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Requirement Engineering Impact on Value Engineering Implementation

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Summary

Value engineering is a demanding part of project design engineering in traditional core engineering fields. Requirement engineering significantly impacts the engineering process; it is a systematic process of defining, documenting, maintaining, and managing requirements. (Pohl &Rupp,2016)

The thesis is performed as part of my master's studies and for Citec Oy Ab, a global engineering company headquartered in Vaasa. When working on projects, the engineering process is often not up to the mark, majorly due to improper communication, unknown and hidden requirements. The responsible project engineers and leaders must clearly understand the challenges that can happen to the project so that they can do early enough preventive actions to improve the success rate. The thesis's primary purpose is to research existing techniques and methodologies used in requirement engineering and design process. Based on the theoretical findings, analysis of the company's existing requirement gathering, and engineering design process methods, the first version of the report will be written for value improvements.

Language: English
Key Words: Requirement engineering, Value engineering, Engineering design process

ACKNOWLEDGEMENTS

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This thesis confirms my past experiences in project management, requirement engineering, and personnel management. During writing the master thesis, I've also learned new approaches and techniques, which I have already implemented into my official work.

Thanks to Kaj Björkqvist, Senior Director at Citec Oy Ab and Mikko Hakkola, Director at Citec Oy Ab. Kaj, who guided me in choosing the topic and other valuable tips, and Mikko helped me to take time off from work to allocate some time for writing this thesis. Also, all my teammates, including externals who support me with answering many questions, are warmly acknowledged.

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I want to acknowledge my wife Annu's efforts, who has been very understanding and supportive during the thesis project. Finally, I hope it will also encourage my daughter Eeva and son Aaden to study hard.

11.06.2022
Eldho Kunnath Onachan

List of abbreviations

RE Requirement Engineering

RM Requirement Management

VE Value Engineering

WoW Way of working

WBS Work Breakdown Structure

ROI Return On Investment

CDE Chief Design Engineer

AI Artificial Intelligence

CI Continuous Improvement

EPC Engineering Procurement and Construction

KRP Knowledge Responsible Person

FAST Functional Analysis System Technique

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1 INTRODUCTION

This thesis aims to research the different requirement engineering principles and concepts, which can apply to improve the design requirement gathering and its implementation for the better life cycle of an Electrical engineering project hence achieving value engineering improvements.

Electrical engineering is one of the core engineering disciplines(chapter 1.1) in a construction project in which it deals with modification, expansion, renovation, or new construction that requires multiple aspects of electrical equipment's instruments that use Electricity(Kirby, Withington, Darling &Kilgour 1990 P.331)

With the pandemic due to coronavirus, the construction industry is facing more challenges than ever in the form of material availability/delays and cost increases in materials, thus impacting the project outcome and commitments. In this phase of challenges, Requirement engineering has a significant role in value creation.

The birth of value engineering is during the crisis of the second world war, so it is very relevant to think of this topic when the world is going under similar but different challenges.

For this thesis, The requirement engineering documents and processes currently followed in the Electrical engineering discipline will be researched, compared to Citec's general project management process guidelines. As requirements engineering is the key focus of this thesis, the evaluation is limited to where it is heavily impacted on a construction project, as explained in (chapter 1.4)

1.1 Background

Engineering construction projects are done based on the requirements of various stakeholders. An individual, group, or organization that may affect, be affected by, or perceive itself to be affected by a project's decision, activity, or outcome is defined as stakeholders (PMI,1996). the needs of owners, owners engineers, international or country-specific /local standards, environmental concerns, etc.:-, Tender documents or other technical documentation must have made based on these.

Typically, engineering construction projects for the energy industry are multi-discipline projects. Core engineering disciplines in the construction industry company work for the energy sector are Process, Mechanical, Civil, Electrical, Automation, and Control engineering. Electrical design engineering areas in the company are mainly focused on the second purpose of the thesis.

1.2 Problem Area

Generally, requirement gathering specific steps are available at a general level, But how it applies varies among engineers. In the Electrical discipline, how to collect them for engineering packages is based on their experience and understanding. There is no standard way of informing the requirements at a details level for the engineers who execute the work in the same or other engineering disciplines.

Also, a lack of cost awareness impacts engineering solutions, leading to costlier outcomes. No common way of reaching sub-consultants requirements for engineering support. Creating a uniform Way of working (WoW)among the engineers on requirement gathering is vital to achieving customer trust.

Approach towards different nature of the project in the sense of urgency in execution must have to be different. Fast and ultra-fast track design projects have diverse requirements gathering and execution concepts. Project management guidelines also need to be formulated for the whole CDE group in electrical, so the approach is the same for the entire group. Offer preparations and the estimations for the work to be done are other areas where needed an improved requirement engineering to improve the value from the beginning or sales stage of a project.

The engineering design process varies within the electrical discipline; flexibility in resourcing, lack of an efficient WoW, and willingness to improve are common challenges among engineers.

1.3 Purpose

The first purpose of this thesis is to clarify the different requirements, engineering concepts, and factors that lead to success and improve the value of a project.

My secondary purpose is to make a requirements engineering report for Electrical. The report document will show all the analysis processes of the existing requirement engineering ways in plant engineering. It also reflects the outcomes from interviews; the report will conclude with suggestions for improvements for requirement engineering for all the areas that have undergone the evaluation.

The benefit of this thesis is that it will create a common awareness of requirement engineering among the CDE:s to improve the project's value and help make a uniform WoW on projects. It also identifies each engineering task's coexistence to find the low-hanging fruits.

Identifying Problems and critical factors affecting the Engineering process will improve the efficiency and effectiveness of project engineering work. Identifying the non-value-added tools and removing unwanted processes will increase the value of projects.

1.4 Delimitations

The master thesis will look at technical, tools & people aspects of requirements engineering from a construction project in the energy sector from its design point of view. Engineering procurement construction(EPC)projects life cycle is in many phases. Sales, basic engineering, detailed engineering, procurement, transportation, construction, commissioning, operation, and maintenance; this thesis only focuses on the first three phases, Sales, Basic & Detail engineering.

Requirements engineering must be clarified at the beginning of a project, in the planning and design stage, to achieve a better value on the outcome; hence the focus is mainly given

to the first three phases. Plant engineering recognizes these three are of more interest for the second purpose of this thesis. The report developed for my secondary purpose will be limited to the tools, seven different technical engineering areas on electrical engineering, and its CDEs on electrical in the Citec group.

1.5 Disposition

Theoretical framework Chapter 2 started with an explanation of how to conclude which theories, methodologies, and frameworks are relevant for the thesis.

Chapter 3 explains the different research methods I have used; it was a qualitative study.

Results chapter 4 highlights the results of the interviews and results in general about the FAST and GAP Analysis, questions formulated to confirm the concerns raised in the problem area in chapter 1.2, and the findings will be evaluated based on the theory researched and incorporated in the report which is part of the secondary purpose.

Chapter 5 is an evaluation of the thesis work done by me to check did I reach my purpose, if the theoretical framework is relevant, and if the results are reliable to make the report which will impact the engineer's WoW on the design process and requirement engineering. It also shows my recommendation for future research.

Chapter 6 is my conclusion of the thesis work, showing what I was supposed to do and how I did it; it also describes my limitations and results; finally, it ends with a recommendation.

2 THEORETICAL FRAMEWORK

To understand the topic for the thesis, the literature review on Value engineering, Requirement engineering, and the Engineering design process is what I will do first. After that, I will conduct interviews to collect different views on the existing requirement-gathering process in projects by the CDEs and Key persons. The understanding of requirements must come from the designer to the project management level. Also will be reviewing existing engineering design practices to evaluate them based on the best possible theoretical and practical framework. I will also review other literature, articles, and thesis on this topic to build up the best possible results.

2.1 Value Engineering

Value engineering(VE) is a systematic approach for providing needed functions without compromising quality; thus, the ultimate aim is to reduce costs. In general, Value=Function/Cost, So there are the following ways to increase the value. (Omar,2016, September 19).

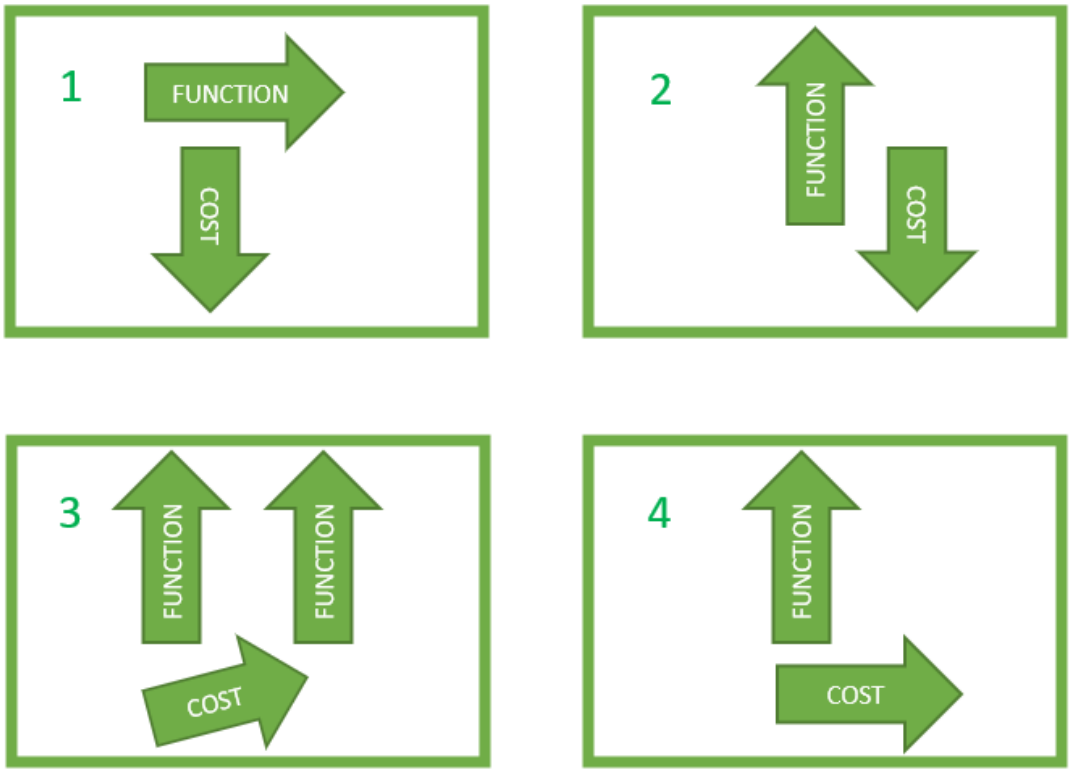

Figure 1 Value improvement in different ways. (Omar,2016)

The above diagram explains the different ways of value addition, it is described below. (Dhounchak & Biban 2017)

- Cost reduction but keep the function as required.
- Cost reduction but keep the improve the function.
- Slight increase in cost but double the function.
- Keep the cost the same but improve the function.

General Electric supplied the United States military with executives and equipment manufacturing during World War II. during the 1940s, there was a severe shortage of skilled labor, Shortage of raw materials and parts; hence it was necessary to find alternate solutions for raw materials and components to ensure the production continued and met the needs. (Value Engineering, 2007)

Therefore GE Engineers looked around for alternate solutions which would reduce the cost without compromising the quality and functionality. Lawrence Miles and Harry Erlicher are engineers responsible for purchasing. They found some cost-effective alternatives and better for the function intended to do. The systematic approach and concept were born, then called value analysis. The Bureau of Ships of the US Navy then established a formal program of value engineering, overseen by Miles and Raymond Fountain, also from G.E.In the 1980s, the value engineering process gained a worldwide acceptance which led to the creation of SAVE international. It formed to practice and the certification of competent practitioners to value engineers; hence, it saved billions in costs. (Value Standard and body of knowledge,2007)

In my opinion, value engineering is a mentality that has succeeded due to the persons involved in it and having eagerness or necessity to achieve the value addition caused due to different challenges. As this thesis intends to contribute toward value improvements, it is essential to understand this systematic approach clearly. after the literature review for value engineering, it gives a clear idea for me to proceed to the requirement engineering as requirements are the foundation of any projects." A good beginning makes a good ending (Louis L'Amour)."

2.2 Requirement engineering

Before going to requirement engineering, it is relevant to look at the requirements; a requirement is a condition or capability to solve a problem or achieve an objective. Also, a state or ability must be met by a system or system component to satisfy a contract, a tender, a standard, specification, or other formally available documents (IEEE 610.12-1990)

Requirement Engineering(RE) is a systematic process of defining, documenting, maintaining, and managing requirements. (Pohl &Rupp,2016). Knowing the requirements for the particular project means achieving acceptance among the stakeholders and understanding the relevant standards applicable to this specific project by knowing the final goal and documenting them according to given standards in understandable formats.

2.2.1 The core four steps

Elicitation: During this Process, use different approaches or techniques for collecting all the relevant requirements for all stakeholders, which can impact the project goals (Value standard and body of knowledge,2007)

Commonly used techniques in project design requirements in construction projects are requirements workshops or meetings and requirement document reviews. Requirement collection process models for software development or such projects are as mentioned in section 2.2.2

Documentation: The collected requirements are described adequately during the documentation stage. Different techniques are used to document the conditions, written in natural languages or made via a conceptual model in a project environment. Requirement specifications are a common way in engineering projects. Requirements specifications are usually noted from a tender or project-specific other documents. First, they will be made at a standard level to gather all relevant inputs for the project. Subdiscipline requirements are then captured separately and different for different designs. (Tenstep 2015)

Validation and negotiation: The documented requirements must be verified, discussed, and negotiated with stakeholders and decision-makers to achieve the best value for the project functions without compromising quality.

Management: After collecting and documenting requirements with all deviations, requirements management is the next step in the project execution. First, it structures the requirement to the needed way in the project and prepares them to be used by different engineers who can handle them to convert to individual engineering outputs. Also, it is essential to maintain them so that the exact requirements must keep during the project lifecycle. Also, the project management ensures the implementation of requirements in the project lifecycle. (Tenstep 2015)

Unlike software development projects, the construction engineering project's requirements won't vary so much during the project execution. However, the situation impacts, such as material availability and cost or transportation challenges, seismic challenges, etc:-could impact the outcome, then they must be recorded as changes and handled in change management.

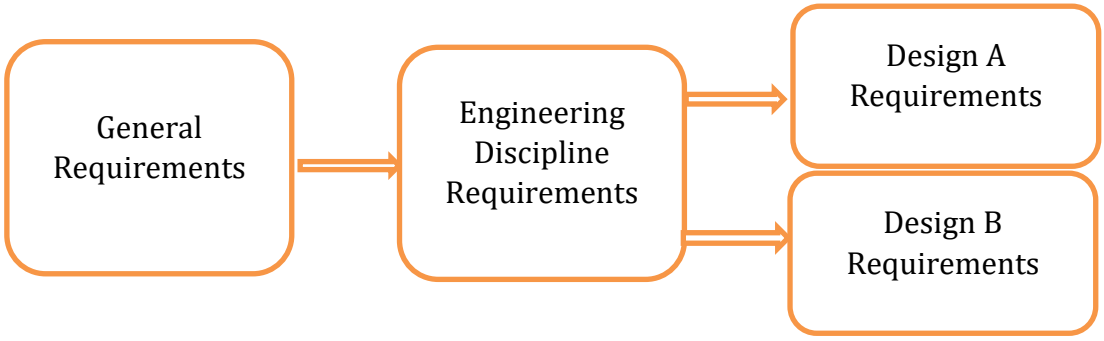

Figure 2 Steps in information gathering

RE for a new build construction engineering projects in the energy industry, the first step is auditing the existing energy source's capability to meet the future demands and make a roadmap for the new builds. As the first step is completed, engineers are usually put on to make requirements based on stakeholders' wishes on the road map by asking where, when, and what is required; these converted documents approved by stakeholders piled up as official tender documents for companies proving solutions.

Companies then involved in the new built is processing with the engineering part based on the received requirements and collect if there are any changes in requirements during early

stages as mentioned in (chaptor 2.2.1); The customer process these requirements into output by following different engineering process models.

2.2.2 Embedding Requirements Engineering into Process Models

In process model, the process is detailed in one way or another. Most often process model states how things must/should/could/be done. Existing process models are classified as below (Dowson 1988)

Activity-oriented models: These models aim for problem-solving by finding a sequential plan. The first widely used process model, the Waterfall model (Royce 1970), is of this category of activity-oriented model. The waterfall is a classic model where every step is defined and must complete previous actions until it jumps to the next step. This process model requires freezing requirements in the desired phase, and there is no turnback.

The spiral model is essential in the software development models (Boehm 1988). In this process model, the activities are divided into four phases, and the process repeatedly goes through them; hence it will look like a spiral. How many spirals a project depends on the desired outcome.

The fountain model (Henderson-Sellers 1990) is an improved version of the Waterfall model in which the process looks like a water fountain. They can have different steps to the final solution, but it can fall to the lower stage for re-evaluation at any stage. This model is more suitable for developing object-oriented projects.

Product-oriented models: In this model, the development processes are centered around the development activities to their output as the products. The ViewPoints model belongs to this category as well. A ViewPoint is a loosely coupled, locally managed object that encapsulates partial knowledge about the application domain, specified in a particular, suitable formal representation, and partial knowledge of the software development process.(Finkelstein, Anthony & Kramer, Jeff & Goedicke, Michael.1991)

The development process model proposed in the European Software Factory project also falls into the product-oriented process models.

Decision-oriented models: All successive transformations or steps will be taken as a consequence of a decision. This model explains how the process proceeds and why these transformations happen

Requirement engineering is integrated into all phases of a project or system development (Richard & Edward,2004).

The waterfall model and its possibilities are further researched (Chapter 2.2.3) to find out the best possible ways which can be adapted to the various designs process for the company part of the thesis.

The waterfall process is the most favorable model in the construction industry, even though the new agile models are in the test phase for new technology projects; hence it is essential to continue reviewing the possibilities of these two models to find out which is the new area or solution the construction industry.

2.2.3 Traditional Models vs. Agile process models

During the company part of the thesis evaluation, it is noted that various design areas and engineering teams follow different approaches. Some follow the traditional models, and some have agile methods without knowing the details of this methodology; hence, it is essential to review their differences to verify which path best fits the purpose. (Danijela et al.,2019).

Table 1 Difference between the traditional and agile approaches

As explained in the video (12. Scrum vs. Traditional Project Management 2013) and also (Špundak 2012) is stated as follows,

Categories	Traditional Approach	Agile Approach
Developments	Process-oriented	People-oriented
Process style	Linear	Iterative
Project management style	Command and control	Leadership and collaboration
Team role assignment	Based on the skill level of individuals	Self-organizing teams
Upfront Planning	High	Low
Requirement prioritization	Fixed in the project plan	Regularly updated
Change management	Formal change management system	More flexible
Return on investment	End of project life	Early throughout the project
Stakeholder involvement	It varies depending on the project	High throughout the project

The main takeaway from this comparison is that software engineering and construction engineering have their own identified challenges in applying these approaches. Hence it has to be carefully chosen which method to utilize in a particular case.

Traditional project management models

As a scientific discipline, project management has been developed since the 1960s (Kerzner, 1987). During these periods, projects were majorly independent and took months and years, and project complexity was relatively high and usually went over budget. Hence it was required to plan the tasks and then control their implementations; the waterfall method was used widely then after, and this method is known as a common traditional process model. (Royce 1970)

The waterfall method is traditionally used in construction and manufacturing firms; from the 70s till modern methods came into use for software development projects, the waterfall method was a common way to build the projects.

As to its name, the process is like a waterfall, and it only flows in one direction and phase by phase; it never allows to go back to a previous phase in such cases; the only way is to start from the first phase. A construction project can be divided into many steps depending on their complexity, and they are focused on Work breakdown structures (WBS) (Jing-jing, Guo-qing, & Wei, 2013)

Work breakdown structure is an essential part of project planning in a waterfall way. It needs to involve the stakeholder's wishes on completion of the project, and then based on that; a detailed work breakdown plan will be made to check all concerns which can cause delays in the projects well in advance and to get rid of those critical factors to achieve the targets.

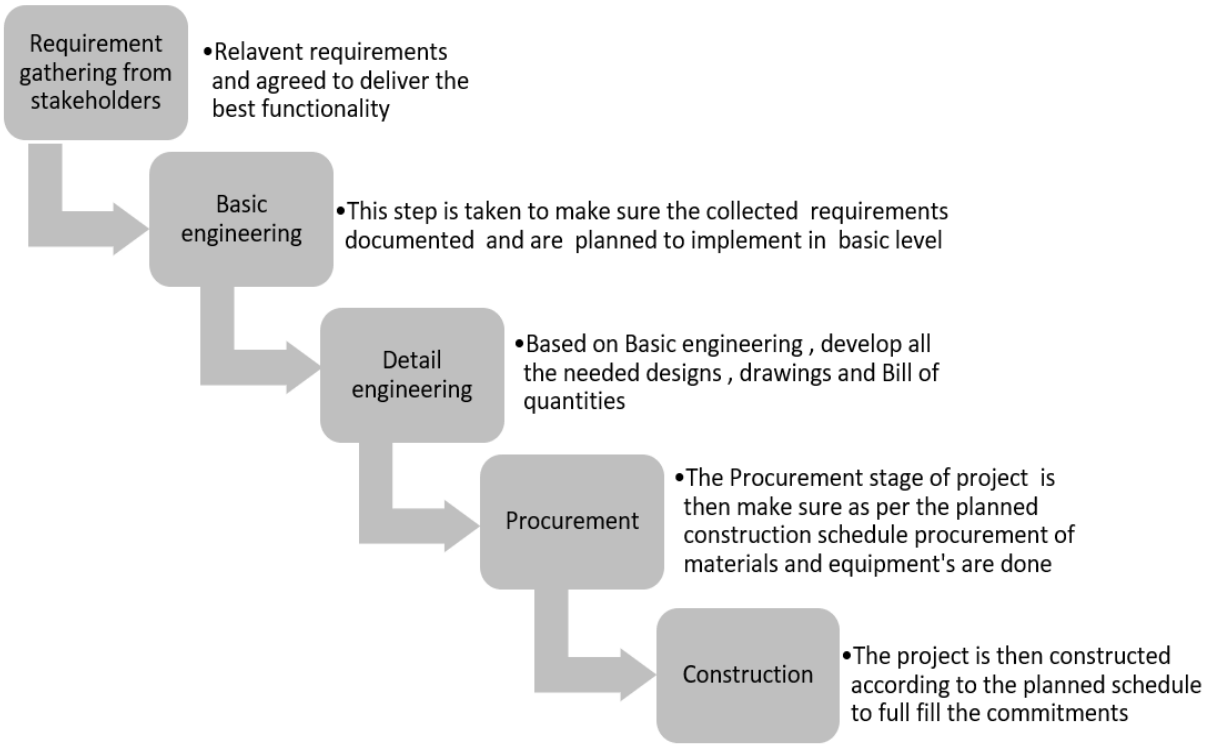

Figure 3 Waterfall method steps for an EPC Construction project (Feng & Todd,2011).

Benefits and disadvantages of the Waterfall method (Waseem 2022)

Benefits: As stakeholders' wishes and requirements are captured in the beginning in a later stage of the project, the involvement of customers or changes in requirements is limited.

In an early stage of the project, preparing a WBS structure will remove or highlight all the concerns or challenges during the design process. Accurate measurements for cost and implementation schedule. As the projects progress phase by phase, it is easy to measure the progress.

Disadvantages: During my project experience, it is noted that even though we try to get the requirements in advance, there is the possibility of changes in conditions. In a complicated project, the WBS structure is also very complicated, so the project planning, maintaining, and updating of the WBS are very time-consuming.

As there is no flexibility in progress phases, it is time-consuming, especially a change is very time-consuming. Efficiency is comparatively less as there is no overlapping of any phases possible. In this method, the deliveries are at the end of the process, and no output is possible in any other. Even though there are certain disadvantages, the waterfall methodology is simple, sequential, and easy to apply; hence, it is often used in construction projects.

Agile models -Kanban and Scrum: Agile methodology is a modern philosophy that breaks projects into sprints or iterations. In this method, the stakeholder's interactions hence involvement much more in comparison to traditional methods; Agile has been used often for software development projects since 2001 when it was created as a method with a set of values and principles.

"*Individuals and interactions over processes and tools, Working software over comprehensive documentation, Customer collaboration over contract negotiation, Responding to change over following a plan*" (Beck. et al., Agile Manifesto, 2001; 1.)

Agile methodology is based on flexibility. It executes on demands. one significant difference from other processes is that different methods have a pre-plan before starting a project. Still, agile methods you plan during the project. (Prince, 2022)

Advantage of Agile

High quality: As on agile method, the communication with stakeholders are more often means all demands of customers are taken care of also much often, quality control ensures the high quality.

Satisfied customer: As mentioned above, the interaction with the customer is more; hence customers are moving along with the projects. It is easy to accept any changes and implement them faster.

Less risk: The improvement in communication reduces the chances of delays or quality concerns and the overall risk in projects.

Return on investment(ROI): is better and faster; when the risk is less for the customer as well as companies, this method is the most value-created model or methodology to use in projects to get better ROIs

In a complicated project environment, a project manager or a project discipline manager like the CDE's must be capable of adapting to any process model, traditional or agile, to generate the best outcome; hence this comparison and further evaluation on this topic are relevant for construction engineering projects.

Four important take-offs from the agile process (Spalek 2016)as mentioned below,

Agile process solutions can give the best output when the main task can be divided into subtasks and assigned to people in small amounts. It could work well for design development projects where details documentation is unnecessary. Could adopt the agile process style for feedback handling on a construction project

Leadership, in general, could see the benefit of using an agile mentality in particular work culture. It is essential to know the culture of the stakeholders to behave with common sense for the project's success. As the agile process has an advantage over the traditional approach in some instances, it is also worth looking at a few common strategies for agile as follows,

Scrum: It is a framework in an agile methodology, and this is one of the most used agile frameworks in software industry projects. Scrum is very effective for collaborations in working on complex projects. Scrum is based on Sprints to achieve the maximum value for stakeholders

Scrum methodology is suitable for complicated projects as it breakdown the process into small pieces to make it easier. This is very beneficial when focusing on efficiency and innovation to drive results rather than rigid detailed processes. The value given to customers is very high in agile and Scrum. Hence, it creates a satisfied customer or will modify to make customers happy. (Peek,2021)

Advantages and challenges of Scrum: The scrum model brings the most flexible framework for projects, and it helps to complete the tasks at lower costs compared to projects done with traditional methodology. It is driven by innovation and creativity, which will elevate the satisfaction of employees and customers.

The challenge I can foresee when looking at the construction engineering perspective is that, as employee contribution is very high in the outcome of the software industry, it is known that every time you have to use your brains to develop something or fix the bugs. Traditional engineering uses the old proven methods, so to make these engineers adapt to the new generation framework needs absolute focus and support of company management.

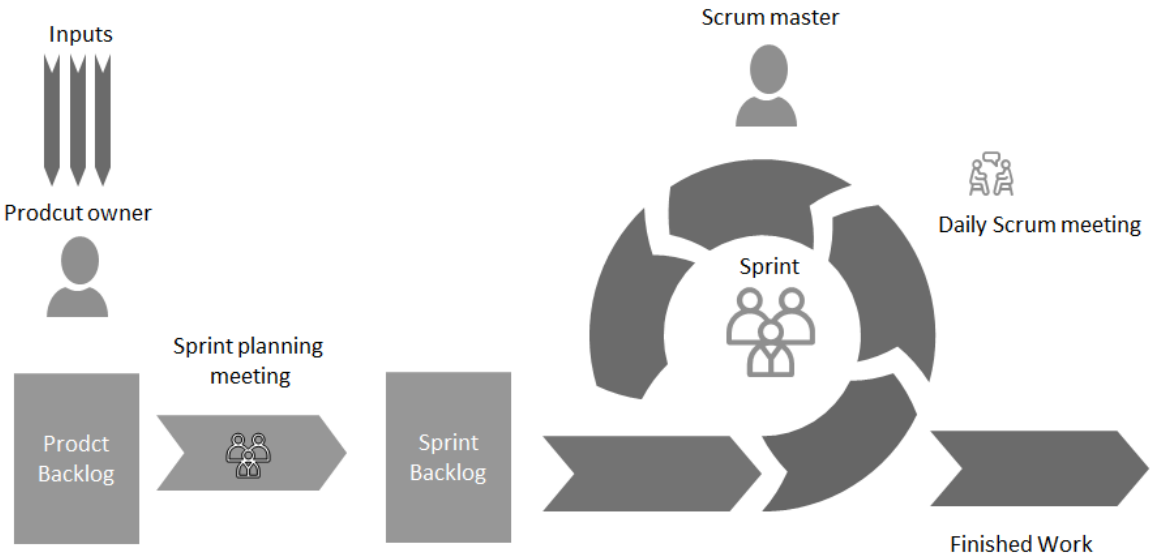

Figure 4 Scrum framework (Measey et al., 2015.)

As shown in figure 4, the product owner is the one who brings all stakeholder's requirements and communicates the goals to maximize the value of the product; on the other hand; the scrum master will be a support leader to make sure the success of the scrum process and meetings, the scrum master take care of the teams and support the team in any challenges in the way. The scrum team works as self-organized for the goals and requirements set by the product owner and is responsible for developing a high-quality product.

Kanban

Taiichi Ohno developed the first Kanban system for Toyota automotive in Japan In the early 1940s. (History of kanban 2020)

A kanban board is an agile tool designed to help engineers to visualize work, limit work-in-progress, and maximize the overall efficiency. (Rehkopf 2022)This is mainly used in software development projects but is also possible in construction industry projects for the sub-tasks that support finalizing the main goals.

The three critical categories of a kanban board: are "to do," "doing," and "completed." (Prince, 2022). A kanban board can be broken into 3 to 5 different components; an example for a construction project as below,

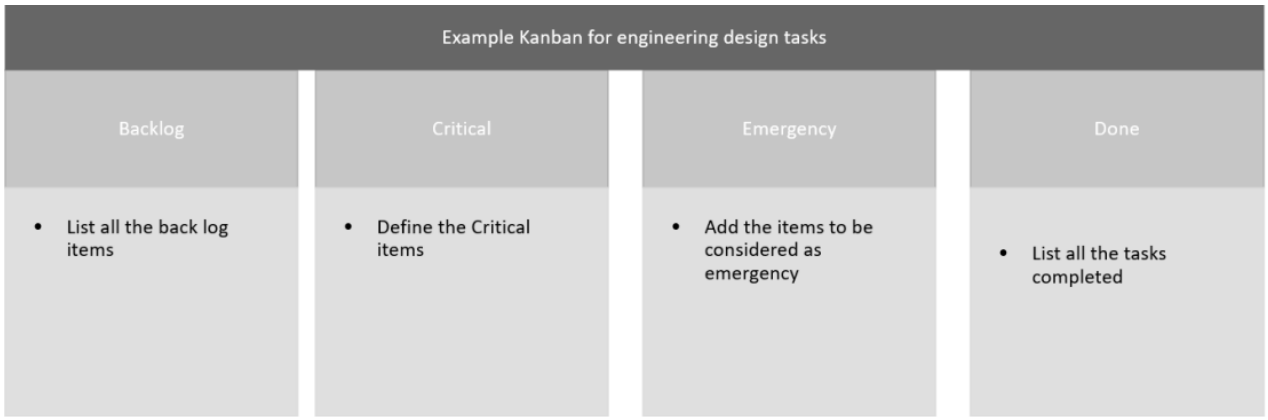

Figure 5 Example of Elements of a kanban board (Personal Kanban 2011)

Kanban vs. Scrum is a discussion about two different strategies for implementing an agile development or project management system explained in an article by (Rehkopf 2022)

Table 2 Kanban vs. Scrum

	Scrum	**Kanban**
Ideology	Learn by experiences, prioritize, self-organize, and reflect on all wins and losses to continuously improve(CI).	Use visuals to improve work-in-progress
Cadence	Regular, fixed-length sprints (i.e., two weeks)	Continuous flow
Practices	Sprint planning meeting, sprints, daily Scrum meeting, sprint review, sprint retrospective	the flow of work will be visualized; limit work-in-progress will be limited, manage flow, also incorporate feedback
Roles	Product owner, scrum master, the development team	No required roles

The construction industry still has immense faith in the step-by-step process of the traditional methods because the projects are big, and it involves much bigger packages and more people at different stages of the projects. The physical part of the work is much more than having a software development project, for example. But considering the advantage of agile methods in terms of quality and flexibility, it is possible to implement them by carefully choosing the correct packages within the construction project. This is my takeaway from this theory evaluation; hence, I will use the possibilities of Scrum and Kanban for the company process evaluation to obtain the report.

2.2.4 Project Requirement Engineering

This chapter focuses on how the requirement of engineering involvement in Projects. Requirement engineering is an essential part of any project. Every project stakeholder wishes for maximum functions and the best in quality but fewer costs; during the requirements engineering phase of a system development project, a significant amount of errors(sixty percent) happens. (Pohl &Rupp, 2016)

The error due to missing requirements can be problematic in a construction engineering project. The magnitude of it can sometimes be catastrophic. In the company part of the thesis, there will be an evaluation of the lack of Requirements effect on projects, and the cost is always the top factor for business. Costs of errors could be significantly removed if requirements engineering happens in a project's sales and basic engineering stage. The later, the higher are the costs associated with fixing it. For instance, the effort to fix a requirements defect is up to 20 times higher if the correction is done during programming instead of fixing the same defect during requirements engineering. If the fault is fixed during acceptance testing, the effort involved may be 100 times higher" (Boehm 1981).

In the growing world, projects need to do so quicker, better, and with a higher level of quality which calls for efficient requirements engineering. Complete requirements free from defects are the basis for a successful project outcome. Must reduce potential risks during requirements engineering to allow for successful project progress. Faults and gaps in requirement documents must be discovered early enough to avoid the challenging change processes. Even if the changes may come in the way, the change evaluation and change management must take care in the best possible way to mitigate the changes. The reason for the change must be evaluated to ensure the reoccurrence of the same.

When a multi-discipline engineering project, one discipline changes may significantly impact many engineering systems; hence, a systematic approach to change management is required. All changes and their effects must be communicated, discussed, and agreed upon in advance before they go to the execution stage to ensure the best project outcome.

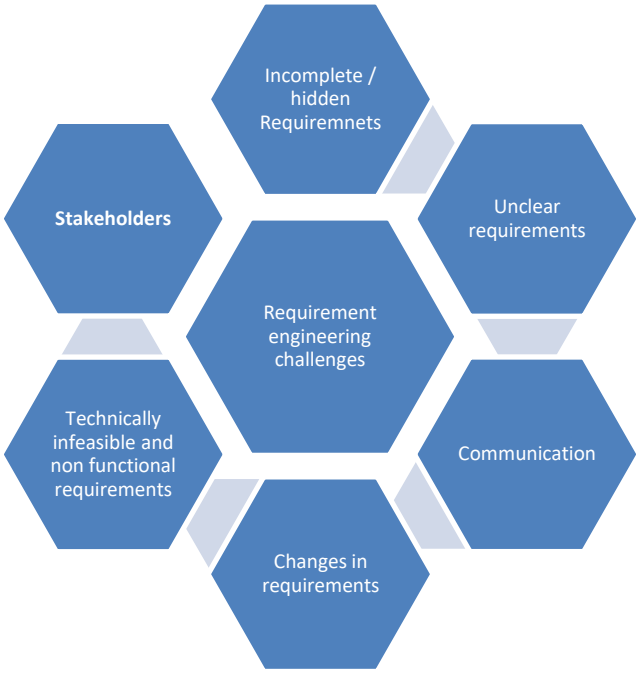

Figure 6 Challenges in requirement engineering (Alam, Nazir & Asim, 2017).

A survey of RE in Austria and Brazil indicated that incomplete and hidden requirements are a significant concern for RE. (Kalinowski et al., 2016.)

According to the survey in Australia, the results show that incomplete or hidden requirements are reported as 64.28% as of in brazil it says a second big concern is the same with 41.89% cited the same issue the second biggest issues seems mentioned in both countries are communication, Communication flow within the project team. Hence communication is one of the critical facts to achieving the requirements as specified in (chapter 2.3); the design process must be followed to obtain all the requirements early enough to reduce the challenges.

Another important thing from the survey is the tight project implementation schedule; this is always challenging, and time is needed to collect requirements, think, develop and implement. The stakeholder's expectation is always based on a previous solution; hence hard to separate the requirements for the new solutions; changes during the project are another concern raised as well. I have also noticed the same circumstances while I did questions to the company engineers during this research; hence I need to know how the

same problems work around the world as one intention of my thesis is to find recommendations for handling such concerns.

2.3 Engineering design process

Engineering is problem-solving; engineers create designs that can solve problems using maths, science, and technology.

The engineering design process is a step-by-step process that the engineers take to solve a problem, and there can be many steps depending on what kind of problem is in front of you.

Engineering design process steps: The following steps are formulated based on (Rolland & Ufr 1994) to fit a construction engineering project.

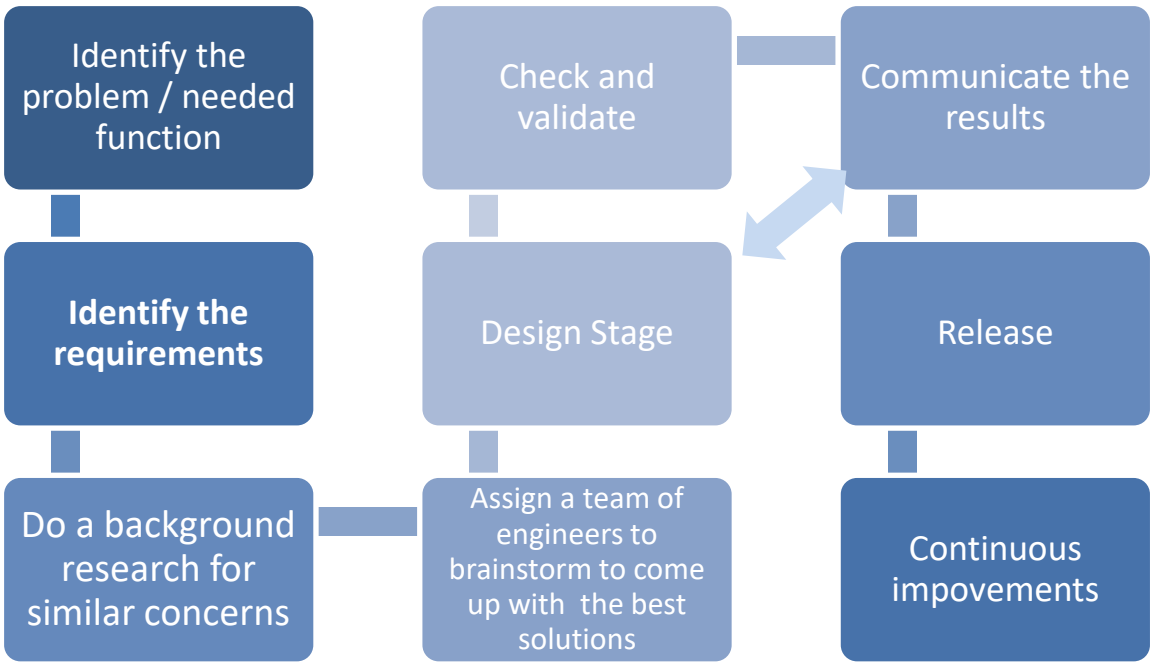

Figure 7 Engineering design process Steps(Rolland & Ufr 1994)

It is not always necessary to follow the process or steps above; engineering with common sense ensures which solution best fits the required functions. The traditional process steps will be used in the evaluation of design tasks for the results of this thesis to make the requirement engineering report. In the design stages of the project where I will also try to formulate which sub-designs can be processed with the agile scrum methodology

The engineering steps are explained below (Rolland, 1996).

Identify a problem or the needed function: Identifying the problem or the required function is always the first step in the design process. The requirement can be anything that needs a new or a modified solution.

So the 3 step questions, what is it, who is it for, and why it is needed to find a solution, will bring the relevant requirement onboard, which will help the engineers to plan to the next step.

Identify and evaluate the requirements: The first step helps to identify a need on a general level; the requirements specified for the best value engineering design are a part of any engineering services as the stakeholders must be happy and satisfied; this step will identify and evaluate the requirements and remove the unwanted with stakeholders agreements.

Do background research for similar concerns: Once the engineer understands what, who, and why, It is relevant to search for suitable solutions, not reinventing the wheels. When thinking about construction engineering projects, searching on your company database or with colleagues is relevant to find a similar solution that could be used directly or modified. As all look for cost efficiency, this step is one crucial step.

Assign a team of engineers to brainstorm to come up with the best solutions: Engineering brains to be approached as the next step for the solutions. Specific areas of engineering can use artificial intelligence to find the answers to similar problems. This thesis is not going into detail about AI as noted in research but will find recommendations for possible automation. A good design engineer's team will brainstorm all possible ideas for any engineering design is done. In practice, if a company is in a particular read of engineering, there is always a solution to traditional problems. Still, new concerns are always raised in engineering in various forms. Also, as cost is the driving factor in projects, old solutions may need improvement concerning technologies, materials, and new ways of implementing design solutions. (Rolland & Ufr 1994)

Design stage: Use the discussed good ideas to covert to designs. If it is a multi-discipline construction project, it is necessary to have communication and cross-discipline design requirement mapping and execute and verify it in different design stages. For example, the Waterfall model (Royce 1970) could be an excellent model for verifying different design stages. In such a process, the design will be done in a different phase, and the previous step must be closed before the next phase begins. According to the engineering solution, several such approaches can be adopted, as mentioned in chapter 2.2.2.

Check and Validate: Checking is an essential step in the design process. The actual checking must have happened during design by the engineer who is doing it, and it is very relevant to get it checked again when it is close to being ready. For the designer's design, checklists that capture the essential feedback from the past projects could be documented to follow while doing the design.

Cross-check can be done by another engineer in the team who know about this project or can be a peer checker who is not directly involved in this design or it can be both as the quality, which is one top requirement on all types of design projects. These checks often add value to the designs as they may find mistakes or improvement possibilities.

When put discipline are working on a project where 3D designs are available, clash checks are a must to avoid the cross disciplines concerns. There are many technologies available to make these checks possible Extended reality technologies can also be used to check and collaborate on design purposes, which will be detailed in the second purpose part of the thesis.

Communicate the results: The findings from the checking stage must be communicated back to the designer, who then checks the same and decides how to continue to improve the design. As part of the quality procedure, it is relevant to store these findings and comments in the appropriate format in a suitable medium for future use.

Release: This is the final stage or Step in the process of releasing the design done for its purpose of manufacturing or procurement and construction.

Any of these stages are equally crucial for value engineering as such crises of pandemics or Countries disputes may make material availability issues, so this must be turned into a challenge in the results of construction engineering, So it is recommended to be in touch with suppliers and product manufacturers to avoid the reworks due to availably concerns.

Continuous improvement (CI): Continuous improvement in engineering creates more value and customer satisfaction. It required a constant effort to improve all engineering elements, whether this is processes, tools, persons, etc. Sometimes the improvements are significant, but more often, they are small. However, most important is that they're frequent, happening all the time, and hence continuous.

Continuous process improvement is the set of ongoing engineering and management activities used to select, tailor, implement and assess the processes used to achieve an organization's business goals. Continuous improvement is recognized as a component of modern quality management (MITRE 2014)

3 RESEARCH METHODS

Any value addition to project design supports its successful implementation; one value addition possibility is to have the best knowledge about the requirements and requirement engineering research to find the best ways for RE to implement in projects by the CDE team. CDE represents the project discipline managers in this context, and This will help early decision-making, which could impact stakeholders' wishes.

The thesis aims to clarify the different requirements, engineering concepts, and factors that lead to success and improve the value of a project by applying or recommending it to engineers. It also suggests the findings to the customer interface to enhance the requirement engineering part.

I have used the qualitative method for my research instead of the quantitative as it was essential to have face-to-face and virtual meetings. The quantitative approach was not suitable as I am afraid to get good enough answers to make them to the percentage level. After theoretical research, I found that Fit-Gap analysis is an excellent method to find the GAPS in the company's existing requirement gathering and engineering design process methods as it finds where problems occur, why they appear, and how bad are they? Gulledge (2006)

The functional analysis system technique (FAST) is the other method I prefer for evaluating company's electrical engineering design process, as it helps to prioritize the function as per their importance. The different sub-design tasks as per their priority are checked and found that it has to be re-arranged. Hence it is added to the company value improvement recommendations.

3.1 Interviews

For the best outcome possible for this thesis, I needed to know the engineer's opinion on the requirement handling for different design activities. Also, the CDE's who collect those requirements must be aware of the concerns of the design engineers; hence the system knowledge responsible persons (KRP) have also been part of the interview. Seven system responsible design engineers and four system KRPs were part of the own company interview. They are chosen as they are accountable for every design system, engineering solution, and customer interaction.

To know how the requirement engineering works in other companies and the engineering design process, I have checked with two companies, one based in the USA and the other in the UK, and interviewed the Electrical team heads.

It was equally important to check how requirement engineering works in other engineering areas than construction engineering; hence, I have checked with two engineers in the software development industry. In total, I have interviewed fifteen experienced engineers globally.

To decide the interview persons and amount, it was obvious to check the different main design systems affected by bad requirement management in the past. I have analyzed the electrical resource allocation sheet maintained for resource allocation. My main concerns are finding out which design areas are mostly delayed due to requirement changes, which are the most time-consuming engineering tasks, and the most criticized engineering tasks per the quality feedback. I manage to get these concerns after the evaluation. From that, I have made a Kanban table to make my plans for the interview prioritization.

Table 3 interviewee information

Interview Number	Date of interview	Role of interviewee	Time at the company	Length of the interview
1	28-Mar-2022	CDE	20 Years	30 Mins
2	30-Mar-2022	System KRP	6 Years	45 Mins
3	30-Mar-2022	System KRP	17 Years	One hour
4	13-April-2022	System KRP	16 Years	45 Mins
5	27-April-2022	System KRP	15 Years	45 Mins
6	29-April-2022	System KRP	16 Years	One hour
7	29-April-2022	System KRP	10 Years	45 Mins
8	29-April-2022	System KRP	10Years	30 Mins
9	20-April-2022	CDE	10 Years	30 Mins
10	5-May-2022	CDE	16 Years	30 Mins
11	6-May-2022	CDE	10 Years	30 Mins
12	23-May-2022	System	13 Years	30 Mins
13	23-May-2022	System	11 Years	30 Mins
14	20-May -2022	Director	20years	30 Mins
15	20-May -2022	General	25 years	30 Mins

Questions: I did ask myself about what is the concern that majorly I found in requirement engineering steps as per my experience in the Electrical engineering department. The research of a survey of RE in Austria and Brazil indicated that incomplete and hidden requirements(Kalinowski et al., 2016.) were used as the base to construct 15 questions for interview purposes. The same checked with an experienced chief engineer and did choose eight of them with some modifications before they went to the internal interviewee. Each interview lasted approximately thirty minutes to one hour. The questions were not sent beforehand to the discussions as it was essential to hear the answers without preparation. The responses were written down during the interviews for further research.

Interview questions for requirements were the following: this is used for internal and external

1. How do you document the needed Requirements for the design you are responsible for?

2. How do you verify the requirements concerning the functionality that stakeholders require?

3. What are the common missing requirement concerns that affect the designs' output?

4. How are you making sure the requirements are reaching the design team?

5. What steps are taken to improve design efficiency for the next projects?

6. What are the steps taken for reusing designs?

7. What are the major concerns that delays the deliveries?

8. How do we gain customer contribution to requirement collection?

External company interviews

1. What is your engineering design process for an electrical design job?
2. How do you handle challenges created by requirement changes?
3. What do you think that working well in your design process?
4. What do you think that is not working in your design process?

3.2 Fit-GAP Analysis

Fit-GAP Analysis brings added advantage of deriving new processes in organizations. It is the formal process of identifying how well a specific organization's current or planned system fits that organization's requirements, where problems occur, why they occur, and how bad are they? Gulledge (2006)

A fit-gap analysis finds where functionality gaps exist when comparing operating or business requirements for the organization to system capabilities. (Berrybunn 2015).The fit-gap process benefits organizations dissatisfied with a particular system but do not clearly understand why. It is majorly used in findings GAPS in the use of software, but an outdated design procedure is the root problem causing a delay or an issue in specific designs. Performing a GAP-FIT analysis at the detail level will quickly uncover these issues, which could be solved with another best fit process. A correctly done GAP analysis that provides the correct priority level to be assigned to each problem scenario is beneficial when planning budgets and implementation schedules.

Data Analysis: During the engineering design process evaluation done for the company, the biggest challenge in front of me was to limit it to specific designs which are relevant. Out of fifty projects, six hundred engineering tasks, and twenty design packages in the electrical discipline, I shortlisted 7 Engineering packages based on their criticality, cost impact, and time consumption.

Then took all those seven designs separately and further divided them into sub-design packages, which are put into a FIT GAP analysis. An efficient GAP analysis was needed; hence I had to split the GAP analysis into three different ways. In General, Technical knowledge of personnel, Existing WoW, and tools called Skill GAP analysis, WoW GAP analysis, and Tools GAP analysis.

In Skill gap analysis is used to find out the GAP in technical skills of the persons; based on face-to-face interviews and collected customer feedback. WoW, analysis Tool gap analysis is done to evaluate GAP in the general design process WoW. The tools GAP analysis is done to find out the GAP in available tools by mapping them and analyzing all its applications and usage in the company vs. other available tools to make the recommendation.

SKILLS GAP ANALYSIS

Employee:

Job Titile

SKILL DESCRIPTION	CURRENT SKILL LEVEL	DESIRED SKILL LEVEL	ACTION PLAN	START DATE DUE DATE	PRIORITY	COMPLETE	NOTES
LEADERSHIP Have initiative & able to take charge of demanding situations							
TEAMWORK Ability to work in a team, specific knowledge of teambuilding							
TECHNOLOGY -1 List the details of technology							
TECHNOLOGY -2 List the details of technology							
TECHNOLOGY -3 List the details of technology							
COMMUNICATION Verbal, written, and comprehension skills							

Figure 8 Skill gap analysis template(Gulledge (2006)

3.3 FAST- Functional Analysis System Technique

It is a systematic approach to discovering the product's redundant or primary and higher-order function by re-designing it by removing the non-value-added parts. How we can find the poor value functions in a process is always a challenge. It is equally important to know how the existing solutions are thought of and whether there are any time constraints. The time constraints will always limit the opportunity to evaluate the alternate solutions in projects; hence it is usually by the designers to follow the existing WoW or the Way of doing designs. (Bartolomei and Miller 2001)

Charles Bytheway developed FAST Diagrams in 1964, which are function-oriented, not time-oriented.FAST permits engineers with diverse technical backgrounds to effectively communicate and resolve the issues which require multi-discipline concerns. (Borza, 2011).

For doing FAST, we have first to put all requirements together initially. How and Why questions are beneficial for understanding the designs' primary and secondary, and tertiary functions. VA in-depth (n.d)

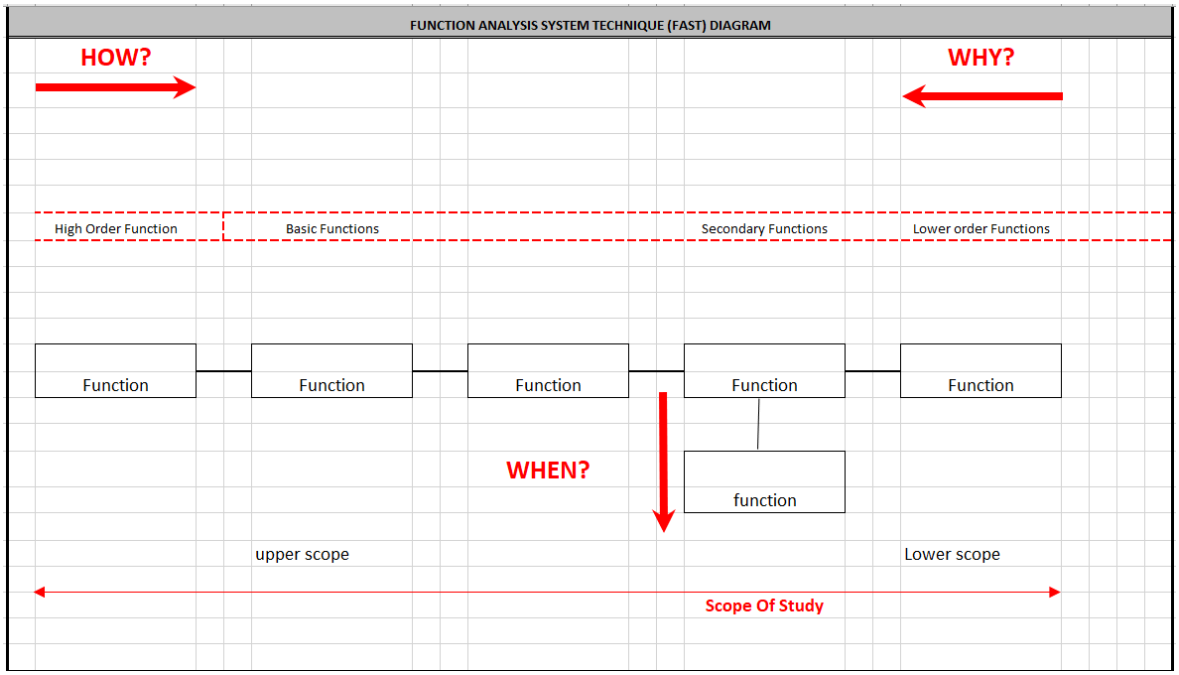

Figure 9 FAST template.VA in-depth (n.d)

Working out a FAST diagram will make you understand the function that can be eliminated or improved to deliver the basic requirements/benefits; an example FAST diagram is shown in (Figure 9)

4 RESULTS

I wrote down all answers during the interviews; there were concerns, suggestions, and recommendations. Once all discussions are finished, they are summarised and written down; these results are used to determine the GAPS in Technical knowledge, WoW, and tools. In general, the recommendation part in this chapter is written based on these findings and interview suggestions. I have also used my own experience to formulate them. As the FIT GAP and FAST are made based on personal opinions, and then the company's existing processes are validated, which are confidential, the detailed results of these analyses will be published only in the company part of the recommendation report.

The summarised results of the Interview questions to the Internal and external Engineers are as follows,

How do you document the requirements for the design you are responsible for?

Most of the internal interviewee's opinion is that requirements have to come from customers in documents. Requirements are gathered in the form of a few general excel or word documents as answered by some participants; the nonexistence of a standard requirement collection system was highlighted; it is the same at the sub-design level, Most often, these missing requirements create challenges, and the first outcome of the project hence makes reworks and loss of money and time.

The software industry works differently compared to the construction industry; the function that needs to be set is clarified initially. The required changes during the course; hence the change in requirements must be captured, and they are using many specialized tools for the purpose like JIRA, ERP &CRM & Polarion, etc.

The recommendation for sorting these concerns is to create a requirement specification template document for every sub-design, which will then contain all the relevant technical details that a designer must know to make the design

This will be checked and updated in the projects as per the project-specific requirement in the basic engineering stage of the project, which will be reviewed and approved by the

stakeholders before it goes to the designer for detailed engineering purposes. Going to any particular software doesn't seem necessary only on the design part. Hence such a tool will not be relevant for designs but is recommended to the customer.

How do you verify the requirements concerning the functionality that stakeholders require?

Missing requirement verification methods and requirement varication must be done in the sales phase where I am not involved are highlighted by most of the engineers. As suggested by one interviewee, requirement verification steps must be taken in the sales and basic engineering phase in communication and meeting.

The software industry has many techniques, Daily scrum meetings, and Spirits as an example with the agile method.

My recommendation for this concern is to actively participate in sales to bring value addition by suggesting the best cost-efficient solution that provides the same level of functionality and quality. also, depending on the criticality or complexity of projects daily scrum meeting could be an excellent addition to sorting all requirement concerns

What are the common missing requirement concerns that affect the output of the design?

In general, when to start to meet the delivery deadline is unclear, and the internal interviewee does not note subtask level delivery planning. And as requirements are not documented, requirement slips happen during communication. For example, a phone call.

Clear identification of delivery deadlines for all design tasks must also be clarified. A scrum meeting per design to be kept where it is possible to discuss the deadlines, requirements and prioritization of the subtasks is recommended. All communication must be documented, and the Project discipline management guidelines contain information on all general communication methods and practices and how to document them.

How are you making sure the requirements are reaching the design team?

It is informed during the kick-off meeting and checked when the designer makes it ready, and the daily Scrum is a solution suggested for the sub-design level.

To make sure the requirement reaches the designers as recommended in the earlier questions, document the requirement as specification and then communicate the needs in Scrum meetings and validate and follow up in different stages of the project.

What steps are taken to improve design efficiency for the following projects?

Designers have noted that more advanced tools could improve the design's efficiency but are not yet available for them. Checking and Peer checking during the design stage could help design feedback to the end of the project to collect what went wrong and what went wrong to decide what we can improve in future projects. Someone proposes a value engineering meeting at the end of every project, then evaluates the design solution with an alternate better solution, if possible.

In the company part GAP analysis, the tools GAPS are identified, and it has been communicated to take necessary steps to improve the challenges caused by specific tools. Feedback which is very necessary for improvements on the designs, it is recommended to collect the feedback from the site and make them reach designers, Value engineering meeting is an excellent suggestion to see if we can improve anything on the design, but it must happen before we complete design hence this will be taken as a part of scrum meeting.

What are the steps taken for reuse designs?

Reusing the design is not often suggested; as many designers noted, steps are taken while we do project layouts. Reusing is impossible as few projects have their requirements notified by some; although there might not be efficiency improvements, reuse of certain parts is possible, says few.

It is always essential to reuse all possible design works to add value. In the sales stage of the projects, as part of value addition, we should ensure that all possibilities of reuse of earlier made designs are taken care of and documented. Then this must be discussed during the basic engineering stage of the project also recommended to have a database that will help the designers search for similar designs and solutions.

What are the significant concerns that delays the deliveries?

The following concerns are noted as the results

- Unknown requirements
- Changes in requirements
- Availability of resources-people and tools
- Missing Project planning

The first three concerns are addressed in the questions above. In addition, there could be a proper WBS structure that details all activities, or good Scrum is recommended in projects to identify the concern on delays and make it happen on time.

How do we gain customer contribution to requirement collection?

Every company has challenges with requirement collection, which could be due to various reasons. There is no easy way. Better collaboration with customer Requirements documentation on right level contribution towards projects best fit function in an early stage. More requirement awareness to sales and the technical team involved in that phase and bringing customers closer to the project designs in all stages will help get more customer contribution.

The results of the Interview questions to the external companies are as follows,

What is your engineering design process for an Electrical design job?

The US company works more traditionally, meaning that the Engineer drafts red pens, and the designer continues with design and engineer checks during the design process. The engineer responsible for the plat plan and senior engineer cross-checked the design document before delivery. Also, they comment that this procedure varies with the size of the company and the projects.

UK Company is more than one project one engineer continues serving, and he will act as a lead engineer in case more engineers are needed to accomplish the deadline.

How do you handle challenges created by requirement changes?

We have to prevent the requirement changes as much as possible. The cost of doing it again is very high in the USA for customers outside Europe; It is tough to provide a solution for requirement changes, and they are hard to predict

UK Company is more on recording the changes to change management and communicates the impact and schedule. Do it according to resource availability or prioritize the urgency of changes.

What do you think that working well in your design process?

Engineers are responsible for design as they are PE stamping the document; hence, the engineer is more involved in the design iteration process in the USA. Design companies, even though they are not buying materials, we are very much in collaboration with the supplier while doing design. The detailing on design is limited, and more freehands are given to the contractor in the USA, which will help reduce the change orders later during construction.

Engineers are responsible as leads of the design in the UK, but they are not involved frequently in the design process when other engineers are doing it; checking innovation in different stages helps to get them in shape.

What do you think that is not working in your design process?

We are engineers who follow the US norms and codes; when it comes to the rest of the world, it is a bit challenging to understand the design process. also, following the traditional approach; There is not a suitable method of understanding the scope of engineering and gathering, says the UK company; hence they recommend also having a structured way of requirement transfers

In general, Both companies follow the traditional requirement engineering methods and do not yet implement the agile process in any projects; the recommendations from these interviews are notified in the company part of the report.

Fit-GAP Analysis

Skill Gap analysis template (figure 8)is prepared to check the leadership, teamwork, and skills in different technology parts and communication. Similar but modified templates are used to work gap analysis and Tools GAP analysis.

In general, the agile process also fits specific design packages currently using traditional step-by-step methods like the waterfall process; these findings were listed in the company part of the thesis.

During Skills GAP analysis, there is also a finding that the handling of requirements and designs varies between the CDEs even though they expect to have the same outcome; this identified GAP is solved with the preparation of the Project discipline management guidelines, which contain the following,

- General information project management
- General tasks in CDE's Work
- Project Discipline responsibility

This guideline will help a new CDE or a new engineer coming to a project understand his role and responsibilities. This is made available in the company document management system.

FAST

The design packages are also analyzed using FAST, listing each design sub-design package's contents based on their functionality, importance, why, and when needed. The results of this were the potential identification of many unwanted engineering small sub-tasks and changes in tools and the recommendation of automation with the support of new tools and re-organizing the activities based on resource availability.

The FAST diagrams will be used to evaluate the designs for the secondary purpose of this thesis. Figure 8 is a template based on FAST. This template will be used to analyze the seven design packages and their sub-packages; as they are company confidential, the results are reported for company recommendations.

In general, on sub-design tasks, there is a possibility of an agile WoW means that the task could follow the Scrum framework.

5 DISCUSSION

As per my understanding, the sources in the form of books, Articles, other thesis, videos, and different internet pages, which are used for this master thesis, are reliable, dated from 1988 to 2022, and similarities are found in these materials. The sources are very diverse as the authors are from all around the world.

In a theory topic, I was mentioned as the understanding of requirements must come from the designer to the project management level. And as I started to formulate the results of the interview, irrespective of the engineers' knowledge, responsibility, and culture, all have to contribute to the success of the projects equally.

I noticed that some of the interviewed people showed a lack of knowledge of the requirements needed, knowledge of existing solutions, and lack of motivation. During my interview with system architects, they highlighted that bringing a change to the engineering world is difficult as they often face the same concerns regarding a new software implementation; patience and communication are essential values needed to be maintained.

The primary purpose of this thesis is to clarify the different requirements, engineering concepts, and factors that lead to success and improve the value of a project. I would say I have achieved as I have managed to state the best requirement engineering concepts and processes that can be adapted to deliver the best functionality for construction project designs for the stakeholder's needs. Among those identified factors, many fall into different groups involved in the project, from sales to project discipline managers.

Conducting interviews internally was an eye-opener that led me to identify the internal issues we had in handling requirements. The different company discussions proved that no uniform requirement handling exists, as some use software, and some do not. Also, there are learning back and forth on the engineering design process; the USA and UK company works based on traditional process but still in different ways on RE. In comparison, there are promising findings that could be recommended to use to improve the requirement engineering and the project design process.

In general, Follow the requirement engineering principles for any type of project. Elicit, document, validate, and manage them for the success of any project. For these steps, all companies must have prepared supporting documents for engineers so that there is a uniform WoW among them; otherwise, engineers intend to do things as per their own experience.

My secondary purpose is to make a requirements engineering report for the Electrical. The guidelines are based on the interviews' findings and GAP and FAST analyses. The same will be available for the Electrical discipline to use to improve the value and will also have the recommendations for further research and development.

There are possibilities for further research in this area, studying more on the Agile process and Scrum framework for EPC energy sector projects to check which other areas than design could be beneficial. My second recommendation is RE must be the same for all the engineering disciplines in a company; hence research on making a common RE policy for the company. A guideline for requirement engineering when working with sub-consultants. I highly recommend researching the best requirement-gathering tools to motivate the customer to use it, and then it can reach up to designers to collaborate well on requirements. A comparison between companies and all existing customer's RE methods could be conducted.

6 CONCLUSIONS

This thesis supposes to find out the best-fit RE methods and optimized design processes, which will improve the value of engineering projects. I researched theories that support my concerns and conducted interviews and analyses on the company's existing systems.

A limited number of interviews was done due to the limited timeframe to conduct the study; hence the data sample was smaller. As the thesis was focused on one part of the company with limited data, it s not possible to generalize.

During the research, it is found that it is not easy to change the WoW in traditional engineering industries unless there is time and the right people with enough management support. All improvement implementations are time-consuming. Communicate to the right people about the improvements at the right time and keep them along.

Efficiency improvement possibilities on electrical engineering design output were found. Recommendations on Efficient utilization of electrical tools and resources were made, and Identified possible processes to automate, which are written in the company part. These could benefit the electrical department by increasing customer satisfaction as it will improve critical factors for success, efficiency, quality, and cost.

The three topics, VE, RE, & design process, are constantly evolving in software engineering; hence I recommend that all engineering companies could benefit from these by validating their existing process every five years.

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