Record - Briefing report	☐	

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3.6 Translation Stage

3.6.1 Translate Client Requirement

Translation client requirement is a process to define the design concept and specifications in order to achieve a successful design development. The brief report from the identification stage is the input information for this stage. The team brainstorming is the element of communication plan in the organisation was created by the project manager to define the client needs and design concept. The Tree Diagram was developed as a tool to analyze the broad objectives from clients in greater detail. According to the literature review in **Section 2.8**, combined with the current company's product and service. There were 3 CSFs from the client's perspective for choosing the company's roof drainage systems, which were Cost Focused, Value for Project Focused, and Safety focused. The detailed information of CSF Tree Diagram in **Figure 29** adapted from Wong & Li, 2006; Wong & Li, 2008; Knotten et al., 2015 can be represented into 3 level:

- The 1^{st} Level represents the broad aspect of the client's objective
- The 2^{nd} Level represents the client requirements; what needs to be addressed in regard to meet the client's objective from the 1^{st} Level
- The 3^{rd} Level represents the functional design requirements of the system; under strict compliance to the design concept and client's objective from the 2^{nd} Level

This diagram help the design engineer in design thinking to formulate the draft of design concept. Once the design concept is generated, the sales engineer informs the client in order to get feedback and confirmation for design concept development. This process can be carried out via e-mail confirmation.

The final output for the Identification Stage will enable the designer to clarify the client needs and generate the appropriate design concept approach for the building project.

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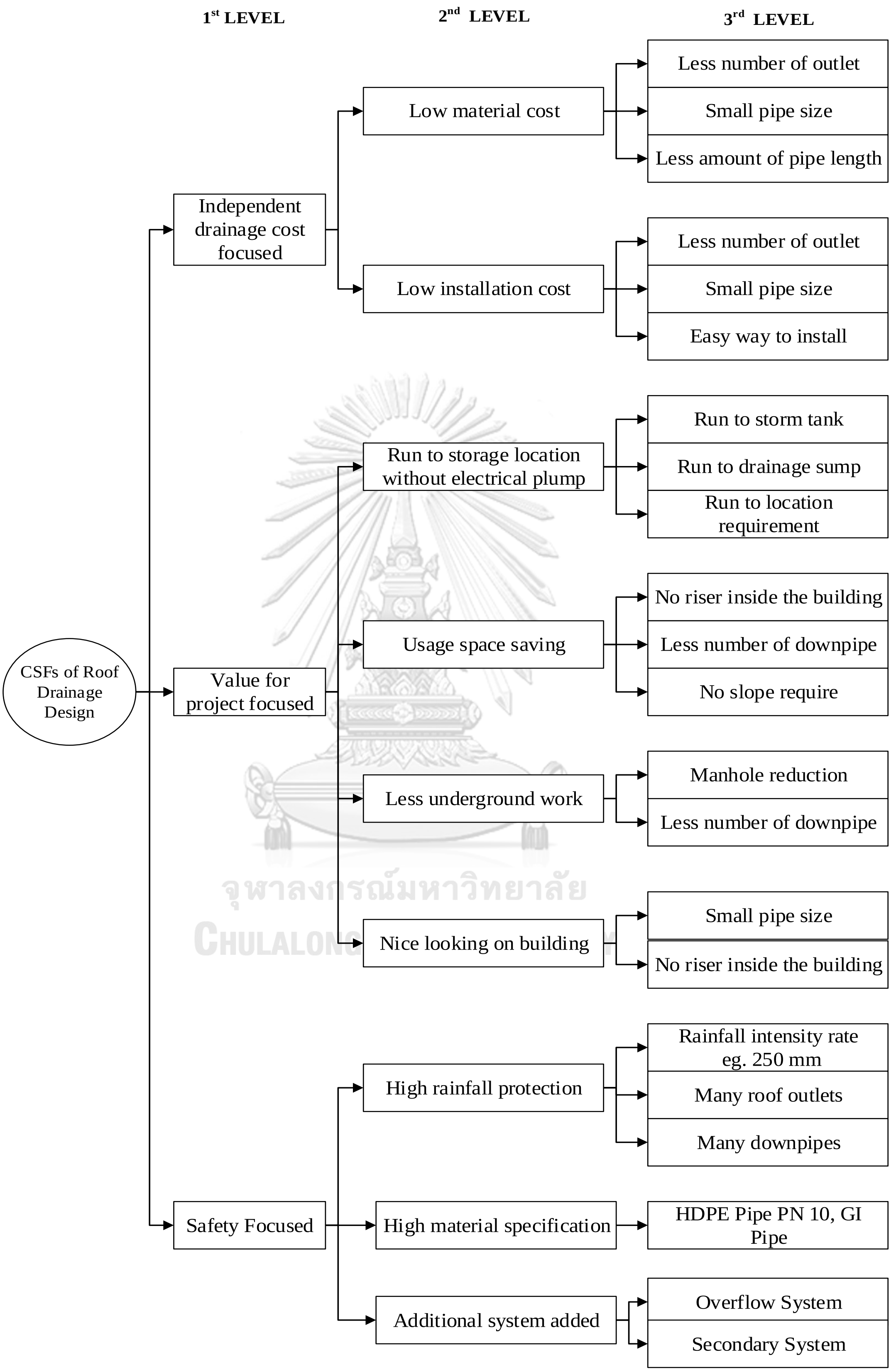

Figure 29. CSF Tree Diagram of Roof Drainage Design

The design information of each project can be managed though communication plan as shown in **Table 14**. Basically, the communication plan can be used throughout the conceptual design process.

Table 14. Communication Plan

What?	Who?		When?	How?	
Communication Title	Provider	Participant	Frequency	Format	Method
Kickoff Meeting	Project Manager	Project Team	One Time Only	Meeting	Face to Face
Project Team Meeting	Project Manager	Project Team	Every 2 Week	Meeting	Face to Face
Design Brief	Design Engineer	Project Team	1 Day After Briefing	Meeting	Email
In-house Brainstorming	Design Manager	Design Team	After design brief	Meeting	Face to Face
Project Status Reporting	Sale Engineer	Project Team	As soon as possible	Chat Group	Mobile Phone

3.7 Specification Stage

Specification Stage is a process to produce the conceptual design output: the designed drawing specification and quotation, the activities of this stage can be outlined as follow.

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3.7.1 Issue the Designed Drawings

Regarding information from the previous stage, the CAD designed drawings of drainage systems, which are based on client requirements can be created at this stage by the design engineer, including the support from draftsmen. This process usually takes time and has to be focused because design errors or other mistakes are possible. Therefore, a drawing review and approval by the design manager is included to minimize the risk of mistake or inaccurate concept requirement.

3.7.2 Material Estimation

The Bill of Materials is created after the design drawing development and re-checking by the design manager.

3.7.3 Quotation

Creating the quotation for roof drainage system which is done by the project manager.

3.7.3.1 Project Charter

Finally, the project charter will be constructed through the expert judgment techniques by designated project manager, who then summarizes for each project the valid design information. This flow process is visualized in the diagram in **Figure 30**. The **Figure 31** shows the project charter template which will help the project manager for planning and control in each design project. The key elements in a project charter template for drainage design project were identified in the literature include: (1) Project information, (2) Objective, (3) Design parameter, (4) Design scope, (5) Project participant, (6) Concept requirements, (7) Risk or problem issue, (8) Constraints, (9) Project status, and (10) Approval milestone

The benefits of project charter for conceptual design process are as follow.

1. Project information
2. Identifying project objective
3. Defining the scope of design
4. Defining the design parameter
5. Clarifying roles and responsibility
6. Defining the requirements
7. Identifying risk and problem issue
8. Defining the constraints for approval
9. Defining the project status
10. Approval milestone

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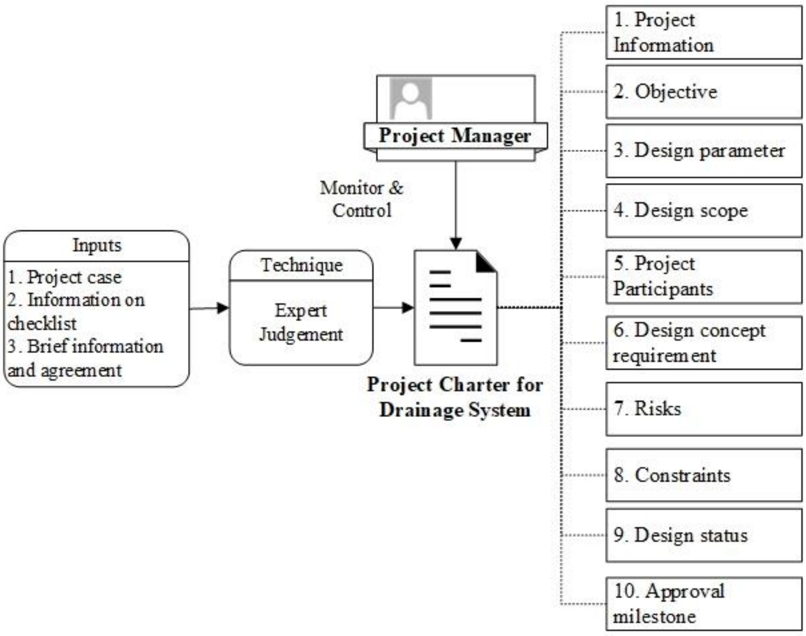

Figure 30. The process development of Project Charter

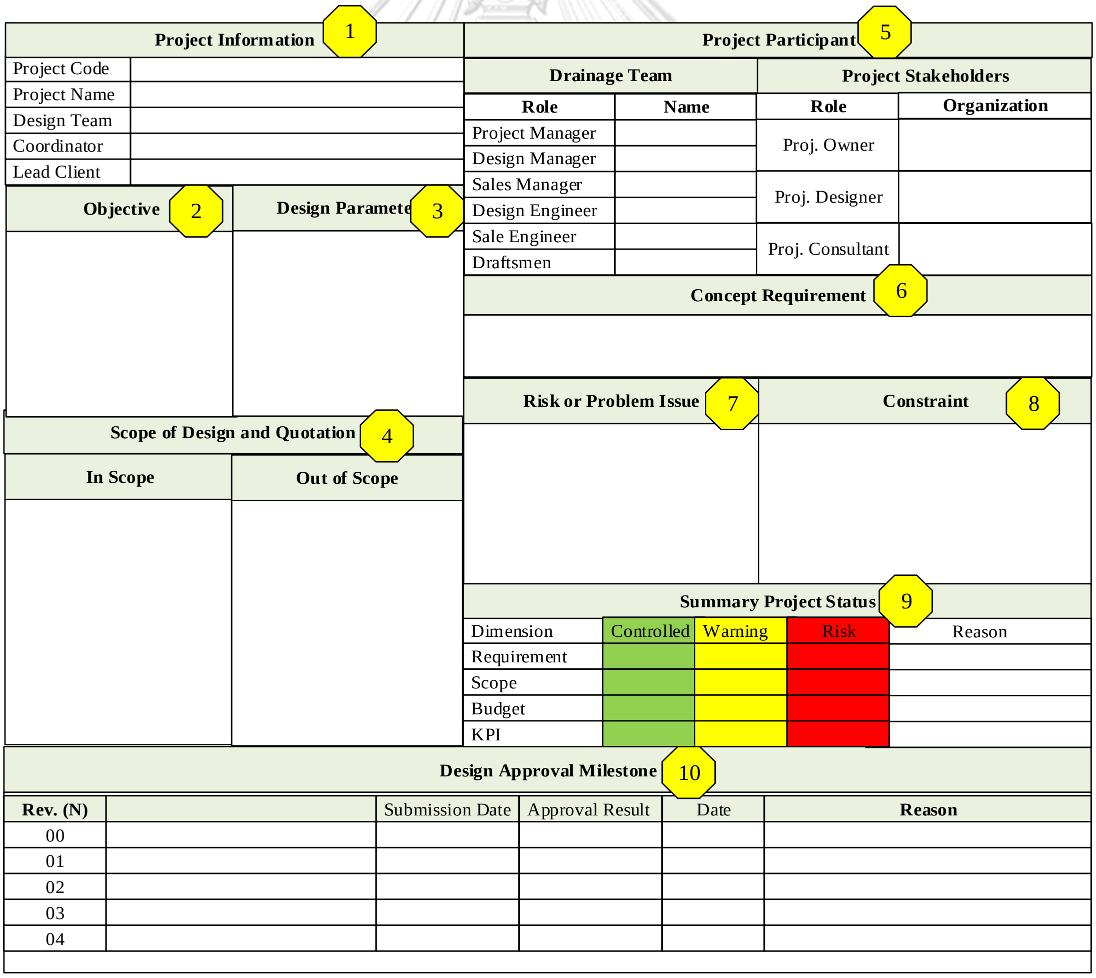

Figure 31. Project Charter Template

3.7.3.2 Master Drainage Plan

The overall design project can be monitored, controlled and tracking by the project manager by using the master drainage plan. The master drainage plan for conceptual design process is shown in **Table 15**.

Table 15. Master Drainage Plan

Master Drainage Plan								Color Coding		Updated
No.	Prepared By:	Project Manager							Approved	
	Control By:	Project Manager							Redesign	13-May-18
	Project Code	Rev.	Name	Design Duration (Day)	Planned Sub.Date	Actual Sub.Date	Returned Date	Status	Cause of Redesign	(N)

3.8 Conceptual Design Management System Approach

The Conceptual Design Management System (CDMS) is defined as a systematic project management program for the case study company to effectively formulate the design outputs based on the client requirements, and to handle with the number of redesign in conceptual design process in order to achieve the research objective *"To reduce the number of redesign though conceptual design process improvement for storm drainage design projects by using project management."* The CDMS will be implemented in the case study company through 4 main stages: Initialization, Identification, Translation and Specification. The new work process activities are created based on the concurrent engineering environment with the integration of control tools and techniques and project plans as illustrated in **Figure 32**.

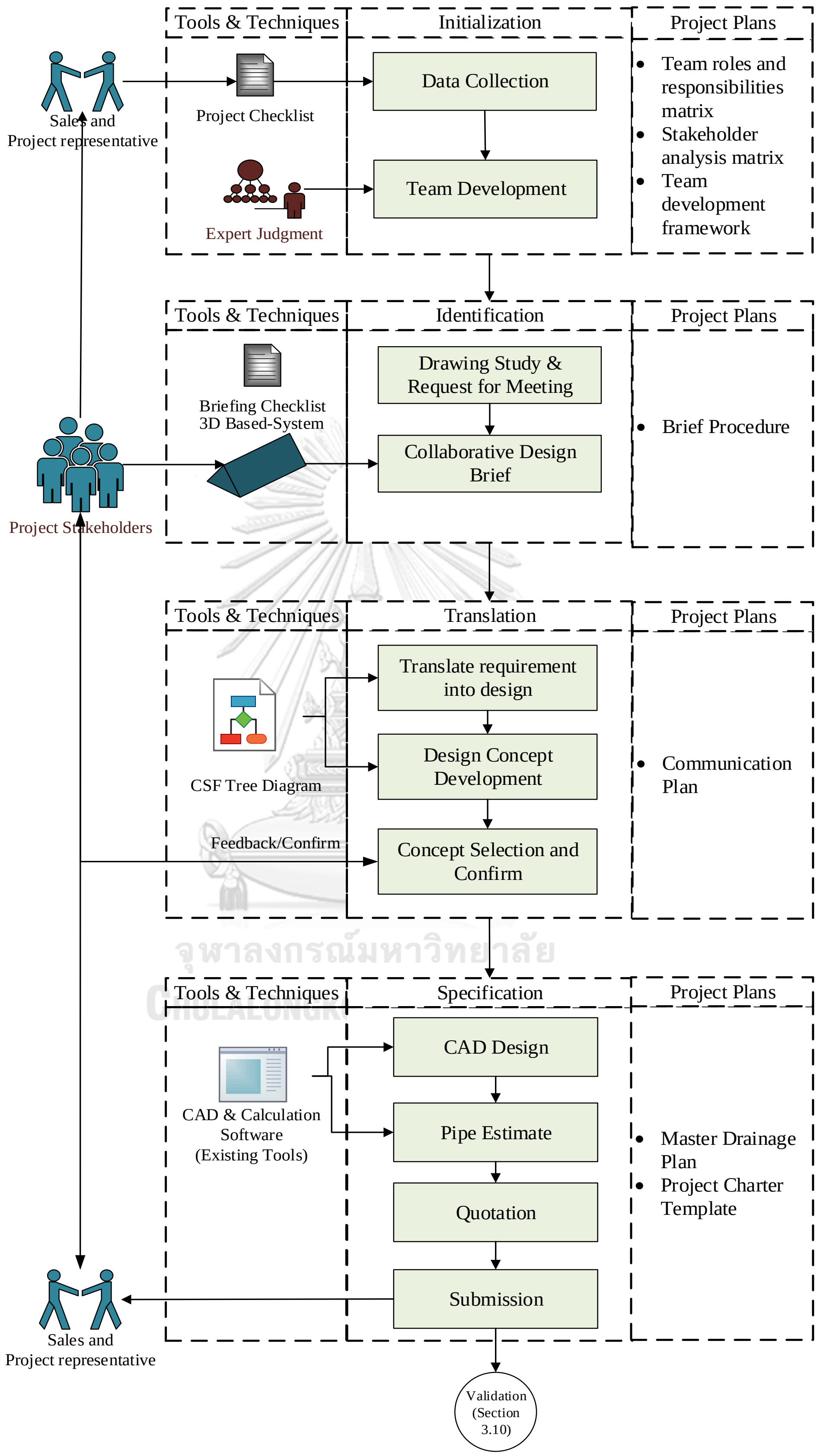

Figure 32. New Conceptual Design Process

3.9 Comparison the traditional process with proposed process improvement

To understand the reason why the new process should be implemented, this part will explain the problems of the traditional process with the proposed process improvement of the 4 main stages; Initialization, Identification, Translation and Specification as shown in **Table 16, 17, 18,** and **19** respectively. After that, the comparison of process activities will be indicated in **Figure 33** and finally, the project baseline to compare and evaluate with the pilot project implementation will be settled in **Table 20**.

Stage 1: Initialization- Collecting data and starting up a project

Table 16. The traditional process and proposed improvement at Initialization Stage

Traditional Process	Proposed improvement: project plans, tools & techniques
• Missing necessary input information at the early stage • Unclarified resource roles and responsibility • Unclarified the project team • The team did not know the project stakeholders and their influencing power on a design project	• Use project checklist to collect the necessary input information • Use RASCI matrix to clarify resource roles and responsibilities • Issue the team development framework • Develop the stakeholder analysis

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Stage 2: Identification – Identify client's needs and requirements

Table 17. The traditional process and proposed improvement at Identification Stage

Traditional Process	Proposed improvement: project plans, tools & techniques
• Lack of proper briefing in design • Poor understanding of technical knowledge from Sales team • Poor understanding from client to define the project requirements • Lack of guideline or procedure in briefing	• Used concurrent engineering concept by creating a multidisciplinary team to clarify the design requirements • Developed the briefing procedure to understand which information should be concerned

• Lack of team integration, low involvement of project stakeholder and design engineer	• Used design briefing checklist to check out all the necessary topics in the briefing session • Used 3D Model based- system (design scenario) to enhance the communication • The discussion will be recorded in briefing report

Stage 3: Translation- Translate the requirements into a design concept

Table 18. The traditional process and proposed improvement at Translation Stage

Traditional Process	Proposed Improvement: project plans, tools & techniques
• The previous designs were mainly based on the supplier's perspective, which couldn't cope with the client's needs and acceptance criteria	• Developed the CSFs Tree Diagram to help the design engineer in design thinking. A variety of client's requirements will be addressed in the tree diagram which will help to define the project's objective into a deeply detail of drainage design specifications. • Confirmed the concept before jumping into CAD drawing development • Developed the communication plan which can be used for all stages in design

Stage 4: Specification- Design specification development

Table 19. The traditional process and proposed improvement at Specification Stage

Traditional Process	Proposed Improvement: project plans, tools & techniques
• The risks were found at the end of process • High number of redesign	• Developed the Project Charter • Created the Master Drainage Plan

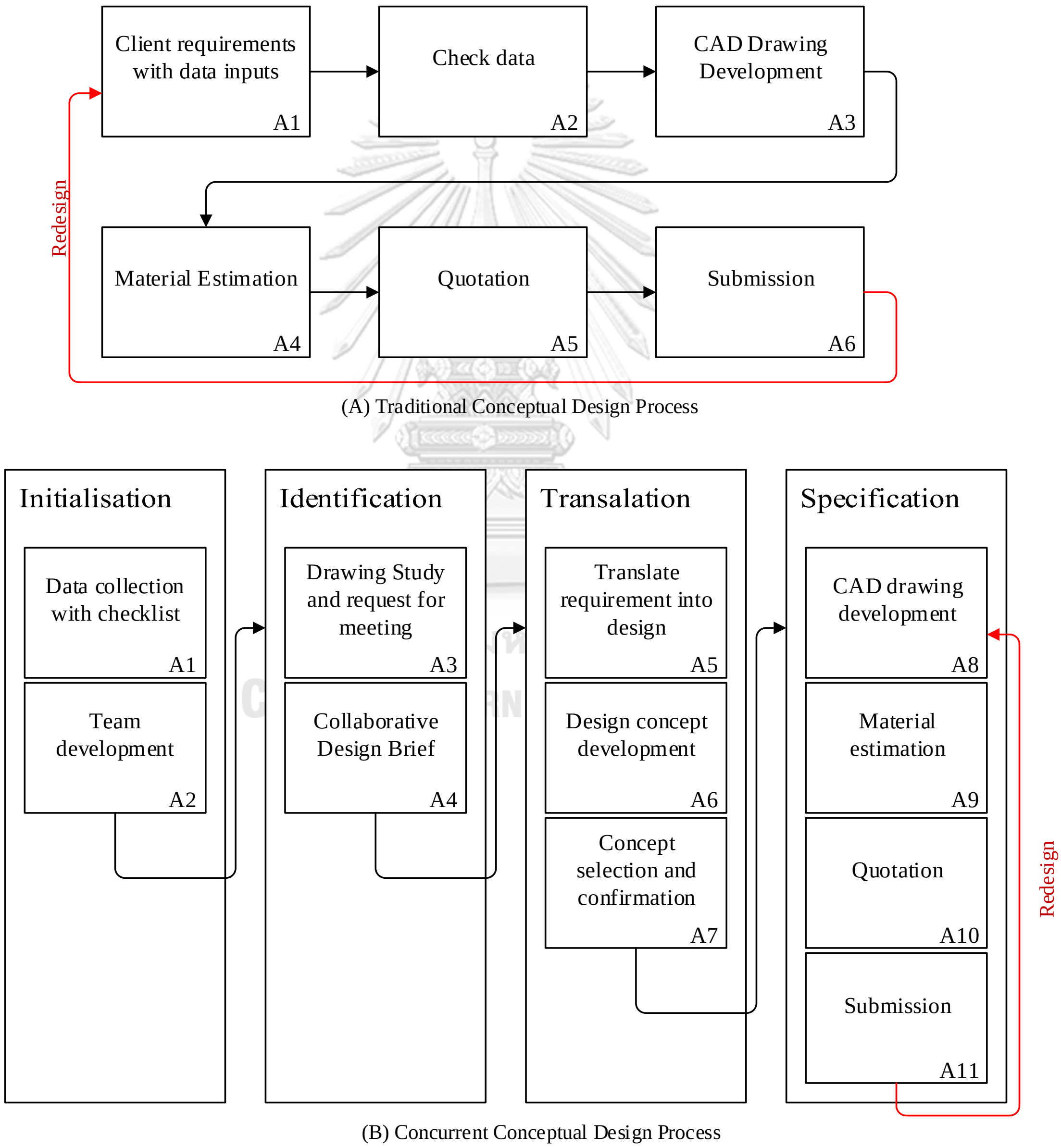

Figure 33. Operational Process Comparison

According to **Figure 33** the traditional design process was operated under the 6 main activities. On the other hand, the new conceptual design process is required the 11 main activities in total to minimize the number of redesign.

Finally, the project baseline was evaluated and estimated from the past project records based on the same project size of this research. The dimensions of project baseline to be compared with the pilot implementation is illustrated in **Table 20**.

Table 20. The Project Baseline

Dimensions	Definition	Traditional Process
Project Scope	The scope baseline of a project to compare the new process with the traditional process	• Factory and warehouse buildings • Roof area between 20,000 - 35,000 m^2 • Design-Bid-Built project • Thailand
Design Quality	The set of possible risks in drainage design that could impact to the project performance in conceptual phase which can be counted by the number of redesign (N)	The average number of redesign per project is at 3.4 (case study company, 2017).
Design Cost	The cost from redoing the design in conceptual phase	The average redesign cost per project is at THB13,000 (case study company, 2017).
Design Time	The duration of design process from the start to formulate design outputs in conceptual phase	The estimate design time per project to formulate the design outputs based on the project size M is at 3.2 days exclude waiting time, transition-duration and non-value adding activities (case study company, 2017).

3.10 Validation Plan

The validation for the new process approach will be completed through pilot implementation in the case study company. The pilot implementation was approved and supported by the company director. The participants would include sales engineer, design engineer, draftsmen, design manager, sales manager, project manager and project stakeholder: designer, owner and consultancy. The pilot project criteria can be described as follows:

3.10.1 Project Scope

Pilot Project Criteria

Scope: Conceptual Design

Building Type: Warehouse/factory building

Project Type: Design-Bid-Built project

Project Size: Roof area between 20,000 - 35,000 m^2

Sample Size: 30 projects

Country: Thailand

3.10.2 Test Period

The implementing duration was 1 year and 1 month, which started in 1st April 2017 and completely tested in 30th April 2018.

3.10.3 Measurement

The project performance in conceptual design phase can be both tangible and intangible, but more often to be intangible which made it difficult to measure. Because they might base on client attitudes and perceptions. Therefore, the results of this research were measured in regard to the countable data which is the number of redesigns (N). The approval process consisting of the approval steps for building specifications in Thailand is shown in **Figure 34**. In this example, the design documents were submitted to the project designer for review and approval of the design specifications for a storm drainage system. The target KPI of the company aimed to achieve specifications approval at $N \leq 2$. In order to achieve approval, the agreement score from the project stakeholders must be more than three; if not, the design output will be rejected, resulting in the need for a redesign for the suppliers.

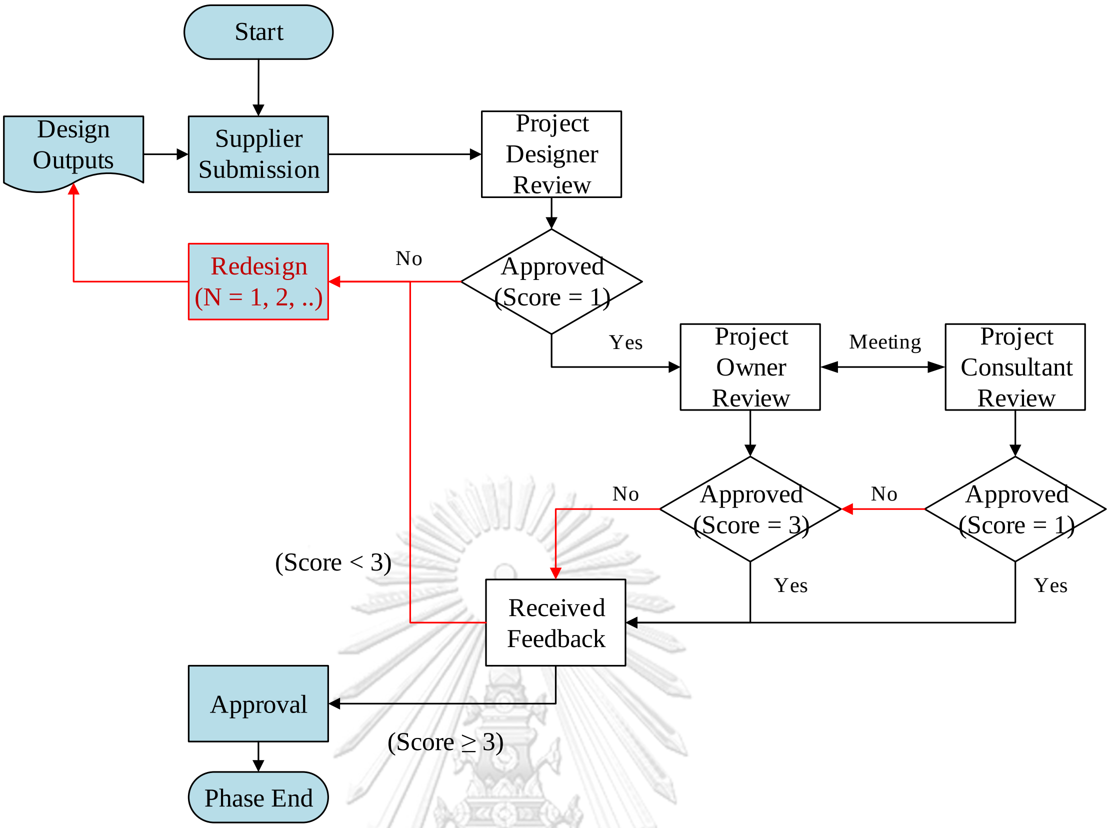

Figure 34. Approval Process for Conceptual Design Phase

3.10.4 Action Plan

Once the director and project team agreed on a process improvement, the action plan for new conceptual design process improvement is required. The work instruction of new process was created by the project manager (See **Appendix A**). After that, the training season was introduced to the design and sales department.

3.11 Project risk assessment and mitigation plan

Project risk management is an important aspect to minimize the possibility of failure. It requires at an early stage, to identify areas of risk, assess the project phase and develop possible mitigation plans.

Knowing and understanding risks is the key for risk management. In this research study, design risks can be seen at all stages of the conceptual project phase as displayed in **Table 21**.

Table 21. Risk in conceptual design phase

Stage in Design	Causes of Risks
Initialisation	• The risks could be occurred when the necessary data inputs such as scope and required design parameter from clients were missing • Poor planning on resource's roles and responsibilities could be impacted overall activities within the phase
Identification	• Due to the large involvement of project stakeholders, this situation was complicated in dealing by one Sale Engineer, resulted to the poor briefing in design that could lead to the mistake in identifying the client requirements
Translation	• A set of requirements were the primary inputs in the drainage design. Poor deeply understanding on client's design criteria requirements could create the wrong concept that not meeting the objective of project
Specification	• Poor planning and controlling the inputs from previous stage could impact to the poor quality of design outputs (specification). Therefore, that would increase a number of redesign, cost and lead-time of a project

According to the consideration of risks throughout the project phase there were six potential risks as mentioned in **Section 1.3.1** that happened in conceptual design process which need to be managed namely:

(A) Incorrect scope of design

(B) Incorrect concept requirements

(C) Design not meeting target budget

(D) Design change by main architect

(E) Human error

To analysis the risks in design project, the risk assessment matrix at **Table 22** can be applied (Garvey et al., 1998) in order to consider the risks based on impact and probability. To respond the risks, the summary of mitigation plan as shown at **Table 23** was developed, this included the consideration of risks in conceptual design, risk scores, the mitigation plan and the person who controlled the risks.

Table 22. Risk assessment matrix (Garvey et al., 1998)

Risk Matrix	Low impact (1)	Medium impact (2)	High impact (3)
High probability (3)	Acceptable risk Medium (Score 3)	Unacceptable risk High (Score 6)	Unacceptable risk High (Score 9) **[A, B]**
Medium probability (2)	Acceptable risk Low (Score 2)	Acceptable risk Medium (Score 4) **[D]**	Unacceptable risk High (Score 6) **[C]**
Low probability (1)	Acceptable risk Low (Score 1) **[F]**	Acceptable risk Low (Score 2) **[E]**	Acceptable risk Medium (Score 3)

Table 23. Mitigation plan

ID	Risks in conceptual design phase	Scores	Mitigation Plan	Owner
A	Incorrect scope of design	9	Used checklist	Sale Engineer
B	Incorrect concept requirements	9	Defined the concept requirement via design brief	Multidisciplinary team
C	Design not meeting target budget	6	Used project charter	Project Manager
D	Design change by main architect	4	Accepted the change due to it is and external factor	Design Engineer
E	Incorrect design parameters	2	Used checklist	Sale Engineer
F	Human error	1	Rechecked drawings	Design Manager

3.12 Summary of the research methodology

Industrial building projects are complex because of the different stakeholders participating during the conceptual design process. The supplier face conflicts and issues due to the poor project management which impact to the poor identifying the client requirements and then effect to the poor quality of design outputs. Implementing the Conceptual Design Management System on drainage design project improved the project performance in terms of quality improvement by providing a CDMS for appropriately manage the design project during the conceptual process specializing in the field of storm drainage system. Furthermore, it aids to reduce the number of re-design and receive the approval within the company’s target KPI.

In summary, the proposed CDMS offers: (1) a tools and techniques to improve the design project performance for better identifying the client requirements for drainage system, (2) re-design the conceptual design process for better alignment with the clients; designer, owner and consultancy and (3) the development of project plans for solving the management problems of the case study company as described in **Chapter 1**.

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Chapter 4. Project Implementation and Result

This chapter described the pilot implementation for the conceptual design process for the case study company. To implement the CDMS in the organization, the agreement from the company director is required. The method of implementations were followed the proposed improvement for managing the design projects as described in **Chapter 3**. The proposed CDMS was implemented into an industrial building project which is the 30 project cases of the case study company.

4.1 Description of the Project

P Factory is a factory building project, located in Samutprakarn province of Thailand. This project was in the design stage. The client wanted to apply a siphonic roof drainage system on 35,795 sq.m of roof surface. The specialist supplier was invited to provide the specifications of storm drainage system to the main project designer for approval during the design stage.

4.2 Initialisation Stage

4.2.1. Data collection

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First, the design drawing inputs and project information of project A were collected from client by sale engineer **(See Figure 35).** The project checklist and drawing inputs in **Figure 36** were transferred to the design team and project manager by sale engineer.

The list of design inputs for project were

- Roof Plan Drawing
- Floor Plan Drawing
- Type of piping material
- Design parameter
- The list of client project stakeholders
- Scope of Design

Figure 35. Data Collection

PROJECT CHECKLIST

1. Data collection

Project Information*	Project Participants*	Drawing Input*
☑ Project Name : P Factory	☑ Sale : SI	☑ Roof Plan*
☑ Location : Samutprakarn	☑ Owner : TICON, Power buy	☑ Section*
☑ Request Date : 13/2/18	☑ Designer : CRH	☐ Site Drainage
☑ Due Date : 28/2/18	☑ Consultant : IECM	

2. Scope of design, feasibility of design and the limitation of building

Scope of Design*	The height from gutter to discharge point is greater than 3 m.?*	Are there no limitation of building that could impact to the roof drainage system?*
☑ Roof ☐ Terrace	☑ Yes	☑ Yes
☑ Canopy ☐ Garden	☐ No (this project is not feasible for Siphonic system)	☐ No (Please specify)

3. Design parameter and concept requirements

Select Design RFI*	Select Piping Material*	☐ Primary System*	☐ Addition System
☐ 150 mm/hr	☑ HDPE	☐ Stack	☐ Overflow System
☑ 200 mm/hr	☐ UPVC	☑ Siphonic (Multi-Outlets)	☐ Secondary System
☐ 250 mm/hr	☐ GI	☐ Stack & Siphonic	
☐ Other ______	☐ Other ___________	☐ Depend on designer	

4. Piping system requirements

Position of downpipe	Maximum pipe diameter	Piping route line
☐ Anywhere, depend on designer	☑ Any size, depend on designer	☐ Anywhere, depend on designer
☑ Specify in drawing	☐ Max. dia require _____ mm.	☑ Specify in drawing

5. Service requirement

Need gutter size recommendation?	Service option preference
☑ Yes	☐ Design & Supply Mat. ☑ Turnkey
☐ No	☐ Design, Supply Mat. And Supervision

6. Additional Comments

Figure 36. Project Checklist for P Factory Project

4.2.2 Create a Project Team

After checked the information, the Design Team A was assigned to create the design solution for this project. The members of P Factory Project is shown in **Figure 37**.

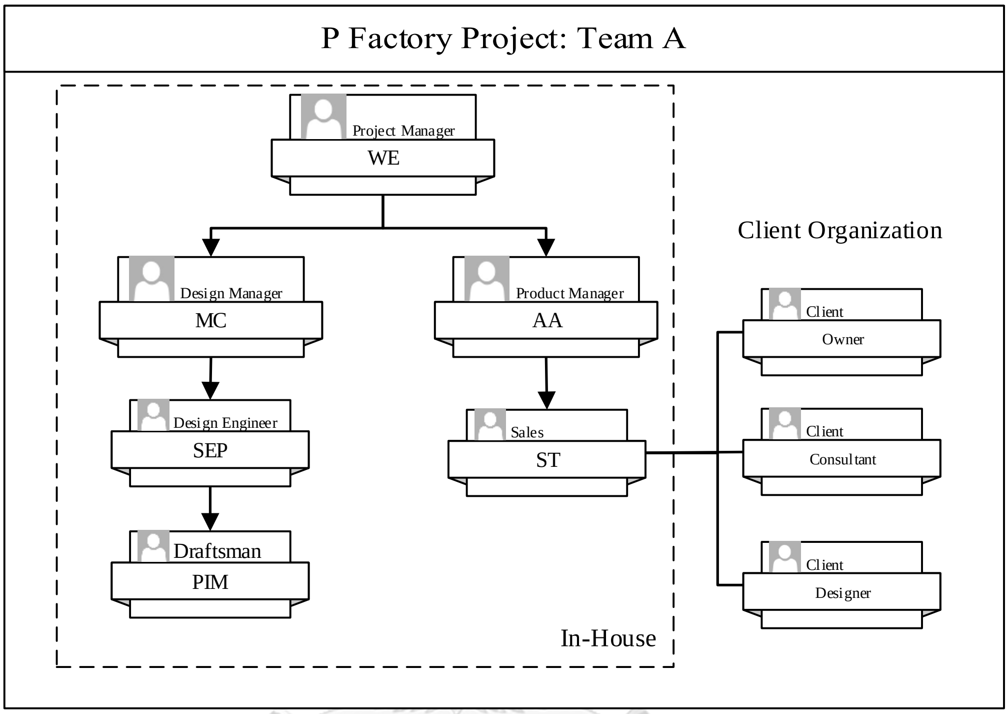

Figure 37. Project team for P Factory Project

The project stakeholders during the conceptual design consisted of the owner, designer and consultancy. The stakeholder analysis was created by the sale manager. According to the analysis result in **Table 24**, a high influencing power in the project came from the project owner, therefore this design was mainly depended on the requirements of project owner.

Table 24. Stakeholder analysis of P Factory Project

Stakeholder Organization	Project Stakeholder	Focus Issue	Influence/Power	Communication Plan
Powerbuy, TICON	Owner	Total Project Cost	High	Keep satisfied
CRH	Designer	Cost & Scope	Medium	Keep informed
IECM	Consultant	Safety	Medium	Keep informed

4.3 Identification Stage

4.3.1 Drawing Study

Next, the design engineer is liable for studying the drawing inputs to formulate the design feature based on the information on the checklist and develop the draft concept of drainage system. The design parameter of P Factory Project is shown as below.

Design parameter of P Factory Project are as follows:

1. Roof area = 35,795 sq.m.
2. Design rainfall intensity rate = 200 mm/hr
3. Total discharge = 1988.6 lps
4. Pipe material = HDPE (PN6)

After that, the design brief season was requested to identify the client requirement in details.

4.3.2 Collaborative Design Brief

The collaborative design brief for a P Factory design project developed by the project team (the supplier and client stakeholders: owner, designer, consultancy) in order to identify the client requirements, as shown in **Figure 38**.

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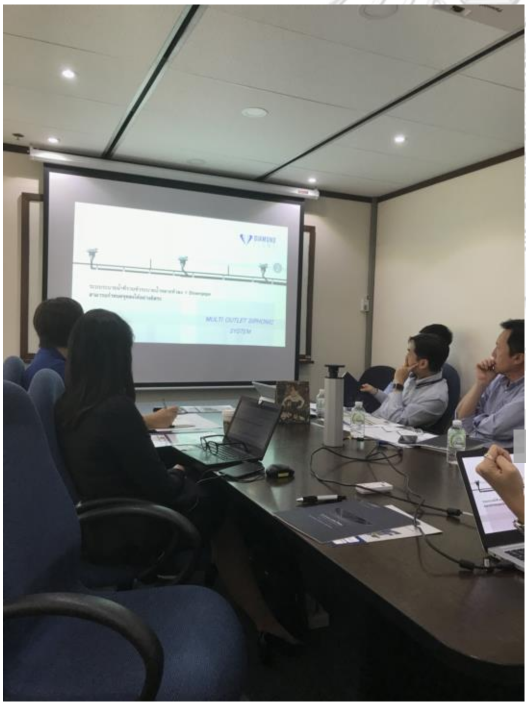
(A) Product Introduction

(B) System Performance



(C) Design Concept

(D) Project Conditions and Solution Discussed

Figure 38. Collaborative Design Brief of P Factory Project using 3D-Based System

The lists of briefing content as shown in **Table 25** were completed at the briefing session to ensure that all necessary tasks of drainage design were discussed in the meeting.

Table 25. Design briefing checklist of P Factory Project

DESIGN BRIEFING CHECKLIST		
Design briefing content	Provided	Remarks
Task 1. Introduction - Introduce the project team - Product & Service - System performance	☒	
Task 2. Drawing Review - Drawing revision - Roof Plan - Section - Floor Plan - Site Drainage	☒	
Task 3. Scope Clarification - Roof area, Number of building - Aboveground - Underground	☒	- Main roof and canopy
Task 4. Requirement - Design rainfall intensity rate (mm/hr) - Piping spec. (HDPE, PVC, etc) - Piping route line	☒	- 200 mm/hr - HDPE
Task 5. Project Condition - Spacing under gutter - Gutter size - Shaft location - Storm tank location	☒	- Gutter size 400x400mm.
Task 6. Risk Consideration - Safety factor - Overflow system - Warranty	☒	
Task 7. Solution Discussed based on the design services: - Single-outlet system - Multi-outlets system - Primary-secondary system	☒	- Multi-outlets system
Task 8. Expected Results & Closing - Due date for submission	☒	
Task 9. Record - Briefing report	☒	

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Regarding the information from design briefing program, the design briefing report of P Factory Project can be summarized in **Table 26**.

Table 26. Brief Report

Project : P Factory	**Date: 20/2/18**
Project Participant	
• Owner • Designer • Consultancy • Drainage Supplier Team: Sale Manager, Sale Engineer, Design Engineer, and Design	
Brief Report	
• Scope: The roof areas to be designed were the main roof and the canopy area. The office building is not included. And, the underground pipe to manhole is out of design scope. • Objective: Focusing on project cost reduction and downpipe reduction. • Project Conditions: The downpipes are not allowed to locate along the gutter line due to site drainage condition. • Risk/Problem Issues: The location of public site drainage is only located on gridline 1 and gridline 2. The gutter length is 272.5 m. which considered as a very long gutter so the consultancy and designer were very concerned about the appropriate size of gutter to be used. • Design Solution: Due to the high volume of rainwater on the main roof and the preference downpipe location by the owner. The design solution should be developed to cover this subjects. • Additional requirement: Gutter calculation sheet • Expected result: 28/2/18	

4.4 Translation Stage

Define the design concept and specification to aligning with client requirements is the purpose of this stage. According to the CSF Tree Diagram in **Figure 39**, and the in-house brainstorming, it can be summarized that the value creation of total project was the main objective of this project to be focused. By the design was covered the underground work reduction in order to remove the water capacity of 1,988.6 l/s from the building to the discharge point. According to the company's types of concepts as mentioned in **Table 2**, the appropriate design concept to be used for this project was the multi-outlets system. Once the draft of concept was developed and confirmed the process can be moved to the next stage.

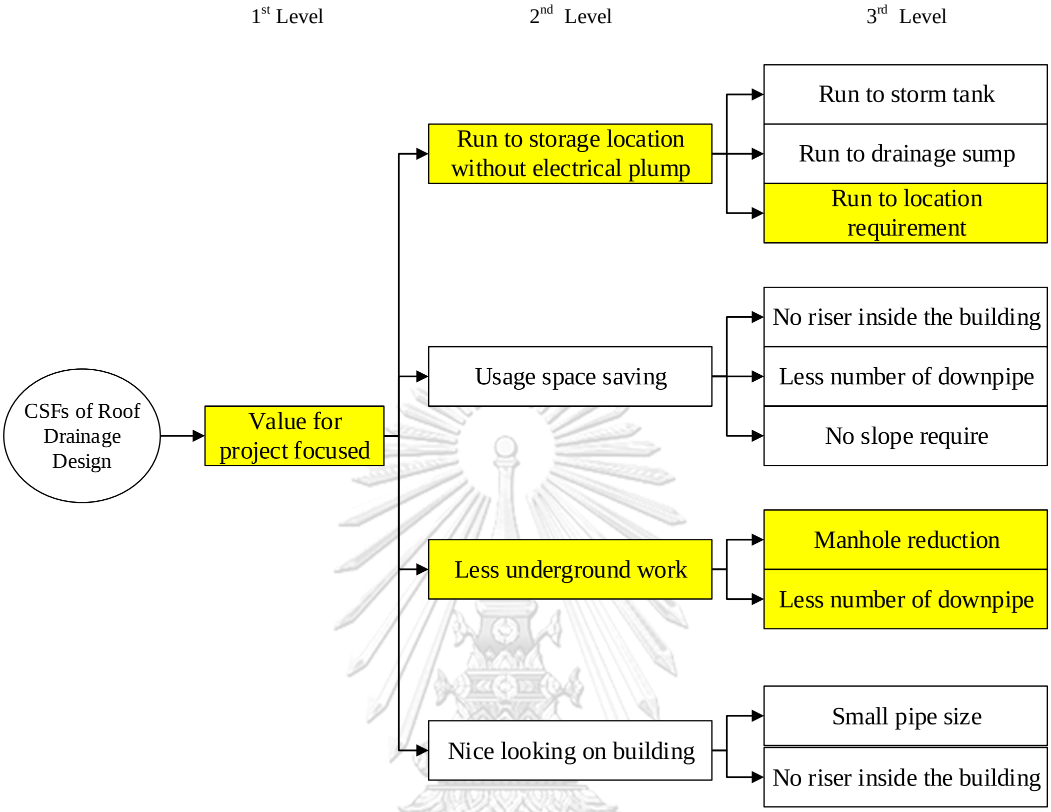

Figure 39. CSF of P Factory Project

4.5 Specification Stage

The final conceptual design outputs are developed in this stage. The roof drainage specifications for P Factory Project are summarized as follows.

4.5.1 Issue the designed drawing

Once the concept was confirmed, a set of designed drawings and specifications were created by the design engineer and approved by the design manager. (See **Table 27**, **Figure 40**, **41**, **42, 43** and **44**.

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Table 27. The Designed Specification of P Factory Project

Storm Drainage System	Design Specification
Project Name	P Factory Project
Roof area (A)	35,795 sq.m.
Rainfall Intensity in Design (RFI)	200 mm/hr
Total Discharge Capacity (Q)	1988.6 l/sec
System Type	Muli-Outlets System
Number of Outlet (n)	73 Outlets
Capacity/Outlet (Q)	27.2 l/sec
Type of Outlet	Primary Outlet
Number of Downpipe	11 Downpipes
Pipe Material	HDPE (PN6)
Gutter Size	500x500 mm.

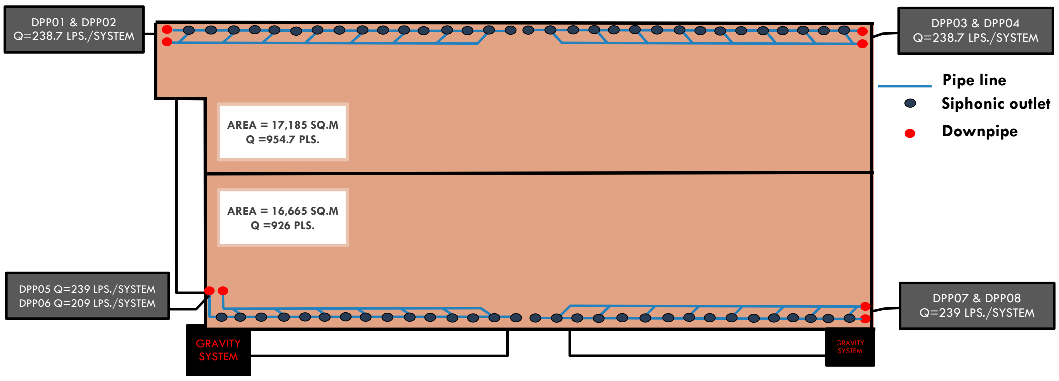

Figure 40. Conceptual design on main roof of P Factory Project

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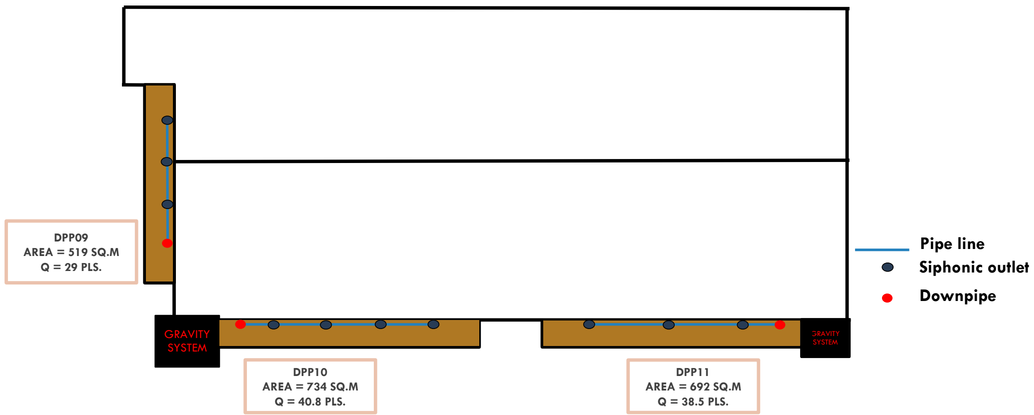


Figure 41. Conceptual design on canopy of P Factory Project

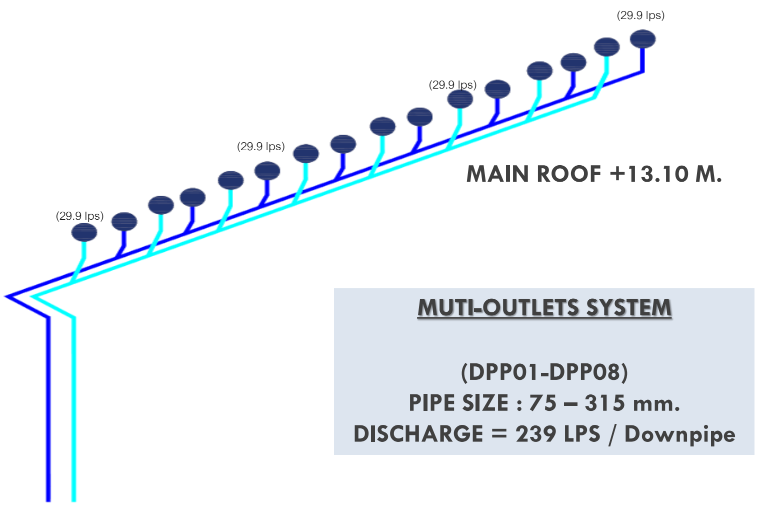


Figure 42. The example of riser diagram for DPP01 and DPP08 on main roof

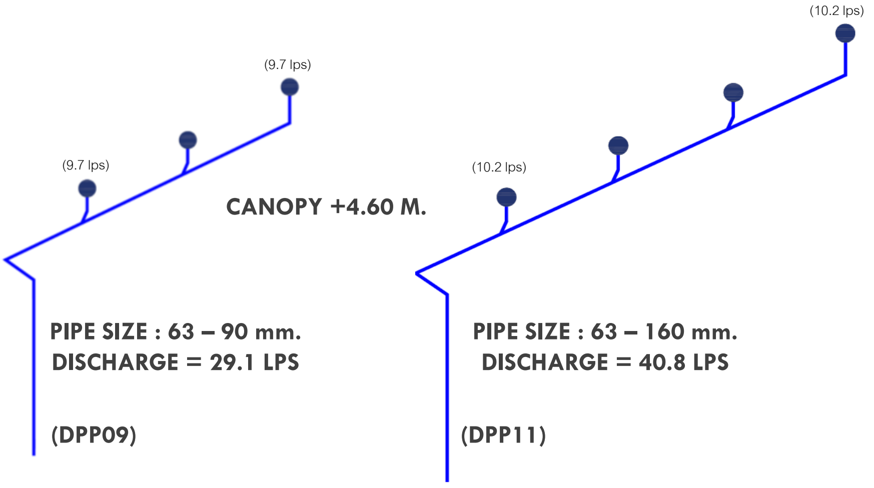
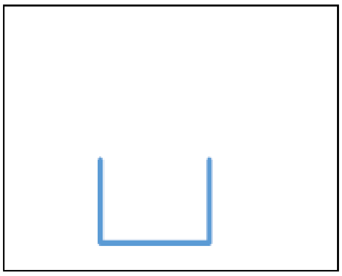


Figure 43. The example of riser diagram for DPP09 and DPP11 on canopy

Design Standard : BSEN 12056-3

Gutter Properties

Gutter Type	Eave	
Sole Width (S)	400	mm.
Height (W)	400	mm.
Side Slope 1	0	degree
Side Slope 2	0	degree
Segment Length (L)	8200	mm.
Top Width (T)	400	mm.



Eave Gutter

Cross Sectional Area (A_E)	=	160,000.00	mm^2
F_D	=	1.0000	
S/T	=	1.0000	
F_S	=	1.0000	
Nominal Flow Capacity (Q_N)	=	111.36	l/s
L/W	=	20.50	
F_L	=	1.0000	
Actual Flow Capacity (Q_C)	=	100.22	l/s
Flow for gutter with angle	=	85.19	l/s

Valley Gutter

Minimum Freeboard (Y)	=	75.00	mm.
Maximum Design Depth of Flow (W)	=	325.00	mm.
Width of Water Surface (T)	=	400.00	mm.
Cross Sectional Area (A_E)	=	130,000.00	mm^2
F_D	=	0.9494	
S/T	=	1.0000	
F_S	=	1.0000	
Nominal Flow Capacity (Q_N)	=	91.17	
L/W	=	25.2308	
F_L	=	1.0000	
Actual Flow Capacity (Q_C)	=	82.05	l/s

Figure 44. Gutter Calculation

4.5.2 Material Estimation

After that, the bills of material was created by the design engineer and re-checked by the design manager are shown in **Table 28**.

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Table 28. The Bills of Material for P Factory Project

Bills of Material	Quantity	Unit
Number of Outlet	73	Set
HDPE Pipe Dia 63 mm.	5	m.
HDPE Pipe Dia 75 mm.	12	m.
HDPE Pipe Dia 90 mm.	43	m.
HDPE Pipe Dia 110 mm.	53	m.
HDPE Pipe Dia 125 mm.	122	m.
HDPE Pipe Dia 160 mm.	9	m.
HDPE Pipe Dia 200 mm.	185	m.
HDPE Pipe Dia 250 mm.	369	m.
HDPE Pipe Dia 315 mm.	537	m.
HDPE fitting	1	lot
Pipe Support	1	lot

4.5.3 Quotation

Then, the design drawings and the bills of material were transferred to the project manager to quote the price of P Factory Project. The turnkey price of storm drainage system for this project was THB 4,000,000. After that, the design outputs were sent to the sale engineer to submit to the clients for approval.

4.5.4 Project Charter

Figure 45 represents the project charter of P Factory project, this created by the project manager in order to monitor, control and update the project.

Project Information	
Projecr Code	T8012
Project Name	P Factory
Design Team	TEAM A
Coordinator	SI
Lead Client	CRH

Objective	Design Parameter
Value for project fouced	(a) Rainfall intensity = 200 mm/hr (b) Pipe system = HDPE (PN6)

Scope of Design	
In Scope	**Out of Scope**
(a) Main roof and canopy	(a) Underground work
(b) Roof area = 35795 sq.m.	(b) opening on meltal gutter
(c) Above ground system	(c) Scoffolding machines
(d) Material Supply	(d) Temporary system
(e) Installation works	(e) Office building

Project Participant			
Drainage Team		**Project Stakeholders**	
Role	**Name**	**Role**	**Organization**
PM	WE	Proj. Owner	TICON,Powerbuy
DM	MC		
SM	AA	Proj. Designer	CRH
DE	SEP		
SE	SI	Proj. Consultant	IECM
D	PIM		

Concept Requirement
Multi-Outlets System

Risk or Problem Issue	Constraint
Request for gutter calculation and gutter size recommendation	No underground work along the gutter line

Summary Project Status				
Items	C	W	R	Reason
Req.		W		Incorrect concept requirements
Scope	C			
Budget	C			
Quality (KPI)		W		

Design Approval Milestone					
Rev. (N)	Description	Submission Date	Approval Result	Date	Reason
00	Conceptual Design	28-Feb-18	No	13-Mar-18	Incorrect concept requirements
01	Re-design	16-Mar-18	Yes	10-Apr-18	Design approval
02					
03					
04					

Note: C = Controlled, W = Warning, C = Risk

Figure 45. Project Charter of P Factory Project

4.5.5 Master Plan

The master drainage plan of overall project implementation is shown in **Table 29**. The implemented results have achieved the company’s target KPI. However, as indicated in the scope of research, the causes of redesign that subjected to “D”- the design drawings changed by main architect, did not count in this research.

Table 29. Master drainage plan

No.	Project Code	Rev.	Name	Design Duration (Day)	Planned Sub.Date	Actual Sub.Date	Returned Date	Status	Cause of Redesign	(N)
	Master Drainage Plan							Color Coding		Updated
	Prepared By:	Project Manager							Approved	
	Control By:	Project Manager							Redesign	13-May-18
1	T7035	0	Project 1	5.1	07-May-17	07-May-17	06-Jun-17	Approved		N=0
2	T7040	0	Project 2	5.1	02-May-17	02-May-17	03-May-17	Redesign		N=1
	T7040	1	Project 2	1	03-May-17	03-May-17	05-May-17	Approved	A	
3	T7042	0	Project 3	5.1	07-Apr-17	07-Apr-17	18-Jun-17	Approved		N=0
4	T7052	0	Project 4	5.1	28-Jun-17	28-Jun-17	07-Jul-17	Redesign		N=2
	T7052	1	Project 4	4	17-Jul-17	17-Jul-17	28-Aug-17	Redesign	B	
	T7052	2	Project 4	4	01-Sep-17	01-Sep-17	12-Sep-17	Approved	C	
5	T7053	0	Project 5	5.1	05-Jul-17	05-Jul-17	08-Jul-17	Redesign		N=1
	T7053	1	Project 5	3	22-Sep-17	22-Sep-17	29-Sep-17	Approved	A	
6	T7054	0	Project 6	5.1	11-Jul-17	11-Jul-17	26-Jul-17	Redesign		N=2
	T7054	1	Project 6	3	13-Oct-17	13-Oct-17	05-Nov-17	Redesign	A	
	T7054	2	Project 6	3.5	11-Nov-17	11-Nov-17	20-Dec-17	Redesign	B	
	T7054	3	Project 6	3	25-Dec-17	25-Dec-17	13-Feb-18	Approved	D	
7	T7062	0	Project 7	5.1	18-Jul-17	18-Jul-17	29-Jul-17	Redesign		N=1
	T7062	1	Project 7	3	03-Aug-17	03-Aug-17	15-Aug-17	Approved	E	
8	T7066	0	Project 8	5.1	14-Jul-17	14-Jul-17	21-Jul-17	Approved		N=0
9	T7067	0	Project 9	5.1	24-Jul-17	24-Jul-17	13-Aug-17	Redesign		N=2
	T7067	1	Project 9	2	15-Aug-17	15-Aug-17	16-Aug-17	Redesign	B	
	T7067	2	Project 9	1	17-Aug-17	17-Aug-17	10-Oct-17	Approved	C	
10	T7068	0	Project 10	5.1	24-Jul-17	24-Jul-17	01-Aug-17	Redesign		
	T7068	1	Project 10	4	5-Aug-17	5-Aug-17	20-Mar-18	Approved	C	N=1
11	T7069	0	Project 11	5.1	28-Jul-17	28-Jul-17	13-Jul-17	Redesign		N=1
	T7069	1	Project 11	3	02-Aug-17	02-Aug-17	02-Aug-17	Approved	A	
12	T7074	0	Project 12	5.1	18-Aug-17	18-Aug-17	24-Aug-17	Redesign		
	T7074	1	Project 12	3	28-Aug-17	28-Aug-17	30-Aug-17	Approved	A	N=1
13	T7076	0	Project 13	5.1	21-Aug-17	21-Aug-17	14-Dec-17	Approved		N=0
14	T7096	0	Project 14	5.1	12-Oct-17	12-Oct-17	18-Oct-17	Redesign		N=0
	T7096	1	Project 14	2	20-Oct-17	20-Oct-17	20-Nov-17	Approved	D	
15	T7099	0	Project 15	5.1	30-Oct-17	30-Oct-17	03-Nov-17	Redesign		N=1
	T7099	1	Project 15	3	10-Nov-17	10-Nov-17	17-Nov-17	Approved	E	
16	T7100	0	Project 16	5.1	24-Oct-17	24-Oct-17	10-Nov-17	Approved		N=0
17	T7106	0	Project 17	3	14-Nov-17	14-Nov-17	21-Nov-17	Approved		N=0
18	T7115	0	Project 18	5.1	21-Dec-17	21-Dec-17	09-Jan-18	Redesign		N=1
	T7115	1	Project 18	1	9-Jan-18	9-Jan-18	19-Mar-18	Approved	A	
19	T8001	0	Project 19	5.1	24-Jan-18	24-Jan-18	30-Jan-18	Approved		N=0

20	T8003	0	Project 20	5.1	29-Jan-18	29-Jan-18	05-Feb-18	Approved		N=0
21	T8006	0	Project 21	5.1	26-Jan-18	26-Jan-18	29-Jan-18	Redesign		N=1
	T8006	1	Project 21	1	29-Jan-18	29-Jan-18	30-Jan-18	Approved	A	
22	T8012	0	Project 22	5.1	28-Feb-18	28-Feb-18	13-Mar-18	Redesign		N=1
	T8012	1	Project 22	3	16-Mar-18	16-Mar-18	10-Apr-18	Approved	B	
23	T8015	0	Project 23	5.1	20-Feb-18	20-Feb-18	15-Mar-18	Redesign		N=2
	T8015	1	Project 23	4	20-Mar-18	20-Mar-18	30-Mar-18	Redesign	B	
	T8015	2	Project 23	3	02-Apr-18	02-Apr-18	03-Apr-18	Approved	A	
24	T8027	0	Project 24	5.1	26-Mar-18	26-Mar-18	22-Apr-18	Approved		N=0
25	T8028	0	Project 25	5.1	03-Apr-18	03-Apr-18	07-Apr-18	Approved		N=0
26	T8029	0	Project 26	5.1	03-Apr-18	03-Apr-18	07-Apr-18	Approved		N=0
27	T8010	0	Project 27	5.1	08-Feb-18	08-Feb-18	12-Mar-18	Redesign		N=2
	T8010	1	Project 27	3	15-Mar-18	15-Mar-18	19-Mar-19	Redesign	D	
	T8010	2	Project 27	1	19-Mar-18	19-Mar-18	28-Mar-18	Redesign	A,B	
	T8010	3	Project 27	2	30-Mar-18	30-Mar-18	06-Apr-18	Approved	A	
28	T8016	0	Project 28	5.1	27-Feb-18	27-Feb-18	13-Mar-18	Redesign		N=2
	T8016	1	Project 28	2	15-Mar-18	15-Mar-18	26-Mar-18	Redesign	A	
	T8016	2	Project 28	3	29-Mar-18	29-Mar-18	02-Apr-18	Approved	B	
29	T8020	0	Project 29	5.1	06-Mar-18	06-Mar-18	20-Apr-18	Redesign		
	T8020	1	Project 29	4	24-Apr-18	24-Apr-18	28-Apr-18	Approved	B	N=1
30	T8023	0	Project 30	5.1	16-Mar-18	16-Mar-18	27-Mar-18	Redesign		
	T8023	1	Project 30	3	30-Mar-18	30-Mar-18	14-Apr-18	Approved	A	N=1

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4.6 Results

After implementation of the 30 pilot projects was completed, it was found that the number of redesigns (N) were reduced to achieve the company's KPI. The number of redesign of 30 projects pilot implementation is illustrated in **Figure 46.** However, the cause of over KPI for Project 6 and Project 27 were from the design change made by the main architect that is not accounted in the KPI.

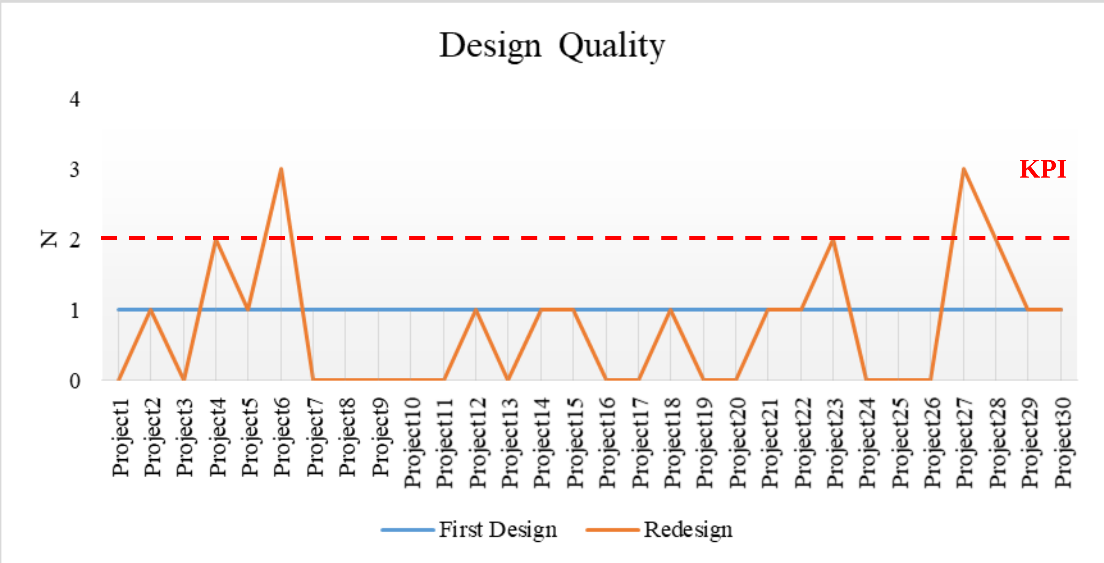
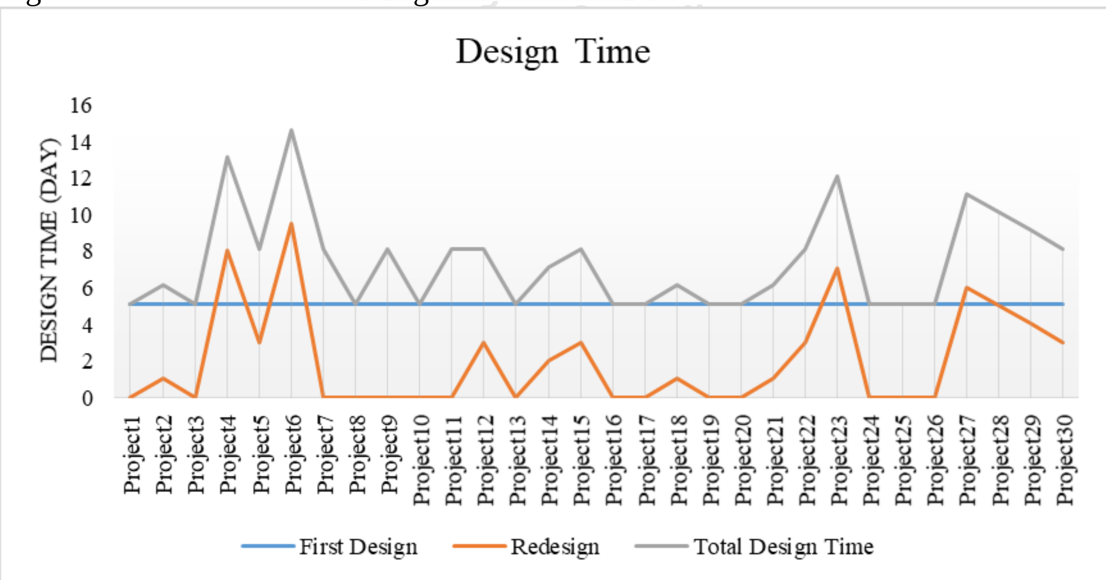


Figure 46. The number of redesign results



Remark: The design times are exclude waiting time, transition-duration and non-value adding activities.

Figure 47. The design time results

Figure 47 shows the design time results from the start to formulate design outputs in conceptual phase of 30 projects implementation. The comparison of redesign ratio per project of the pilot test with previous data from 2011 to 2016 is shown in **Figure 48**. The ratio of redesign per project was reduced from 3.5 (in 2016) to 0.8 (pilot test).

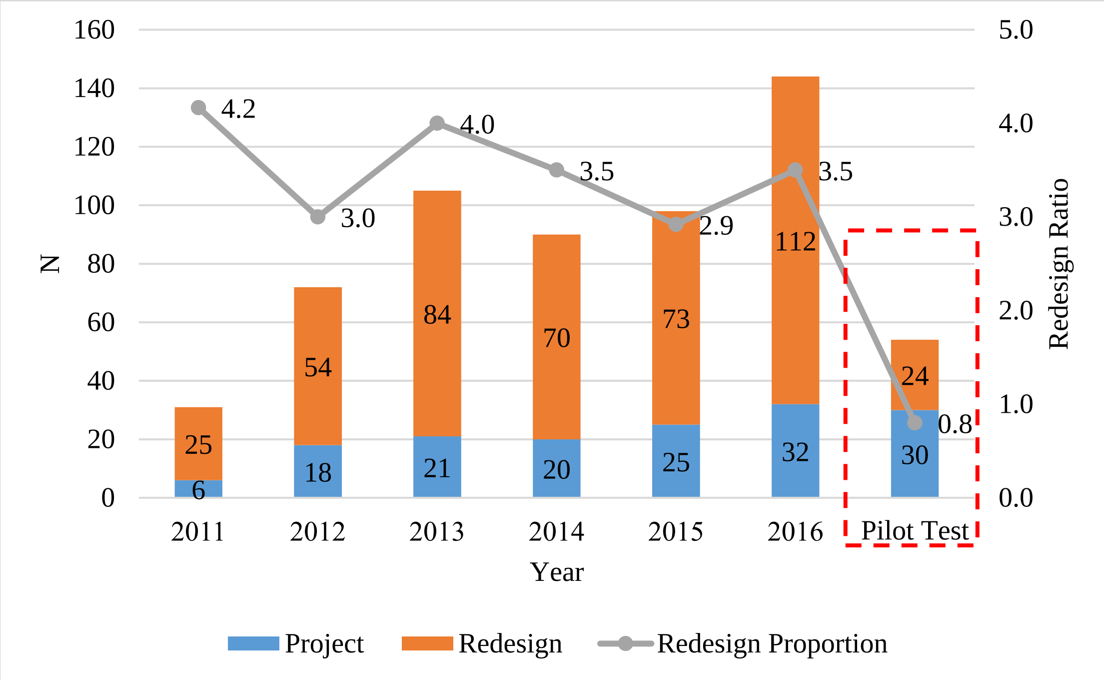


Figure 48. The redesign ratio results

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Table 30 summarizes the cost breakdown for pilot project implementation in one year. These were included implementing tools, process monitoring and controlling, training cost, traveling cost and software license. The total cost of proposed process improvement was THB 162,400. The process improvement cost was calculated according to the following equation:

$$\text{Process Improvement Cost} = \text{Fixed cost} + \text{Variable cost} \quad (1.2)$$

Table 30. Process improvement cost

Item	Fixed Cost
Software License	THB 18,000.00
Process Monitoring and Controlling	THB 43,200.00
Implementing tools and plans	THB 55,000.00
Design Training	THB 15,000.00
Item	Variable Cost
Traveling Cost	THB 31,200.00
Total improvement cost	**THB 162,400.00**

In the end, the project baseline was used to measure how the proposed improvement impacts to the project performance. 30 pilot projects implementation of project size M were used to compare the project performance in respect of quality, time and cost of design**.** Referring to **Table 31**, it can be seen that the total number of redesign was reduced from 102 to 24. Furthermore, the total cost of redesign was decreased from THB 1,326,000 to THB 31,200. In addition, the total design time from the start to finish the specification output was reduced from 327 days to 212 days.

Table 31. Comparison of Project Baseline and Pilot Implementation

Item	Project baseline	Pilot Implementation
Total Number of project	30	30
Total Number of redesign (N)	102	24
Redesign ratio/project	3.45	0.8
Total redesign cost (THB)	1,326,000	31,200
Total design time (Day)	327	212

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Chapter 5. Discussion

After the CDMS was implemented in the company case study projects, it was shown that effective conceptual design project management could reduce the number of redesigns and reworks during the early design stage. Discussions of the implementation included the findings and improvement, implementing problems challenges, sustainability improvement, and the critical analysis.

5.1 Discussion of Findings and Improvement

The general findings and discussion after pilot project implementation can be considered in 4 main aspects including project manager, project plans, processes and tools & techniques.

5.1.1 Drainage Project Manager

People in the design project for the company serving as the case study comprise the design team, sales team and leadership. The drainage project manager plays an important role in terms of managing the processes within the organisation. According to the literature review in Chapter 2 and the method approach in Chapter 3, this paper identified various management knowledge areas for the Project Manager of storm drainage design. In addition, the characteristics of project management and individual project leaders for a design supplier firm should also cover specific skills and competencies, as shown in **Table 32**.

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Table 32. Skills and competencies necessary for drainage project management

Knowledge Areas	Skills and Competencies
Understanding client objectives	• Understanding client needs and requirements for system design in terms of cost, safety and value of total building
Design knowledge	• Understanding the company's products and services • Thorough understanding of design and calculation for drainage systems

	• Ability to provide technical knowledge and solutions for the design of roof drainage systems to the project team
Human resources management	• Clarify team roles and responsibilities • Develop the project group • Manage and supervise the project team to achieve the project goals, including planning and team development • Monitor and control work progression
Stakeholder management	• Management of project stakeholders • Understanding the influence and impact of each party in the project
Scope management	• Managing the scope of the design within project stakeholders including the primary designer, consultancy, owner or owner's representative • Monitoring the scope of the design as created within the budget and parameter requirements
Requirement management	• Refine needs and client requirements, including design parameters and pipe specifications
Communication management	• Management of in-house communication; team meeting, status updating, reporting • Maintain harmony among project team members
Risk management	• Early risk identification • Managing and controlling the risks

5.1.2 Project Initiation Plans

An appropriate project Initiation plan documents were introduced in the process improvement, which defined how the design process were planned, monitored, updated and controlled. This documents can be used to dealing with the complexity in conceptual design to make the decision in design for achieving the client requirements.

5.1.3 Concurrent Design Process

Since a large number of people tend to be included in the decision-making for design outputs, the new conceptual design process aids the designer to fulfil the information and design requirements. By accomplishing the client requirements, the author used a design brief to identify the client needs at the beginning of the design process rather than during early work in CAD design and detail specifications, which uses a large amount of effort and time. To have design team involvement at this stage, a rewarding system for the design team was considered by the director to achieve the winning of the contract from the client. Moreover, the control activities such feedback reports, brief reports, updating and confirmation throughout the process enhanced communication between the suppliers and clients. This can be accredited to the integration of project management, comprising project plans, which resulted in improvement of the operation design process. Further, the number of redesigns was reduced, which increased satisfaction on the part of the customer. Therefore, the success of a project in the conceptual design phase may depend significantly on the decisions made at the beginning of the process (Abdul-Kadir et al., 1995).

5.1.4 Design Tools & Techniques

Conceptual design tools & techniques are the major elements in the conceptual design process. Since each stage in the conceptual phase requires different objectives and outputs, it is important to have the appropriate tools and techniques to support the work process as well as assist the project team. This research addressed how such tools could be applied for every design project of the same building type. The proposed tools were quickly able to help the customer define the needs and requirements. However, the appropriate tools and techniques depend on the characteristics of the products and services as well as the capability of the people in the organisation that use the tools. Therefore, the findings confirm that the selection of tools and techniques tend to be based on product characteristics and the skills of the people using them.

In summary, it's vital to consider how the different elements of the people-process-tools & techniques are linked and managed from a service design supplier perspective. When delivering design services in the conceptual phase, the project team follows a specific work process and uses tools to achieve the desired design criteria as well as any client requirements. The processes themselves are supported by the tools and techniques used by the people. Such conceptual design tools should be constructed to support the design processes and align with the organisation's services. Further, they should be easy to use, easy to share between project team members, help the design engineers to refine the design concept to meet the client requirements, and be portable for client meetings or project sites. The essential linkages between these 4 elements can be summarized in **Figure 49**.

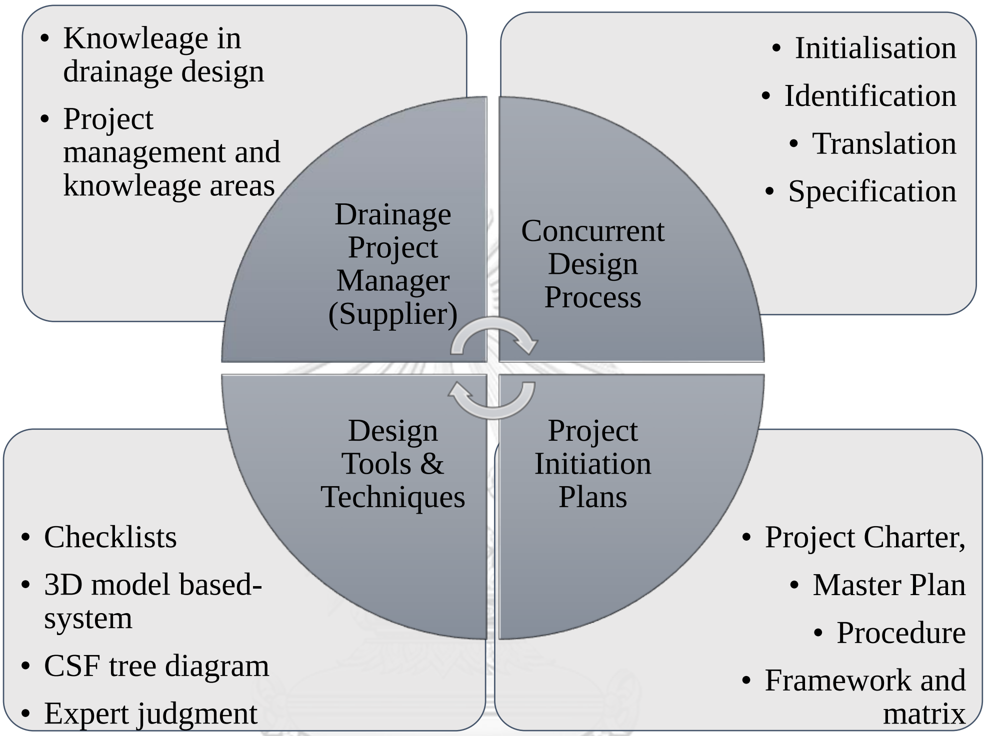

Figure 49. Elements of Conceptual Design Project Management of Drainage Design

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5.2 Process improvement related with project stakeholders

Project stakeholders (Clients) in this paper are the main designer, consultancy and project owner or owner's representative. The listed below summarizes how the effective process improvement systems worked for complexity in conceptual design phase regarding the relations with project stakeholders.

(1) ***Improved understanding of project stakeholders:*** The collaborative design brief and communication plan were enhanced the understanding of project stakeholders in design concepts, and the elements in piping design process to achieve the target project requirements.

(2) ***Improved relationship with project stakeholders:*** A better relationship with project stakeholders can be improved thought the effective design process

planning and communication and management which can bring the potential benefits. Such as , rather than pushing high effort on looking for a new project themselves, the company can gains more project inputs by using a strong relationship with project stakeholders, better information responding and easier for design approval.

(3) ***Influenced the commitment and success of winning project:*** According to the clarify project stakeholder's objective though CSF Tree Diagram and controlling with project charter, theses influenced the commitment and success of winning project to suppliers.

(4) ***Improved service and customer satisfaction:*** Managing the process to overcome such incorrect, missing and mistake in design was enabled to improve the service and customer satisfaction.

5.3 Problems, constraints and challenges of the company

The problems, constraints and challenges of implementation is normally happened in every organization. The topics related to the company's pilot implementation is shown in **Table 33**.

Table 33. Problems, constraints and challenges of implementation

<table>
<tr><th>Problems</th><th>Constraints</th><th>Challenges</th></tr>
<tr><td>• Resistance to change from the sales team
• People did not know how to use tools and techniques
• More responsibilities of design team in new process</td><td>• High number of redesigns (reworks)
• Long lead-time for approval due to the need to redesign caused from poor project management
• Customer dissatisfaction due to the design not meeting certain needs and requirements, which impacts the need to redesign</td><td>• Proposed the improvement plan to the director for approval
• Training people in how to use the tools
• Maintain harmony in the project team under complex situations
• Monitoring and control of the process
• Achieving the company's target KPI</td></tr>
<tr><th colspan="3">Action plan and solutions</th></tr>
<tr><td colspan="3">• Work instruction
• Training
• Approval for process improvement from the director
• Approval of rewarding system for design team</td></tr>
</table>

5.4 Sustainability and Continuous Improvement

Sustainability and continuous improvement of this research comes with project management which can be outlined into 3 main parts.

(1) ***Build understanding of design in a context*****:** a context of understanding in design can be defined as the requirements that were agreed or required from the project stakeholders as well as the influencing factors for approval. In the past, this were transferred with little amount of contexts and not in a proper format. The design engineer wanted to understand what customer needs. The proposed plans and tools of this research could be a continuous improvement to sustain the understanding of design for the company.

(2) ***Build operational knowledge management system of drainage design*****:** the operational knowledge management system in the area of conceptual design process for drainage system in this research has carried out in the systematic processes to develop the sustainability of improvement at early design phase where the project performance can be improved. In addition, the company could save more operating cost, time, with quality output as a result of operational knowledge management.

(3) ***Build process integration with a concurrent engineering****:* The traditional design process was required a lot of effort in redesign to meeting the client's demands as design team and clients did not confer with each other. The research proposed a concurrent briefing program which enable to reduce the impact from redesign and enable sustainability and continuous improvement of early design process.

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5.5 Critical Analysis

The implemented solutions not only reduced the number of redesigns and reworks within the supplier firms, but also enabled to reduce the complex relation with the project stakeholders. Heightened party involvement in the design concept and requirements from the beginning of the project enhanced communication, which was reflected by more effective design outputs that meet the client objectives and requirements.

The implementation of tools and techniques may take more time in the beginning, but can be applied to other new design projects. More importantly, applying tools and techniques has the ability help the designer engineer and project team to make better decisions while improving design rationale. The development of project management plans also shifted the resource capability to improve design organisation and management. Finally, the new conceptual design process employs more steps in the design operation, but the implemented results have shown that the work can be done with the design time reduction, reduced redesign cost and the better design outputs based on client's requirements which can be improved project performance ay conceptual design phase.

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Chapter 6. Conclusion

6.1 General Conclusion

This research project is about the conceptual design process improvement of drainage system attention to the siphonic roof drainage that provide by the design service company who is the design supplier for commercial storm drainage solution. The case study company had poor project management problems. The summary of the main causes of redesigns associated with **poor project management** that is covered:

(1) Poor briefings
(2) Poor project planning and control
(3) Lack of tools and techniques to define client requirements

The objective of this research is *"To reduce the number of redesign though conceptual design process improvement for storm drainage design projects by using project management"* The proposed process improvement program of this research called conceptual design process management (CDPM) program which was introduced in 4 stages-Initialization, Identification, Translation, and Specification. The element of process improvement included (1) applying a tool and technique to improve the design project performance for better identifying the client requirements for drainage system, (2) re-designing the conceptual design process for better alignment with the clients; designer, owner and consultancy and (3) developing the project plans for solving the management problems of the case study company. The detailed of CDMS program are covered:

(1) Design tool and technique
   a. Checklists
   b. 3D Based-System
   c. CSFs Tree Diagram
   d. Expert judgment
(2) Concurrent conceptual design process
   a. Initialization stage: data collection, create a project team

b. Identification stage: study the drawing, collaborative design brief
c. Translation stage: translate the client requirement
d. Specification stage: issue design drawings, material estimation and quotation for submission

(3) Project Initiation Plans

a. Team roles and responsibilities matrix
b. Project stakeholders analysis matrix
c. Project team development framework
d. Briefing procedure
e. Communication plan
f. Master plan
g. Project charter

The new tools and techniques that have been applied is better support the sales team and design team, as it is more accurate and easy to use to identify the design scope and client requirements. In addition, the new conceptual design process have improve the operational design management systems to be more effective. Moreover, the development of project plans were shifted the managerial capabilities of project manager for better manage the design thought out the conceptual design phase.

In conclusion, after the CDMS program has been implemented in the company the project performance was improve by the total number of redesigns in the conceptual phase was reduced from 102 to 24 revisions. Moreover, the total redesign cost was minimized from THB 1,326,000 to THB 31,200. Finally, the total design time was reduced from 327 days to 212 days.

6.2 Research Contribution

The contribution of this research can be described into both practical and theoretical contribution as follows:

6.2.1 Practical Contribution

The practical contribution to its construction design supplier businesses can be divided into 3 main levels:

(1) *Short-Term Level:* Allow a better understanding between suppliers and main project stakeholders (owner, consultant, designer or design and built contractor) in order to create the design specification.

(2) *Medium-Term Level:* The collected data from client can be a source of knowledge and database for the supplier firm in design development for other commercial building projects.

(3) *Long-Term Level:* The resulted data can be a source of database for the supplier firm in new product or service development for more closely meet the client requirements.

6.2.2 Theoretical Contribution

Theoretical contribution that is the basis of this research is a new conceptual design process and project management plan along with the application of tools and techniques for the redesign reduction of the siphonic roof drainage system on behalf of the drainage system design supplier Company. A set of methods adapted in this research could be a useful project management tool for other design supplier companies in the construction industry that are facing similar problems. However, with that tools and techniques used in this research may not be fully effective for every design services organization, but it could be a concept solution that can be applied in other customized design services. Finally, this research has adapted the project management view as being an essential project integration of the supplier business in the construction project.

6.3 Limitation

The limitations of the research are summarized as follows.

(1) The process improvements are designed based on the company's records which were reported by the Sales Team from January 2014 to December 2016. If any information was changed or excluded by the Sales Team, the proposed solutions may not work in an effective way.

(2) The type of building for improvement and implementation in this paper is related to the industrial building project particular in factories and warehouses. Therefore, the feature of improvements were limited to only factory and warehouse buildings. However, this building type is sufficient to be used as the ideal solution for other commercial buildings. And it has improved the overall conceptual design process since they are the main market group of the case study company.

6.4 Future Work

The further studies from this research can be outlined as follows.

(1) *Developing the project communication platform*: The proposed solution still uses the basis design brief via face to face meetings. The future research would consider developing the design brief communication platform which will change the way construction design creates and to shorten the process time.

(2) *Extension the scope of study by covering the contract design process*: This work finished with the proposed process improvement and pilot implementation of the conceptual design process, to make the process more effective. The contract design process should be considered to complete the construction design project life cycle.

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(3) *Measuring other dimensions in design process improvement:* The measurement in this research was only focusing on redesign data. Other measurements such as success rate of project, work utilization and customer satisfaction surveys should be considered.

(4) *Alternative method for improvement:* The proposed improvement used the project management method, the future study should consider using alternative methods for comparison and selection.

(5) *Modifying tools and techniques:* In the future the proposed design tools and techniques in this research might be modified. This is in order to respond to the architects and engineering communication trends including other design services.

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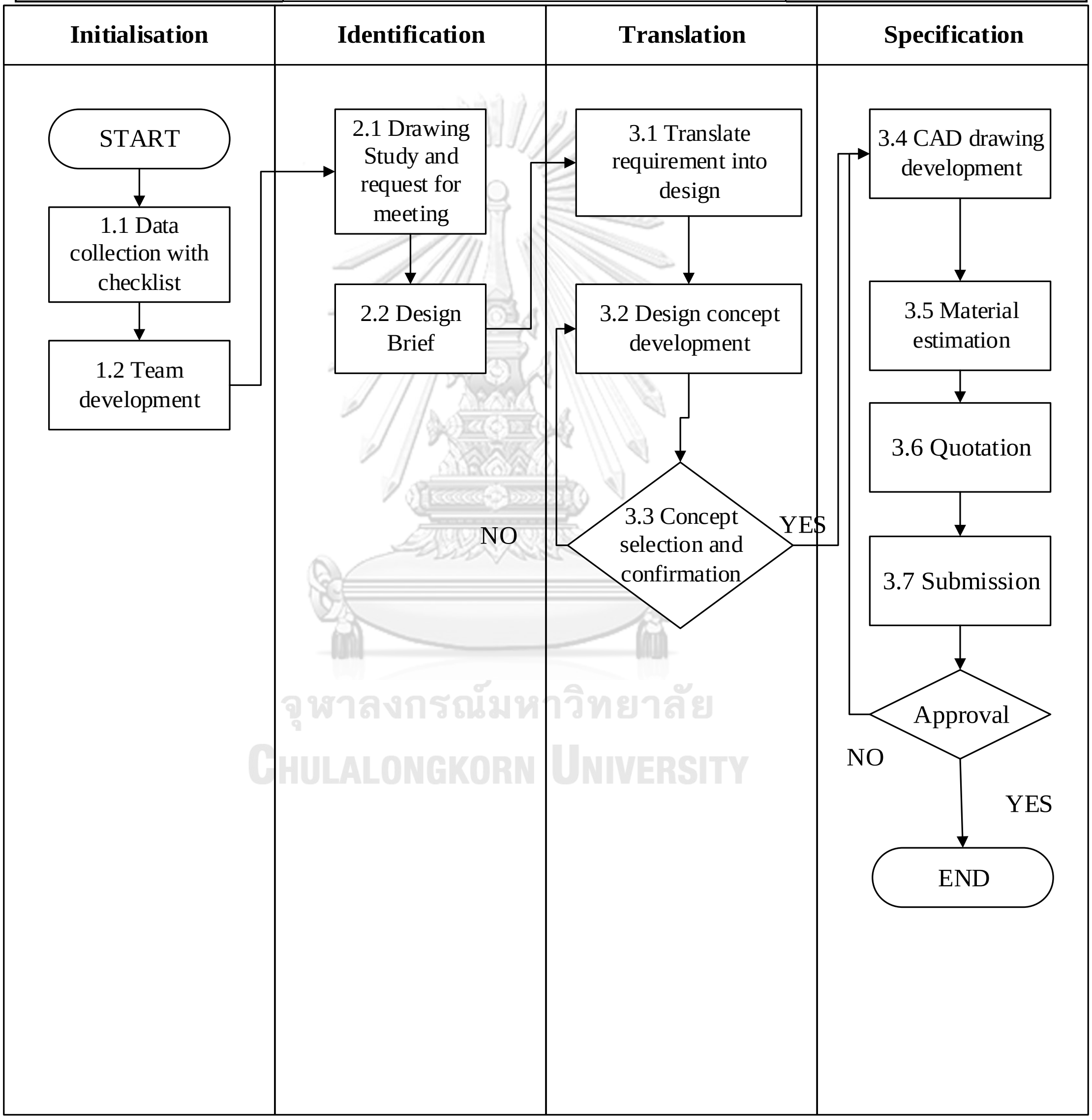
Appendices

Appendix A: Work Instruction

DIAMOND FLOWS	Conceptual Design Process	Page 1 of 2
Eff. Date : 1-Apr-17	**Document Number : WI-JAS-T-001**	**Rev. No. : 00**



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1	1-Apr-17	Adding Document			

No.	Change Date	Change Description			

Detailed description

Detailed Steps R - Responsible , A - Accountable, S - Support, C - Consulted, I - Informed	Project Manager	Design Manager	Sale Manager	Design engineer	Sale Engineer	Draftsmen	Client	Document
Stage 1: Initialisation								
1.1 Data collection and complete the checklist			A	C	R/I		I	Checklist
1.2 Create a project team	R/A/I	C						Team development framework
1.2.1 Stakeholder analysis	R/A	C	C		I			Stakeholder analysis matrix
Stage 2: Identification								
2.1 Drawing study	C	A		R	I	S		Drawings
2.1.1 Request for a meeting		A		C	R/I			
2.2 Design brief	A	C		R	I		I	Brief procedure
2.2.1Report				R	I			Brief report
Stage 3: Translation								
3.1 Translation requirements into the design				R				
3.2 Design concept development				R				
3.3 Concept selection and confirmation		C		A	I		R	Email or phone call
Stage 4: Specification								
4.1 Issue the design specification and mate	C	A	C	R	I	S		Designed Drawings
4.2 Issues material estimation		A		R				BoM
4.3 Issue the quotation	R/A	C	C	I	I			quotation
4.3.1 Issue the project charter	R/A	C	C	I	I			Project charter
4.4 Document submission for approval	A	C	C		R/I			Design specification and quotation
4.4.1 Status updating	A	C	C	I	R/I			Master plan updated
4.4.2 Approval	A	C	C	I	I		R	Master plan updated

Figure 50. Work Instruction

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REFERENCES

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

APPENDIX

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VITA

Wantanee Kongpanya was born on January 29th, 1884 in Bangkok, Thailand. She completed a Bachelor's Degree in Sustainable Development Technology, Thammasat University. After graduating, she worked for 4 years as a Sales Excusive at Tokai Rika Asia, 1st tier supplier of Toyota Motor Company. After that, she completed a Diploma of Business at Ozford Institute of Higher Education, Melbourne, Australia. And later, worked for TAC-M Group as a Project Manager, specializing in Siphonic Roof Drainage System. During that time, she decided to study a dual degree program to pursue for a Master of Science in Engineering Business Management from Warwick Manufacturing Group, the University of Warwick and a Master of Engineering in Engineering Management from Faculty of Engineering, Chulalongkorn University.

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