INTEGRATED CONCURRENT ENGINEERING AND APPLICABILITY TO CONSTRUCTION PROJECTS DURING DESIGN PHASE

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ABSTRACT

The construction sector has been struggling with low productivity issues during the last decades, mainly due to relatively low Research & Development investments compared to other industries, old-fashioned practices, and a fragmented market structure with Clients, Designers and Contractors.

The construction sector urges a digitalization revolution in order to overcome the aforementioned old-fashioned practices, but this digital revolution should go along with adequate methodologies that allow the digitalization to achieve its full potential.

The work presented in this thesis aims to improve the efficiency of the construction sector by having a look on more collaborative approaches between Clients, Designers and Contractors in Construction Projects. The collaborative approach researched in this thesis is the Integrated Concurrent Engineering methodology, which covers aspects of Project Management, Organization, Communication and Leadership, exploiting the digitalization capabilities that nowadays' Technology offers.

This thesis develops a theoretical framework for Integrated Concurrent Engineering in Construction Projects, with the aim to enhance their efficiency. The theoretical framework is based in literature research as well as experiences from project managers in the construction sector.

The result of this study includes guidelines and recommendations on how to effectively implement the principles of Integrated Concurrent Engineering. The guidelines are applicable for Clients, Designers and Contractors, and can be seen as a tool for the Project Management Team to improve construction project's efficiency, especially in the design phase.

Keywords: *Construction, Clients, Designers and Contractors, Integrated Concurrent Engineering, Project Management, Project Organization, Project Communication, Technology, Leadership*.

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1 INTRODUCTION

Urban development in large cities all over the world is becoming an increasingly sensitive topic, since large cities today grow at rates that we haven't seen before. This dramatic growth in large cities affects all dimensions of the urban space, not only housing demand but also the usage of the infrastructure around it (parks, tunnels, roads, etc.). Therefore infrastructure administrators, city halls and other public administrative figures have the task to satisfy citizen's needs in a feasible time horizon at the right quality and at an adequate budget.

Infrastructure projects are becoming more and more challenging, not only larger, but also much more technically demanding than ever before. On top of that, project management in the construction industry is well-known for being last in class, characterized for low productivity issues and old-fashioned practices. The main reason for this has been the fact that different "actors" (Clients, Designers and Contractors) with different goals take part into the design and construction processes, supported by contractual terms.

The increased access to technology and technological capabilities during the last decades haven't reached out so far their full potential in the construction industry, in opposition to other industries like manufacturing or IT & software development. This clearly signals the need of an urgent digitalization revolution in the construction industry. In order to implement satisfactorily the digital principles to a sector that has been typically "stuck in the past", there should be a common top goal and the drive forces should be all participants in the construction projects: Clients, Designers and Contractors with a common goal.

1.1 BACKGROUND AND PROBLEM STATEMENT

According to Changali et al. (2015), the productivity in the construction sector has remained flat during the last decades while, on the other side, the productivity in the manufacturing industry has almost doubled. It is a fact that there is a high correlation between productivity increase and investments on new technology and Research & Development, see e.g. Headrick (2017). However, based on McKinsey (2017a), the construction industry has only invested less than 1 % of its revenue on Research & Development, while other industries such as automotive have invested 3,5 %.

The overall project flow in the construction sector is that first, Client´s requirements are converted into plans and technical documentation by a Designer (during the design phase). Afterwards, these plans and technical documentation are converted into a physical result by a Contractor (during construction phase). The fact that different "actors" take part into the design and construction processes has fragmented the market led the construction sector to be one of the most inefficient industries, see e.g. Egan (1998) and Farmer (2016). The fragmented market structure, together with the short-term project focus, has also prevented large investments on technology development and Research & Development (Headrick, 2017)

Due to the inefficiency of the construction industry, the sector has urged for a change for several years now, but some of the core problems have not been fully addressed. According to Changali et al. (2015), the principal factors that contribute to the low productivity of the construction industry are organizational problems, inadequate communication, flawed project management, contractual misunderstandings and poor risk management.

In order to overcome low productivity issues, innovative firms suggest that acting in seven areas simultaneously could boost productivity by 50 to 60 %, according to McKinsey (2017b). These action areas have been identified by Barbosa et al. (2017) and are the following: reshaping regulation; rewiring the contractual framework; rethinking design and engineering processes; improving procurement and supply-chain management; improving onsite execution; infusing digital technology, new materials, and advanced automation; and reskilling the workforce.

According to a study from Fulford and Standing (2013), a more collaborative network approach could involve considerable productivity gains, but it is not clear who will be the agent that will lead the change. This study also points out the importance of standardized procedures, lifecycle costs and emphasis on project management activities.

1.2 OBJECTIVES AND RESEARCH SCOPE

As mentioned before, the construction sector has been typically divided in Clients, Designers and Contractors with different driving forces and therefore different goals, which has driven efficiency levels in the sector to be one of the lowest among all the industries. However, the problem has not been yet fully tackled although the several decades of awareness of the problem.

The work presented in this thesis includes an overview of the general project management strategies in the construction sector with focus on a more collaborative approach between the Clients, Designers and Contractor, the so-called Integrated Concurrent Engineering theory. This study will develop a theoretical framework for implementation of the Integrated Concurrent Engineering approach that will cover topics such as management, organization, communication, technology, innovation and leadership. The digitalization capabilities that nowadays' technology offers will be further researched, since it has the potential to dramatically increase the effectivity in the construction industry.

Summarizing, the research question that is going to be addressed in this thesis is:

"*How can Integrated Concurrent Engineering contribute to improve the efficiency in the construction sector?*"

1.3 DISPOSITION OF THE THESIS

The outline of the master thesis is as follows:

Chapter 2 presents a short literature study, starting with a basic explanation of the construction sector structure. The literature review develops afterwards the concept of Integrated Concurrent Engineering with focus on its main dimensions in a construction project, and gives initial insights on the applicability of the theory of Integrated Concurrent Engineering to the construction sector.

Chapter 3 gives an overview of the followed methodology for the development of this thesis, which includes the problem description, research method, analysis of the data and presentation of the results.

In Chapter 4, the obtained results from the research are presented together with a discussion of the results.

Chapter 5 includes a case study in which specific suggestions and advice from the results of this research are given for a Client.

Chapter 6 presents the concluding remarks of the research work, as well as suggestion for future research.

1.4 LIMITATIONS

This study has been based in an extensive literature review as well as project managers' experiences in construction projects in Sweden. The situational and cultural factors when it comes to construction projects in Sweden cannot be fully disregarded. This means that the effectiveness of the implementation of the Integrated Concurrent Engineering methodology can vary depending on the country.

The implementation of Integrated Concurrent Engineering methodology described in this thesis has focused on the design phase of construction projects, and the principles should be applied in other phases with caution and engineering judgement. Given the fact that the focus has been the design phase, the effectiveness of the implementation of the Integrated Concurrent Engineering methodology can vary depending on the contractual terms established between Clients, Designers and Contractors.

2 LITERATURE REVIEW

2.1 INTEGRATED CONCURRENT ENGINEERING

2.1.1 CONCEPT

Integrated Concurrent Engineering (ICE) is a methodology where the different stages for design and development of a product run simultaneously rather than consequently. The concept arose in the late 1980s within the manufacturing industry (Winner et al., 1988), in an attempt to improve the quality of the final product and reducing the manufacturing time in order to increase customer satisfaction while keeping a competitive advantage.

The Integrated Concurrent Engineering approach has focused on processes during the past decades, while a more recent approach zeroes in on team-based and computer-based approaches (Fischer et al., 2018). This highlights the need of a collaborative approach and technology development in nowadays projects.

Typical features of Integrated Concurrent Engineering are that the work is carried out simultaneously in multidisciplinary teams, the life cycle perspective when it comes to decision-making, development of effective means for collaboration and communication and integration of tools and technologies in the product development process (Akintoye et al., 2012).

The concept of Concurrent Engineering has been successfully implemented in several industries during the last decades, such as manufacturing, aerospace and oil- and gas industries, see e.g. Prasad (1996), ESA (2015), Abbas & Manarvi, (2011) and Lawson and Karandikar (1994). All these references report that design cost and production times have been greatly reduced.

It is important to mention that Integrated Concurrent Engineering is not a project management method itself; it is a flexible methodology where different types of project management methods can be used.

2.1.2 DIMENSIONS

There are four main dimensions that ICE methodology can be applied in each project, which are explained in the following subchapters. The four dimensions are: Management and Organization, Communication, Technology and Innovation and Leadership.

MANAGEMENT AND ORGANIZATION

A project can be defined as a temporary organization created to perform a predefined goal, and due to its ad hoc nature, there might be uncertainties at the beginning of a project regarding organizational aspects. The presence of uncertainties can be seen as a risk, and therefore a clear project structure adapted to the project needs should be in place before the start of the project. The general objective of having a defined organization during the course of a project is to optimize the available resources in order to achieve high efficiency.

The project management method that is best suited to the design phase of a project should be a decision taken by Client and Designer since a construction project can vary greatly when it comes to size of deliverables, investment costs, time and Client's requirements. In this sense, agile methods are a very well-known technique in some industries such as IT and software development, but they have not been widely implemented in the construction industry.

Agile methods are embraced by the ICE methodology and have been defined through the agile manifesto (Beck et al., 2001) that states the following:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

COMMUNICATION

Given the amount of different disciplines and personnel that have to collaborate with each other in order to achieve the project objectives, internal communication is obviously a key aspect of the project. Effective communication is essential in every project and therefore a communication plan that identifies which target group gets the right information at the right time should be defined in the early stages of the project.

The communication plan will set the basic principles to define how the information will be exchanged between different actors, namely project meetings and communication platforms. An example of a schematic communication plan is shown in Figure 2.1.

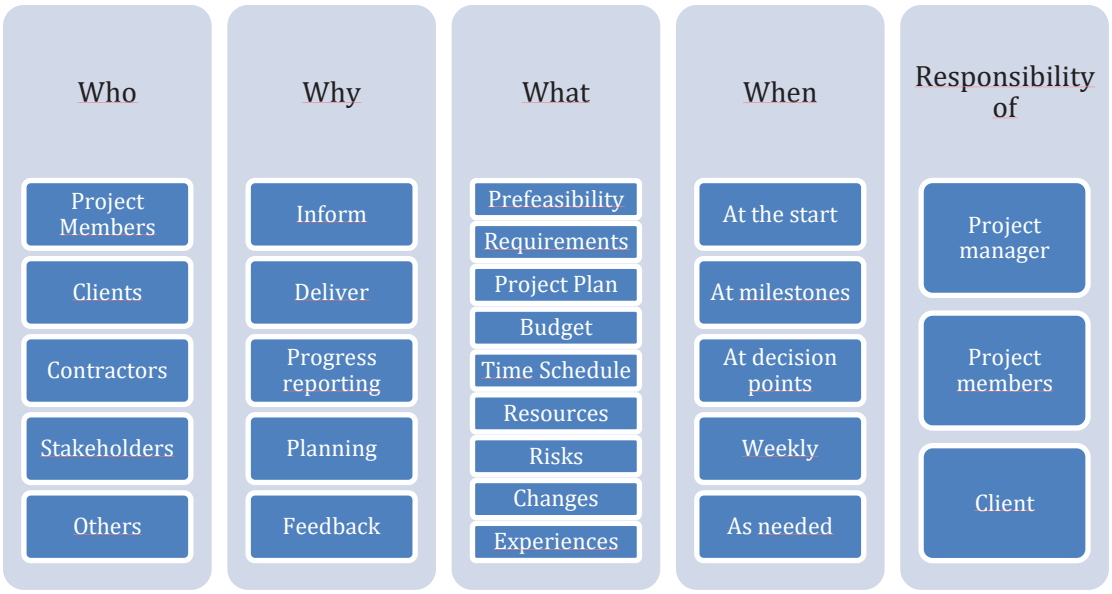

Figure 2-1 Schematic communication plan

TECHNOLOGY AND INNOVATION

Technological advancements along with availability of cutting-edge-technology have benefited the construction sector during the last years. These technological advances have made possible to improve the quality of the final product, while reducing costs and shortening the time schedule. However, the use of these technological advances is not well spread within the industry, which means that there is a great potential for optimization.

As stated in Kulatunga et al. (2011), special attention should be paid on the role of the construction client to drive innovation in the construction industry. It is evident that some of client´s characteristics, like competence, vision towards innovation, etc. are a good indicator of its capacity to drive innovation; but some other characteristics of the client (and not so obvious), will also positively influence in innovation. These characteristics are client's ability to be a team player, respect for people, promotion of mutual trust, proactive involvement or effective communication.

Recent research (e.g. Loosemore and Richard, 2015; Dedahanov et al., 2017) has demonstrated that centralization and formalization in organization lowers employees' innovative behaviour. This means that employees were less likely to collaborate with new ideas when rules and procedures are in the core of the organization, or when employees are not included in decision-making processes.

LEADERSHIP

Leadership is needed at all levels in a successful project (Dubrin, 2013), which means that not only the project manager should have good leadership skills; also project members should have at least some insights onto leadership. Therefore leadership should as well focus on helping/encouraging project members on developing these skills in order to achieve project's goals in a more efficient way.

For an effective project progress, it is essential a good understanding between project manager and project members. Here comes into play the concept leader-follower, effective project members (followers) should have the following characteristics: (i) self-managed, (ii) committed, (iii) competent and focused, and (iv) courageous.

There are numerous types of leadership, and there is no specific style that fits better for ICE methodology. However, it is an important task to find out which type of leadership fits to the specific project team.

2.1.3 READINESS ASSESSMENT

According to Khalfan et al. (2001), it is essential that previous to implementation of ICE methodology, a readiness assessment of the specific organization should be carried out. Several models for readiness assessment were developed during the late 90's and early 00's, for instance the models presented in Bergman and Öhlund (1995) and Brookes et al. (2000).

However, due to the specific factors that characterize construction sector compared to supply chain sector, Muya et al. (1999) stated that none of the developed readiness assessment tools could be adequately applied to the construction industry. Some years after, Khalfan et al. (2005) developed a readiness assessment tool for the implementation of Integrated Concurrent Engineering customized for the construction sector. This tool includes characteristics of typical Concurrent Engineering readiness assessment models that are applicable to other industries, but with the advantage that also takes into account important factors in the construction industry.

The BEACON model developed by Khalfan et al. (2005) is divided into four quadrants that cover the following key aspects or dimensions: process, people, project and technology (see Figure 2.2). Each of these key elements is depicted in a circle quadrant and its inner characteristics can be classified according to five levels of readiness, which can be seen as an indicator of the maturity of a project organization.

The content of each of the quadrants is described here shortly, whereas the description of the maturity levels is shown in Table 2.1 below. The process element quadrant covers factors regarding management and methodologies; the people element quadrant covers aspects related to team performance; the project element quadrant is comprised by specific project aspects, like design or requirements; and the technology element assess how tech-friendly an organization is.

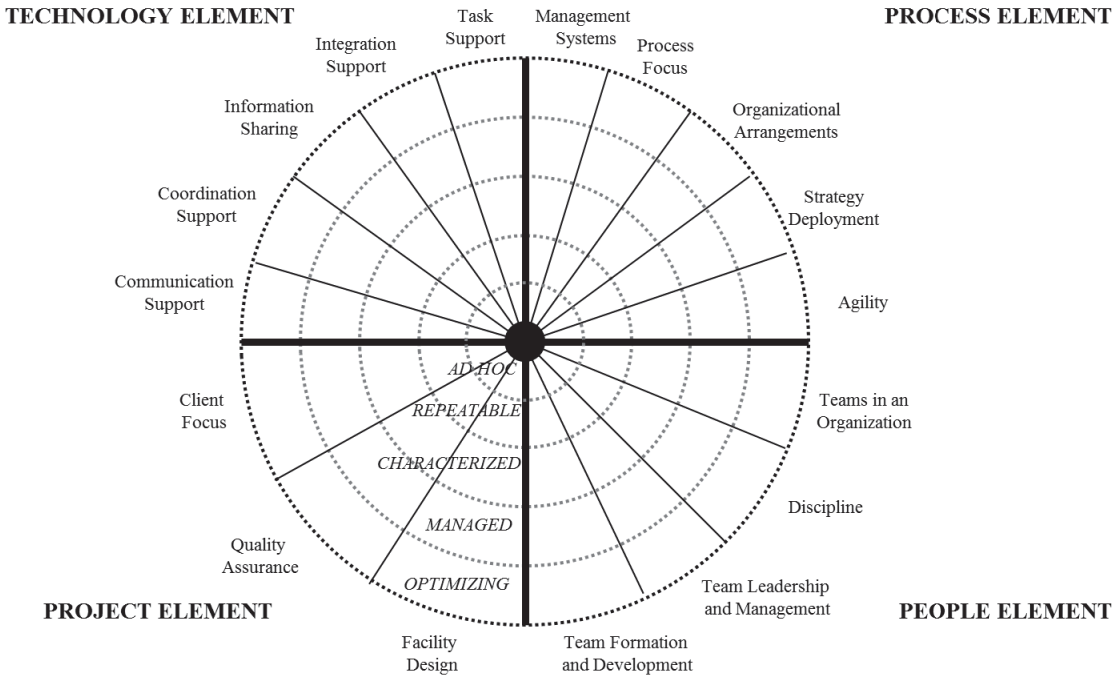

Figure 2-2 BEACON model (Khalfan et al., 2005)

Table 2-1 BEACON model maturity levels (Khalfan et al., 2005)

Maturity level	Description
Ad-hoc	This level is characterized by ill-defined procedures and controls, and by confused and disordered teams that do not understand their assignment or how to operate effectively. Informal interaction with the client is observed, management of the project development process I not applied consistently in projects, and modern tools and technology are not used consistently.
Repeatable	Standard methods and practices are used for monitoring the project development process, requirements changes, cost estimation, etc. The process is repeatable. There are barriers to communicate within the project development team. Interaction with the client is structured but it is only at the inception of the project. Minimal use of computer and computer-based tools.
Characterized	The project development process well characterized and reasonably well understood. A series of organizational and process improvements have been implemented. Teams may struggle and fall apart as conflicts are addressed but a team begins to respect individual differences. Most individuals are well aware of client´s requirements but client is not involved in the process. Moderate use of proven technology for increasing group effectiveness.
Managed	The project development process is not only characterized and understood but is also quantified, measured, and reasonable well controlled. Tools are used to control and manage the process. The uncertainty concerning the process outcome is reduced. Work is accomplished by the project development team and conflicts are addressed. Client is involved throughout the process. Appropriate utilization of available technology and computer-based tools.
Optimizing	A high degree of control is used over the project development process and there is a major focus on significantly and continually improving development operations. Team performance is regularly measured, and performance measures are continuously validated. Client is a part of project development team from inception and all project decisions are prioritized based on client´s needs. Optimal utilization of appropriate plant and technology and technology-mediated group work is observed

2.2 Applicability of Integrated Concurrent Engineering to Construction Projects

The construction sector, as mentioned previously, has a very particular market structure that does not facilitate the collaboration between the parts involved in different stages of the project. This is one of the main reasons that Integrated Concurrent Engineering methodology has not been widely researched and/or spread within the industry.

Given the broad spectra of the concept of Integrated Concurrent Engineering, it falls within several of the improvement categories mentioned in Chapter 2.1: it can give a framework that aims to rethink the design, engineering and procurement process as well as it promotes effective and smarter means of communication that can be achieved by digital transformation.

Only a few construction projects have formally reported the use ICE methodology, see i.e. the project Stigbergsgaraget in Stockholm (Öhr Hellman & Johansson, 2015). The output of this project is that involvement of the different parts and effective communications have been key aspects that led to budget decrease and reduction of the construction time. However, according to Khalfan et al. (2005), it is essential that previous to implementation of ICE methodology, a readiness assessment of the specific organization should be carried out.

Closely related to Integrated Concurrent Engineering is the term Virtual Design and Construction (VDC), which can be seen as a "tool" in the Integrated Concurrent Engineering" environment. VDC involves the use of integrated multidisciplinary performance models of design-construction projects to support explicit and public business objectives (Kunz and Fischer, 2012).

Having said that, it is clear that the implementation of an Integrated Concurrent Engineering standard framework in the construction sector could lead to large benefits for the industry. ICE methodology has the potential to make the construction projects less fragmented since the interests of all the stakeholders (Client, Designer and Contractor) are brought closer and their goal becomes common. The ultimate impact of the implementation of the ICE methodology is to increasing the quality of the final product as well as to reduce the construction time.

3 METHODOLOGY

The following subsections explain the philosophical and technical approaches that have been chosen for the development of this thesis. A general overview of the methodology followed during this study is shown in Figure 3.1 below.

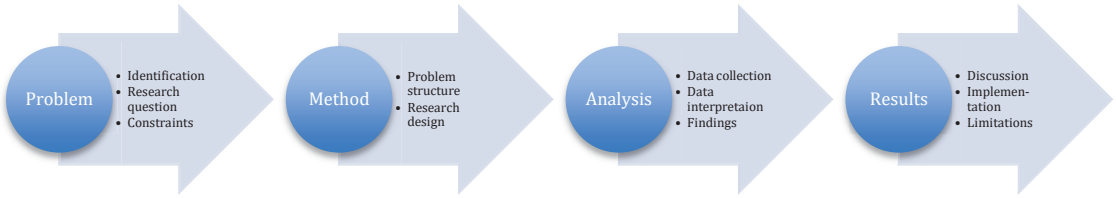

Figure 3-1 Overview of the general methodology for the development of the thesis

3.1 PROBLEM

As mentioned earlier in this thesis, the efficiency in the construction sector is one of the lowest among all the industries. Furthermore, digitalization capabilities are far from reaching its full potential in the construction industry.

Based on the initial problem statement and literature review, it seems that an approach through the concept Integrated Concurrent Engineering can give very valuable insights on how to improve the efficiency of the construction industry.

3.2 RESEARCH METHOD

Based on the problem description given in Chapter 3.1 as well as the initial literature review, the research study for this thesis can be seen as a somewhat unstructured problem, since the reasons for the inefficiency in the construction sector are not completely understood and/or have not been fully solved.

The method chosen for this study is a qualitative research approach due to the unstructured character of the problem of low productivity in the construction industry, in accordance to literature, e.g. Ghauri & Grønhaug (2010). A qualitative research implies that an exploratory approach will be used, which involves that new information is continuously collected and interpreted during the analysis phase in the research process. Therefore the collection and interpretation of data will be performed simultaneously, where the research questions and subtopics might need to be adapted to new conditions and/or constraints.

This approach implies that not all the available a priori information should be used with the main purpose of not having somewhat biased results, see Ghauri & Grønhaug (2010). The explanatory approach that is going to be used for this study gives certain flexibility to the research process rather than clear structure and an expected result.

3.3 Analysis

Qualitative research can be seen as an iterative process where new information is gathered continuously and might affect the main focus for some of the subtopics. This aspect differs as well from quantitative analysis since the need of information is well defined in a sampling plan. That means that the qualitative approach will give more flexibility to the study.

The data collection is an important part of the research process in this study. Given the fact that a qualitative approach has been used, a great amount of theoretical data has been gathered though the literature review. In order to proceed with the analysis, the collected data has to be first carefully analyzed, with focus on identifying data that fulfils the constraints that have been defined in the problem identification phase.

Further data was obtained from previous experiences of Integrated Concurrent Engineering methods in real construction projects through interviews with project managers of infrastructure projects in Sweden. A total of two on-site interviews were conducted. The interviews were semi-structured with the intention of helping the author to identify the core ideas and experiences. The outline of the interviews is shown in Appendix 1.

Since ethical aspects are an important part of the research process, all the interviewees were informed, prior to the start of the interview, of the non-commercial character of the study along with its purpose. The next step is to filter out the data in order to avoid the problem. This subprocess will be the so-called reduction of data, which facilitates the researcher tasks in the next substeps in the analysis phase.

Once the data has been filtered out, the next subprocess is the data interpretation. In order to adequately interpret the data, it has to be first displayed in an appropriate way. The appropriate way of displaying the data means that valid assumptions have been included, and the quantity of data is enough. This step of displaying part of the collected data against certain assumptions can be seen as an iterative process that might include several trials in order for the researcher to be able to draw suitable and concise findings that answer the research question, see Miles and Huberman (1994).

Another important part in the analysis phase is validity. In order to assure the validity of the findings of the study, those need to be proven correct. This validation will be done through continuous quality assurance review against existing literature as well as feedback from experts in the field of Integrated Concurrent Engineering.

3.4 Results

The results of the thesis will include a procedure for implementation of Integrated Concurrent Engineering methodology, based on the findings from the previous phase “analysis”. When it comes to the accuracy of the result compared to the initial idea of the expected result, qualitative analysis has in general a lower agreement than quantitative analysis. The main reason for this is that qualitative analysis is chosen for research topics that have an unstructured solution, whereas quantitative analysis is chosen for topics where the problem is clearly understood and therefore the solution of the problem is somewhat expected.

There will also be included in this thesis, in a different chapter than the results, an example on how to implement the theoretical framework proposed in the results through a case study. This can be seen as validation of the achieved results, and will hopefully shed some light on how to practically apply the results of this thesis for future construction projects.

During the discussion phase, all the findings will be stated avoiding interests and biases of companies, governments, public figures or the researcher itself.

4 RESULTS

The results from this study are divided into the four main dimensions that Integrated Concurrent Engineering methodology can be implemented in most of the projects, which are Management and Organization, Communication, Technology and Innovation and Leadership.

In order to ensure the success of the implementation of the Integrated Concurrent Engineering methodology in a project, a strategy in each of the four aforementioned categories should be defined first. The strategies for each dimension should be based on a readiness assessment, which is described in subchapter 4.1.

4.1 READINESS ASSESSMENT

Prior to conduct the implementation of the Concurrent Engineering framework, it is advisable to conduct a readiness assessment in order to evaluate the difficulty of this task, according to literature. Furthermore, this assessment can give an indication on which figures and aspects are important to zero in on.

In this thesis, the author suggests the use of the readiness assessment tool BEACON model, with some minor modifications to match the focus in nowadays' construction projects. A picture of the modified BEACON model is shown below in Figure 4.1 (modified after Khalfan et al., 2005).

The readiness assessment should be performed by all "actors" involved in the project: Client, Designer and Constructor. This readiness assessment based on the modified BEACON model will obviously give different results for these three entities. Afterwards, optimal strategies for implementation of ICE methodology can be defined for each of the actors based on the obtained results.

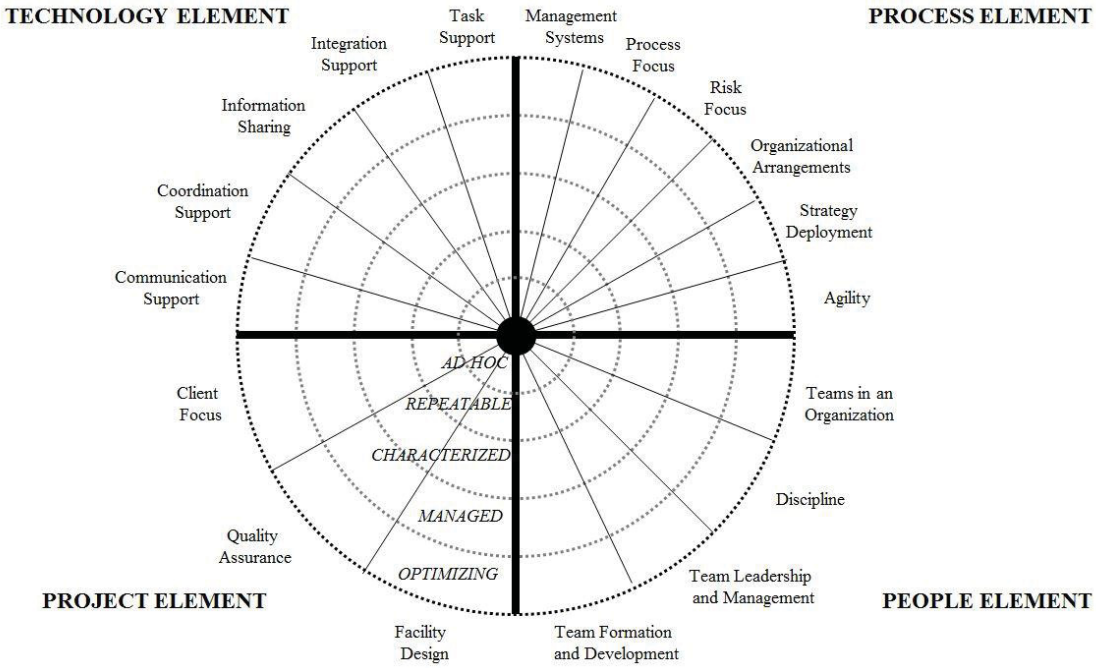

Figure 4-1 Modified BEACON model (modified after Khalfan et al., 2005)

4.2 MANAGEMENT AND ORGANIZATION

In order to enable an Integrated Concurrent Engineering approach, the organizational barriers and management oversight should be kept at a minimum in order to speed up the decision making process. In other words, agility and responsiveness of project members during the design phase of the project are crucial factors to achieve an efficient project organization.

However, in the construction industry, a common problem between Clients is to keep up with the design work produced by the Designer due to slow internal decision-making processes, according to experiences from project managers. In order to mitigate this risk, decision-making processes as well as responsibilities should be clearly defined in the early stages of a project. In addition to this, with the aim to facilitate the implementation of the ICE methodology, the decision-making processes should be kept at a reasonable level in the hierarchy scale – not all the decisions should be taken by the Project Sponsor; otherwise there is a high probability that Concurrent Engineering will not work.

A standard project organization of a construction project during design phase is depicted in Figure 4.2. In order to facilitate the implementation of the ICE methodology, the author advises to divide the project organization in Work Breakdown Structures ("Project Team" Rectangles in the figure). Interviewees stated that the most important aspects to have into consideration when forming the WBS' are that there should be a clear goal, the groups should have adequate number of people (7-10 people) and to avoid the so-called "multitasking".

Construction projects are well known for having a wide range of technical areas to cover, for example road works, foundation works, electrical works, HVAC works, etc. By having a rational WBS structure, project teams will focus in tasks related to the competence of the project team members.

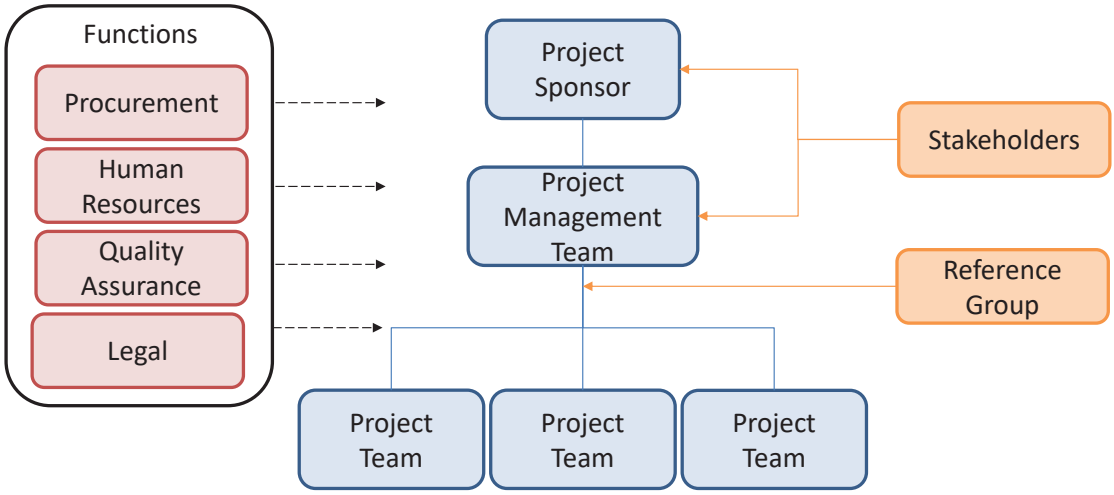

Figure 4-2 Standard organization of a construction project during design phase

4.3 COMMUNICATION

There are two main dimensions of communicational aspects that are crucial for completing the project on schedule and adjusted to the budget following the ICE methodology, according to the author: Project meetings and communication platform. Project meetings are important since a large part of the time is invested on those, and the communication platform is important since it is the channel. Advice on project meetings' structure and communication platform for construction projects is given in the following subchapters.

4.3.1 PROJECT MEETINGS

There are many different types of meetings: work meeting, decision meeting, review meeting, information meeting, etc. In order to maintain a high efficiency in the construction project, ICE meetings should combine several of the meeting forms, but with a clear agenda on which topics are to discuss and which topics are to decide.

According to the results of the interviews with project managers, ICE meetings should be held on a weekly basis, and one full working-day should be devoted for this type of meetings. Furthermore, there are clear advantages if ICE meetings are held where all the participants are at the same geographical location in order to reduce communicational barriers.

When it comes to meeting participants, it is necessary that ICE meetings include representatives of the Client and the Designer, and the Contractor. In addition, it is highly recommended that at least one person of the Client project management team (with possibility to cover all the decisions that have to be taken) participates in these meetings in order to avoid Client internal bottlenecks in the decision process, according to interviewees. Furthermore all the technical disciplines in the project should be present in the ICE meeting. An adequate number of meeting participants according to experiences of the project managers is between 10 and 15 people, but this depends of course on the scope of the project.

The agenda and content of the ICE meetings should be flexible in order to allow covering different topics each week depending on the progress of the work. These meetings should have a specific structure that facilitates the work between the different actors and technical disciplines in order to avoid get stuck in some specific detailed questions. Based on the performed interviews, the author suggests below an agenda for an ICE meeting in a construction project (see Table 4.1).

Table 4-1 Suggested agenda in ICE meetings in a generic construction project

	Time	Topic	Description/Rationale
1	15 min	Summary of previous meeting and decisions made	It is important to keep track of all the decisions made throughout the process and the moment that they were taken.
2	60 min	Today's work	Go through all the participants and answer the questions: - What do I need to keep up with my work? - What is it expected from me so others can keep up with their work?
3	30 min	Construction model	An interactive go-through the 3D construction model in several screens, so all participants are aware visually. Changes in the model could be done directly when all participants agree.
4	180 min	Own work	Each project member uses this time to work with own tasks, but will be available for others.
5	15-30 min	Risks	Go through risks that have been identified, assessment and possible solutions (mitigation or remediation).
6	30 min	Time schedule	An interactive go-through the time schedule, where all participants answer the following questions: - What do I need, from whom and when do I need it? - What will I deliver and when will I deliver it?
7	30 min	Summary of today's meeting and the decisions made	Since ICE meeting are very intense and demanding, it is important to keep track of all the decisions made throughout the day. Work assumptions till the next meeting should be very clear
8	15 min	Other matters	There always should be some time set aside for discussing other matters that can affect the progress of the project.
9	5 min	Time and place for the next meeting	This is a standard way to finish a meeting.

4.3.2 COMMUNICATION PLATFORM

Technology advances and digitalization trends in nowadays' projects have driven forward the development of the so-called project portals (also called project workspace). More and more projects are using this kind of solutions, especially middle to large size projects. The main goal of a project portal is to act as a communication platform that facilitates collaboration between different project members by gathering and exchanging documents (for example reports, plans, drawings, etc.).

The key aspect of the project portal is how the project information is organized, which basically means who has access to which information. These two questions have already been decided / answered in the communication plan, so the project portal has to mirror these responses by filtering the information in an optimal way for each of the project members.

An advantage of project portals is that project members in different locations are able to collaborate with each other in an easy and transparent way. Other interesting features of project portals are that they are cloud based services, and that they are available on several platforms (PC, tablets and smartphones) that also offer traceability.

When it comes to collaboration in an easy and transparent way between Client, Designer and Contractor, a common feature is to have a log with Question-Answer, where all the three actors can state "public" questions to the others. By doing this, the interested project members (tagged by categories, for instance) can have access to the information right away.

The concept of traceability in the construction sector does not differ much from the general definition of traceability: the degree to which it is possible to get hold of information of interest for all information entities at a given point. In a construction project, it is important that there is access for all the members to the so-called decision log where all decisions that affect the project have been summarized.

4.4 TECHNOLOGY AND INNOVATION

One of the pillars of ICE methodology in construction projects is that the 3D model of the construction is the main focus most of the time, according to interviews. This can only be achieved if the so-called Building Information Modelling (BIM) is used. BIM means that every single object in the model includes some kind of information, for instance the name of the provider of a specific door, the exact time that it will be placed or its cost. With all this information available, the task of the cost-controller and designers of different technical disciplines becomes much easier, due to the collaborative approach. Another feature of BIM is that models allow the project schedule to be implemented, resulting in a so-called 4D-model. 4D-models allow Client, Designer and Constructor to easily visualize the advance of the construction project and identify possible conflicts between technical disciplines.

According to the author, in order to ensure that BIM methodology can be applied effectively to the construction project, there should be routines and processes in place that describe the working methodology, usually established by the Client. In addition to that, it is important that all the project members are aware and feel comfortable to work with the technological tools that are going to be used (i.e. software programs), as well as eventual compatibility issues should be detected and solve as soon as possible. In order to improve this, short courses and workshops can be helpful.

Along with BIM, another technological advance that can be observed in the construction industry during the design phase is the use of the Virtual Reality (VR), which allows users to "go around" the model with the help of 3D glasses and movement sensors. On the other hand, Augmented Reality (AG), the use of drones as well as the standardization of tablets and construction mobile

Apps are technological advances that can be observed during the construction phase. Tablets and mobile construction Apps filled with 3D drawings at the construction site have facilitated the understanding of complicated drawings and the communication between workers of different technical disciplines. Augmented Reality is basically software that allows data and images to be overlaid onto physical spaces, so site workers can visualize drawings and plans in the real space.

As stated in the literature review, a flexible organization will enhance employees' innovative behaviour. This means that, by applying the principles described in Chapter 4.2 when creating organizational charts, project innovation will be boosted.

4.5 LEADERSHIP

The type of leadership suggested for construction projects should be based in the specific needs of each unique project and other situational factors (like project manager skills, project members' skills, personalities, etc.). However, the author suggests a leadership approach that can be adapted to the vast majority of construction projects, which is a mix of transformational and participative-consultative leadership.

There are a number of studies that have proven the positive influence of transformational leadership on organizational performance, see e.g. García-Morales *et al.* (2012). Achievement of project goals and becoming a transformational leader can be speeded up with skill development prioritisation, according to Sunindijo (2012). This prioritisation consists of: (i) building up some base skills about the self, (ii) work on observational skills, and (iii) develop social skills.

Participative leadership means that decision-making process goes through the group members, and is based on management openness (Dubrin, 2013). Management openness is something that is quite common in Sweden, where strive for consensus is the focus of many meetings or negotiations, as explained by Lubin (2014). Participative leadership will influence positively in most cases the performance of project members, whereas some authority has to remain in the leader in order to keep the efficiency in the decision-making process in a good level (consultative approach).

The project manager of a construction project should develop a leadership action plan that enhances and fully exploits the benefits of the ICE methodology. The author suggests zeroing in on the following aspects:

- Focus on relationship-oriented attitudes and behaviours. This task should include development of charisma, by for example enhancing communication skills.
- Improve some of the task-related attitudes, especially the ones related to adaptability to the situation as well as optimizing the decision-making process (having always insights into risk management).
- Try to figure out the characteristics of the team's members, with the goals of developing a contingency theory and to adapt the leadership style to the relevant factors.
- Perform and practice influence tactics (always from an ethical point of view) in order to exert influence in the group. This process might as well include figuring out which tactics are more efficient and which tactics are expected from a leader by the group members.

4.6 SUMMARY

The developed theoretical framework presented in Chapters 4.1 to 4.5 can be seen as a tool for the Project Management Team in construction projects. The guidelines and recommendations can be identified by the acronym RAFMOCOTI, which stands for **R**eadiness **A**ssessment, **F**lexible **M**anagement Strategy and **O**rganization, Collaborative **Co**mmunication, **T**echnology and **I**nnovation. The following list gives a short summary of these recommendations:

1. Perform a **R**eadiness **A**ssessment based on the modified BEACON model. Based on the results, define a strategy of the most critical aspects that should be addressed to facilitate the implementation of ICE in the construction project.
2. Design a **F**lexible **M**anagement strategy and try to reduce **O**rganizational barriers, taking into account the specific requirements for the unique construction project. Processes, organizational charts and decision paths should be the focus during this step.
3. Design a **Co**mmunication plan that focuses on a collaborative approach between Client, Designer and Contractor. Strategy for project meetings and exchange of information through a project portal should be the main topics to focus in this step.
4. Decide which **T**echnologies should be used during the design phase of the project, while assuring that all members understand those and can effectively work with those. The 3D-model should be one of the central pillars of the design work. Formation of the project members by short courses and workshops can be a helpful tool to increase their efficiency.
5. The benefits of implementing technological **I**nnovation during the construction phase should be taken into account, such as mobile construction apps and platform to facilitate site workers' job and their safety.

5 CASE STUDY – IMPLEMENTATION OF ICE METHODOLOGY

5.1 INTRODUCTION

The case study constitutes a practical example of the implementation of the ICE methodology in a real construction project. The aim of this chapter is to verify the results of this thesis as well as to give some guidance and insights to project managers on how to apply the principles of Integrated Concurrent Engineering.

The chosen project is the "Detailed Design of the underground Spent Fuel Repository in Forsmark". In this chapter, some background is given first about the Client that is responsible for the project, followed by a readiness assessment and advice on how the strategies for the three of the four dimensions (Management and Organization, Communication, Technology and Innovation) should be. Leadership strategies are not project related in this case; therefore the general guidelines in chapter 4.5 can be followed.

5.2 BACKGROUND ABOUT SKB

The Swedish Nuclear Waste Management Company (SKB) was founded in 1970s and is owned by the nuclear power companies, which are enforced per law to deal with the Swedish nuclear waste and pay for it. The main task of SKB is to deal with all the radioactive waste from nuclear power plants in Sweden in a safe way. SKB has been developing a method for dealing and isolating the nuclear waste for over 100 000 years.

SKB is planning to build a repository for spent nuclear fuel at Söderviken close to the Forsmark nuclear power plant, in Östhammars Kommun (Sweden). The underground construction is planned to start in 2022 and is expected to last about ten years. Once the facility is completed, the process of deposition of canisters will take place and is expected to last for about 40 years. The underground facility, once completed, will have more than 60 kilometers of tunnels and rock caverns, and it's planned to be fully developed some time in the 2080s.

The design and construction of a nuclear waste repository is full of challenges (called from now on Spent Fuel Repository), some of them related to technical aspects and others related to managerial aspects. Technical challenges have been studied and dealt since 1970s through the core business of SKB, research. The research approach has been suitable for the pre-feasibility and safety assessment phases, but when it comes to process and project related aspects, new approaches could be advantageous during the design and construction phase.

SKB has conducted so far the system design of the underground facility (see Figure 5.1) and June 2019 sent out an invitation to tender for the detailed design of the underground facility to qualified suppliers. The construction of the facility will be a build-only contract, where designers participate in the tendering process. Tenders will be evaluated by SKB early autumn 2019, and after that, the design phase will commence.

Figure 5-1 Surface and underground facilities of the Spent Fuel Repository in Forsmark

5.3 Readiness Assessment of SKB

In order to assess the readiness level of SKB as a client to implement the ICE methodology, a questionnaire was send to randomly selected SKB project coordinators, project managers and staff members that actively work in the project of the Spent Fuel Repository in Forsmark. By actively working is meant that project members spent more than 50 % of their working hours in this project.

The questionnaire was sent out to 30 project members, and a total amount of 9 project members responded within the deadline. The questionnaire was sent out in English (although the main language used in the project is Swedish) and is shown in appendix 2.

The results to the question "rank the four key elements (process, project, people, and technology) from the most important to the least important" are shown in graph form below. Figure 5.2 shows the most important and least important elements for all the participants, where the vertical axis represents the number of respondents. The most and least important elements for project members are Technology and People factors. It is worth to mention that 55% of respondents answered the combined option that People and Technology were the most and least important factors. This indicates that project members see certain incompatibility in these two aspects: it's either one or the other, never both.

Figure 5.3 shows the elements ranked as most important (1st) and neutral positive (2nd), and as previously, the vertical axis represents the number of respondents. The graph reveals that Process factor is characterized in the "positive" side by almost 70 % of project members. In comparison, the other factors are characterized in the "positive" side by 45 % of project members.

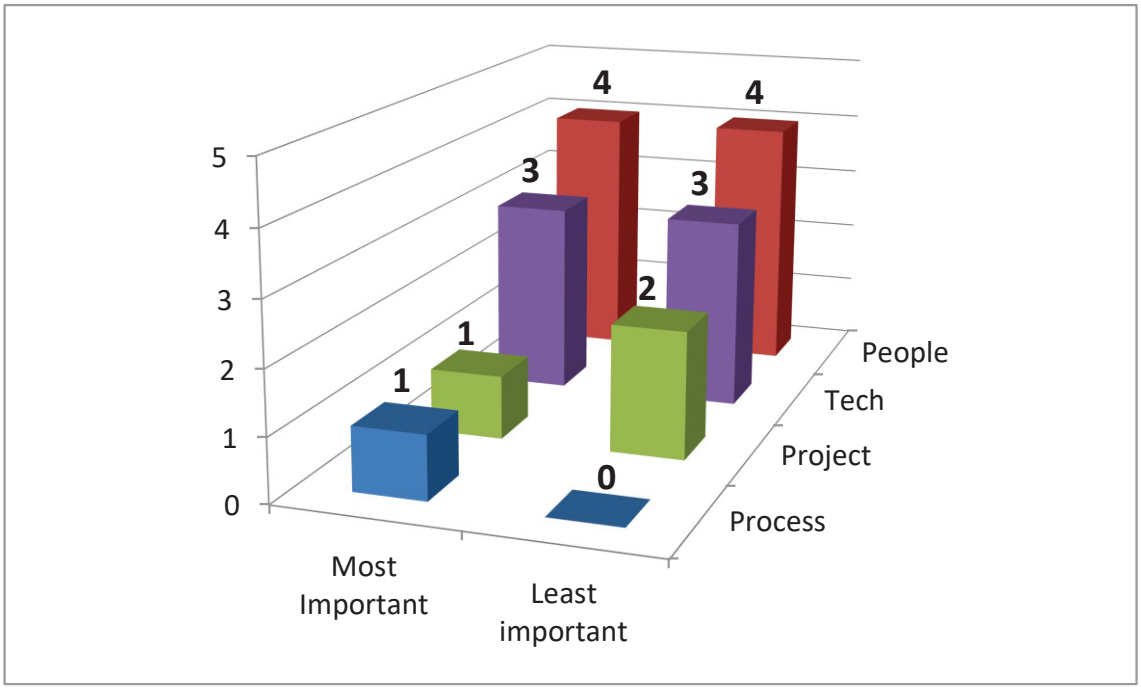

Figure 5-2 "Most Important" and "Least Important" key elements

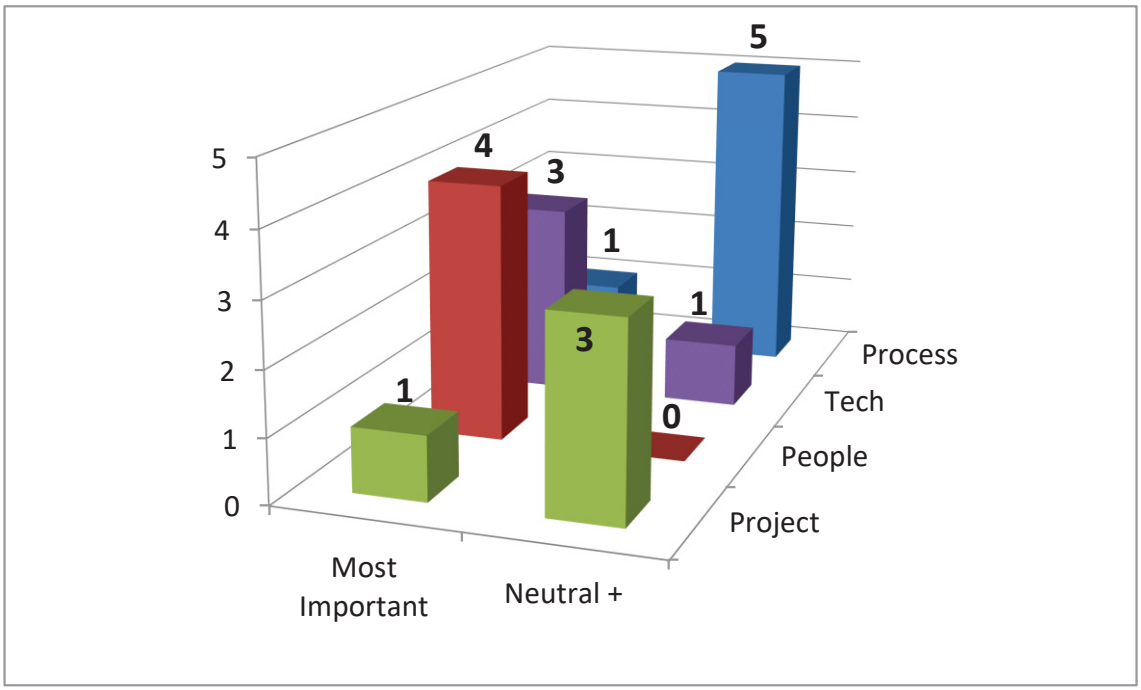

Figure 5-3 "Most Important" and "Neutral positive" key elements

The results from the second part of the questionnaire (Section A to D) are shown in graphical form according to the modified-BEACON model in Appendix 3. Here it is shown instead a summary of the evaluation of these results. As in previous graphs, the vertical axis shows the number of respondents.

The elements that SKB performs better, according to project members, are management systems, team formation & development, and risk focus, see Figure 5.4. When it comes to management systems (traceability), as well as risk focus, these two aspects are an extremely important part of everyday work at SKB given the fact of the business line is conducting (nuclear waste management). It also makes sense that one of the best valued aspects is team formation and development, since SKB's personnel is in general highly qualified.

The elements that SKB performs worse, according to the results from the interviews are strategy deployment and agility, see Figure 5.5. These two factors fall within the process element, and project members clearly pinpoints that, according to their opinion, processes could be much more agile and decision making could be done more effectively.

The results show clearly that the adoption of an ICE methodology with the benefits of quick decision making and agile processes could improve SKB's performance. However, it is important to maintain the good practices regarding management systems and risk management methodologies that have been followed so far. Therefore, it is recommended to implement the ICE methodology focusing on agile strategies but also finding a balance where all decisions are well documented and traceable.

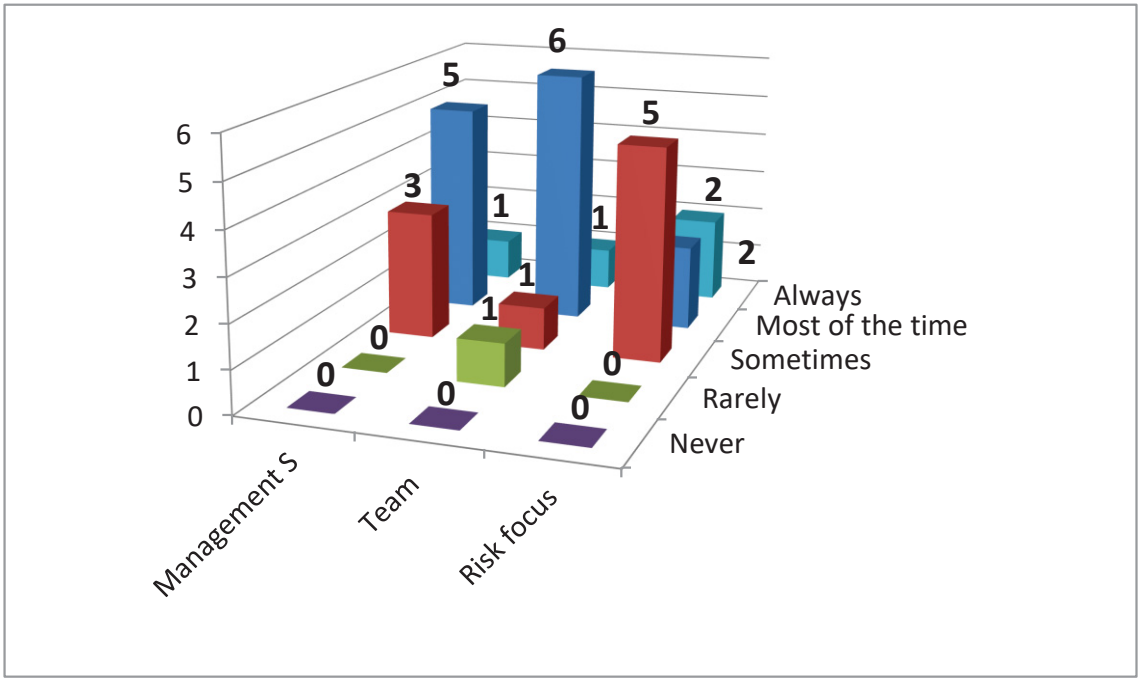

Figure 5-4 Frequencies of occurrence for the three aspects that SKB is performing best

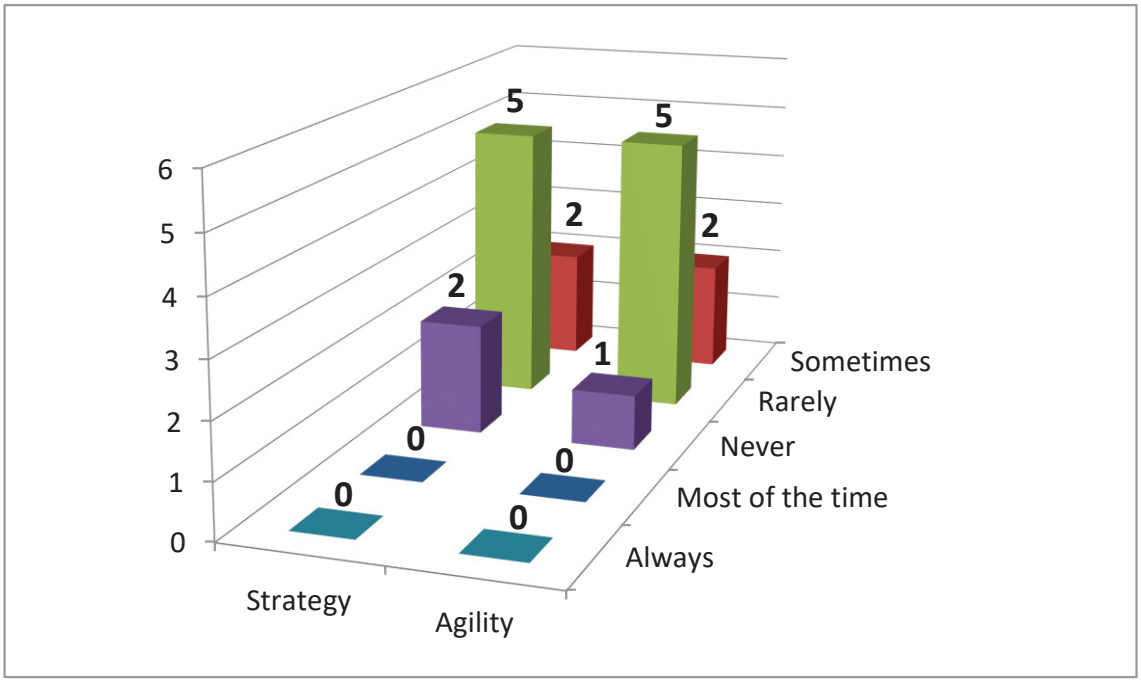

Figure 5-5 Frequencies of occurrence for the two aspects that SKB is performing worst

5.4 Management and Organization

SKB's organization structure for the design phase of the Spent Fuel Repository in Forsmark is depicted in Figure 5.6. It is a quite common practice that Clients in the construction sector have an internal-line organization and a project organization. In SKB's case, the internal-line organization is the natural provider of resources for both the Technical Office and the Performance Coordinating Office (see functions in red squares). The project organization (functions in blue rectangles) is usually less connected to internal routines and procedures of the client, since their main goal is to push the project forward.

As it has been mentioned before, one of the key aspects of ICE methodology is that project members possess the ability to take decisions actively. A common problem between Clients is to keep up with the design work produced by the Designer due to internal decision-making processes. In this sense, it is recommended that decision-making processes as well as responsibilities are clearly defined in an early stage of the project.

In order to facilitate the implementation of the ICE methodology, the decision-making processes should be kept at a reasonable level in the hierarchy; otherwise there is a great risk that Concurrent Engineering will not work. In SKB's case, probably the best alternative is allowing members of the Project Management Team actively participate in meetings with the Designer, so decisions are taken on the spot.

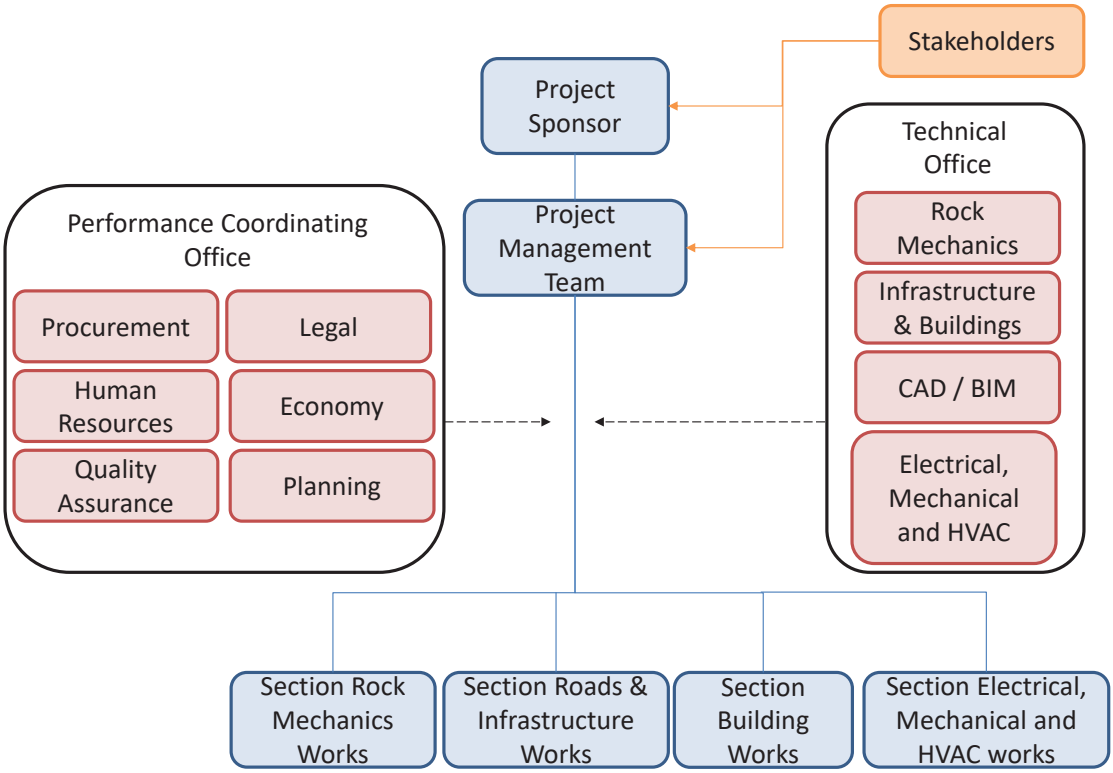

Figure 5-6 SKB´s project organization for the Design phase of the project

5.5 COMMUNICATION

As mentioned earlier in this thesis, the structure of the meetings should be quite flexible in order to be able to set focus to the prioritized questions first. A suggested agenda is shown in Table 5.1 below.

The roles and titles of the participants of the ICE meeting is something that should be kept as flexible as possible in order to set the right focus in the right questions during the course of the project. However, there are some key participants, who are the ones that have decision-making authority and their presence should be prioritized. A scheme of the roles that should be attending the ICE meetings for the underground design is shown in Table 5.2, where darker cell color means higher importance in the decision-making process, and therefore the more important is the presence of these roles.

Table 5-1 Suggested agenda in ICE meetings in the project of the Spent Fuel Repository

Nr.	Time	Topic
1	15 min	Summary of previous meeting and decisions made
2	60 min	Today's work and expectations
3	30 min	3D model go-through
4	180 min	Own work
5	15-30 min	Risks
6	30 min	Time schedule and need of information
7	30 min	Summary of today's meeting and the decisions made
8	15 min	Other matters
9	5 min	Time and place for the next meeting

Table 5-2 Suggested participants in ICE meetings in the project of the Spent Fuel Repository

Client	Designer
Project Manager of the Spent Fuel Repository	Project Manager
Project Manager Underground Facility	Project Coordinator
Project Coordinator Underground Facility	Designer Rock Mechanics A
Technical Manager Rock Mechanics	Designer Rock Mechanics B
Project Coordinator Rock Mechanics A	Designer Technical discipline X
Project Coordinator Electrical works	Designer Technical discipline X
Project Coordinator Mechanical works	Designer Rock Mechanics C
Project Coordinator HVAC works	Designer Technical discipline X
Project Coordinator Roads and infrastructure works	Designer Technical discipline X

SKB has been taking steps into the digitalization trends, which has led to the decision that the communication platform for the project will be the project portal Interaxo. The project portal has already been tried for smaller projects by most of the project members, which has allowed them to become familiar with the interface and the work flows, as well as its capabilities. It is important though that the Designer team receives some hands-on training on the project portal so its full potential can be achieved in order to maximize communication efficiency.

5.6 TECHNOLOGY AND INNOVATION

Work in according to BIM methodology in SKB is regulated by a routine that has been developed internally during the last years by monitoring other players in the infrastructure industry. However, the so-called 4D-modelling has not been implemented yet in any of the models and probably it is not going to be full compatible during the project phase since routines and processes are missing.

The knowledge of BIM methodology of project members from different technical disciplines has increased during the last years, basically through software training courses. This initiative creates positive conditions for applying the BIM methodology.

When it comes to innovation, the many years of research have given results. During tunneling works, one of the key aspects in to characterize the rock mass in order to make a decision on the quantity of rock support will be used (which ultimately has an impact on the project cost). The rock mass characterization will be performed by photogrammetry by an autonomous machine, ROCS, which reduces the time for characterization as well as increases the detail of the data. The next step is to connect this obtained data with the 3D model in order to continuously update the prognosis for rock mass quality.

6 CONCLUDING REMARKS AND FUTURE RESEARCH

6.1 SUMMARY AND DISCUSSION

The main goal of this thesis is to improve the productivity in construction projects. As it is mentioned throughout objectives and research scope of the thesis, this productivity increase in the construction industry could be achieved by applying the principles of the Integrated Concurrent Engineering methodology and allowing a more collaborative approach between Client, Designer and Contractor.

The author has therefore given a theoretical framework that covers process, technology, project and people aspects in a construction project to facilitate the implementation of the Integrated Concurrent Engineering methodology. The developed framework can be seen as a tool for project managers in construction projects and identified by the acronym RAFMOCOTI, which stands for **R**eadiness **A**ssessment, **F**lexible **M**anagement Strategy and **O**rganization, Collaborative **Co**mmunication, **T**echnology and **I**nnovation.

The thesis concludes with a case study on how implementation of Integrated Concurrent Engineering methodology could be performed in the project of Spent Fuel Repository in Forsmark (Sweden) by applying the theoretical framework presented in the results.

The implementation of the ICE principles is however a difficult task for the project manager, since the extra planning work could be seen as ineffective and costly by the higher management. Therefore it is important that the higher management is aware of the consequences of adopting the methodology and fully cooperates in the implementation process. Furthermore, project members need to have specific personalities (open to dialog, problem-solving, etc.) to ensure the functional collaboration within the team in the fast pace environment that the ICE methodology requires.

Experiences from project managers that have worked with ICE methodology in construction projects reported that the main advantage of this work methodology is the shortened decision-making process in the Client's organization, which many times can doom a project to fail. They also pinpoint that there are some risk-taking activities when, for instance, not fully analyzed decisions are made, since this can make necessary to go back and revisit the assumptions that were made.

It is however necessary to pinpoint that the framework implementation of Integrated Concurrent Engineering methodology presented in this thesis is based on infrastructure construction projects in Sweden. Implementation of ICE methodology in other countries can be a more difficult task due to country-specific cultural aspects that have not been taking into account during this research.

The collaborative approach that ICE methodology demands is usually facilitated in large turnkey projects since the so-called Joint Ventures are formed with Designer and Contractor parties. However, in the so-called build-only contracts, designers (representing the Client) have to provide all the material for the Contractor to execute the construction works. This means that implementation of the ICE methodology in build-only contracts is more challenging just because of the nature of the contract.

6.2 Further Research

As mentioned previously, the collaborative approach between Client, Contractor and Designer that Integrated Concurrent Engineering methodology requires to achieve its full potential makes the most suited contractual form the so-called turnkey contract. A topic that can be further researched is how a collaborative approach should be specified in the turnkey contracts to ensure an effective overall construction process, or how to integrate this approach in build-only contracts.

The so-called Early Contractor Involvement is a project delivery approach entering the Swedish market during the last years that can be related to the collaborative approach that the construction sector urges. Therefore, further research could focus on how to make these types of contracts more beneficial for Clients and Contractors, for instance by looking at the contractual terms or the actual measurable profits gained.

Finally, the research presented in this thesis is based on Swedish infrastructure projects. Further research could evaluate how these country-specific cultural aspects can influence the effectiveness of the collaborative approach implementation.

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APPENDIX 1 – INTERVIEW INTEGRATED CONCURRENT ENGINEERING

The interview started with a presentation of the interviewer and the scope of the study:

My name is Diego Lope Alvarez and I work as a Project Coordinator in the field of Rock Mechanics for the Nuclear Spent Fuel Management Company (SKB) in Sweden.

The study is a part of the research for my Master Thesis (MBA Program) in Blekinge Institute of Technology. The goal of the study is to find how productivity in the construction sector can be enhanced with the help of the Integrated Concurrent Engineering methodology.

The interview would continue by the interviewer asking the interviewee to introduce him-/herself and by pinpointing that the content of the interview would be completely anonymous. Then, a set of open interview questions were discussed during the interview between the two participants. The interview questions are shown below:

1. What are your experiences in the Construction sector and specifically in ICE methodology?
2. Which are, according to your point of view, the key aspects for effectively implement the ICE methodology in a given project?
3. Which are, according to your point of view, the key requirements that have to be in place to implement ICE methodology effectively?
4. How are the so-called ICE meetings organized according to your experience?
5. Do you consider that the implementation of the ICE methodology in the projects that you have participated increased the overall effectivity of the project?

APPENDIX 2 – QUESTIONNAIRE READINESS ASSESSMENT

This appendix includes the email sent out to project members as well as the questionnaire to perform the readiness assessment.

Dear colleague,

As part of the research of my Master Thesis (MBA program), I am conducting a readiness assessment for the implementation of Integrated Concurrent Engineering in the project of the Spent Fuel Repository in Forsmark. The readiness assessment will be based on the BEACON model (Khalfan, 2001). For clarification, concurrent Engineering is defined as a methodology where the different stages for design and development of a product/project run simultaneously rather than consequently.

The BEACON model questionnaire attached to this email is based on a simplified version of the questionnaire available in Khalfan (2001). This questionnaire has been modified in order to cover nowadays aspects of a construction project. The questionnaire is addressed to project members of the project "Spent Fuel Repository in Forsmark", and comprises five sections. Section A covers the Process element, Section B focuses in the Project Element, Section C covers Technology aspects and Section D focuses on People aspects.

The assessment of the results will be strictly anonymous. The results of the readiness assessment will not include any names and will be available for participants upon request.

Thank you for your participation in this assessment, your help is very valuable. Please send your answers to diego.lopealvarez@skb.se before the 22th of August

Diego Lope Álvarez

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Before you start filling the questionnaire, please rank the four key elements (1 for the most important, 4 for the least important) from your organisation's point of view.

- Process ____
- People ____
- Project ____
- Technology ____

Please fill in the questionnaire below by selecting the most accurate number according to your judgement (by clicking on the square box). The numbers does not have to do with the previous ranking and represent the following occurrences:

1- Never
2- Rarely
3- Sometimes
4- Most of the time
5- Always

Score	**1**	**2**	**3**	**4**	**5**	**NA**
A. Process Element						
1. Management Systems The project development is documented, traceable, financially monitored, and easily accessible to project members.	☐	☐	☐	☐	☐	☐
2. Process Focus There is a project member or project team that focuses on improving the project processes'. The process development is documented, traceable, and easily accessible to project members and continuously evaluated and modified to optimise cost, quality and time.	☐	☐	☐	☐	☐	☐
3. Organizational arrangements The organizational structure is flexible and the organizational environment supports effective work performance and is flexible to individual's preferred manner of working.	☐	☐	☐	☐	☐	☐
4. Risk Focus Continuous risk assessment is performed, documented, traceable, easily accessible to project members, and it is followed up frequently	☐	☐	☐	☐	☐	☐
5. Strategy Deployment The strategy is consistent with organizational business policy and encourages resolving issues at the lowest appropriate level of the organization.	☐	☐	☐	☐	☐	☐
6. Agility The process development is flexible and adaptable to changes (in short time), that are documented, traceable easily accessible to project members.	☐	☐	☐	☐	☐	☐

Score	1	2	3	4	5	NA
B. Project Element						
1. Client Focus Client requirements are well understood and well-documented procedures for exchange of information, verification and validation are followed during project development. New client's conditions are implemented easily and quickly in the project.	☐	☐	☐	☐	☐	☐
2. Quality Assurance There are clear quality procedures and project standards which allow to ensure the quality of the final product. These procedures are accessible to all team members and applied on a regular basis during project development,	☐	☐	☐	☐	☐	☐
3. Facility Design There are preliminary designs and drawings of the facility (System level) and its design is flexible enough to address changes in the client's requirements.	☐	☐	☐	☐	☐	☐

Score	1	2	3	4	5	NA
C. Technology Element						
1. Task Support There is a project member or project team that focuses on improving project's CAD tools, and these are used in an effective way by project members.	☐	☐	☐	☐	☐	☐
2. Integration Support Software systems used in the project development are compatible with each other and allow effective collaboration between different technical disciplines.	☐	☐	☐	☐	☐	☐
3. Information Sharing There is a project platform that allows project members to find and share information easily and effectively. Project information, taken decisions, meeting minutes, etc. is documented in the project platform.	☐	☐	☐	☐	☐	☐
4. Coordination Support Project development is based on a central project model and is followed up continuously by specific adapted tools that allow to improve the project workflow.	☐	☐	☐	☐	☐	☐
5. Communication Support Communication between project members happens through a specific the project platform. Video tools and screen sharing application are effectively used in meetings.	☐	☐	☐	☐	☐	☐

Score	1	2	3	4	5	NA
D. People Element						
1. Team Formation and Development Project members are enthusiastic and skilled individuals who interact with each other continuously. Project members have continuous access to training courses to improve their technical skills.	☐	☐	☐	☐	☐	☐
2. Team Leadership and Management Project performance is monitored by project managers and is responsible for controlling, organising, directing and planning of the Project. Project managers have the authority to take most of the final decisions. Project members have good leadership skills.	☐	☐	☐	☐	☐	☐
3. Discipline Project members follow disciplinary rules set by the organization, which can be appreciated in meetings.	☐	☐	☐	☐	☐	☐
4. Teams in an organization The project is split in different disciplines (technical areas) that communicate and share information with each other in an effective way. Performance of the different teams is monitored.	☐	☐	☐	☐	☐	☐

APPENDIX 3 – RESULTS READINESS ASSESSMENT

In this appendix, plots of the Modified Beacon Model results are shown. Each graph corresponds to each one of the questionnaire respondents.

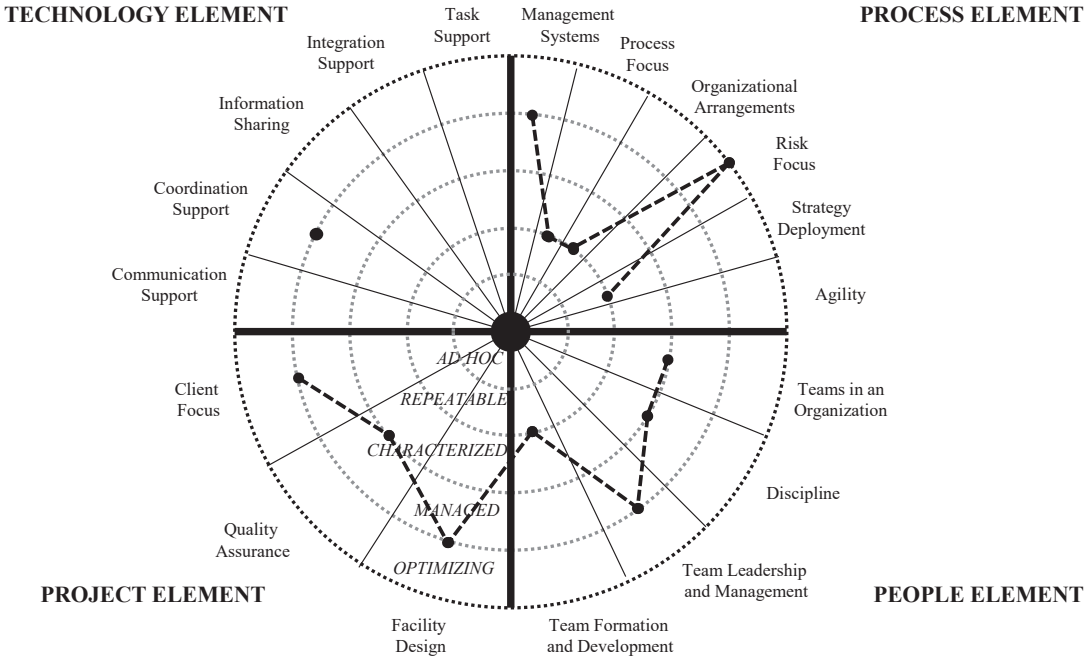

Figure C.1 Respondent #1

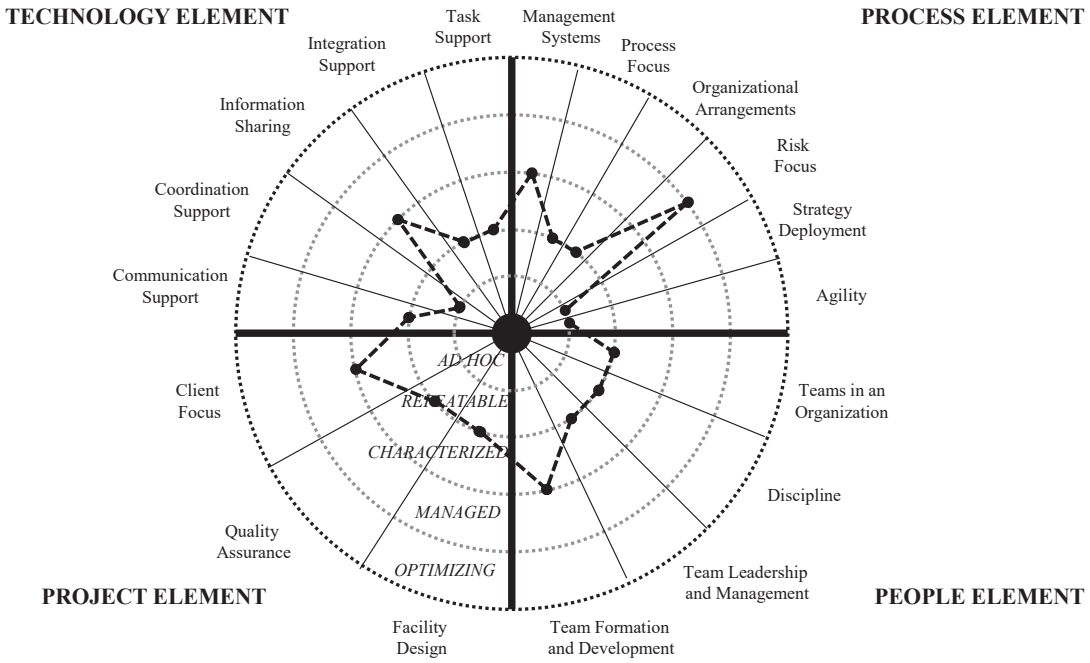

Figure C.2 Respondent # 2

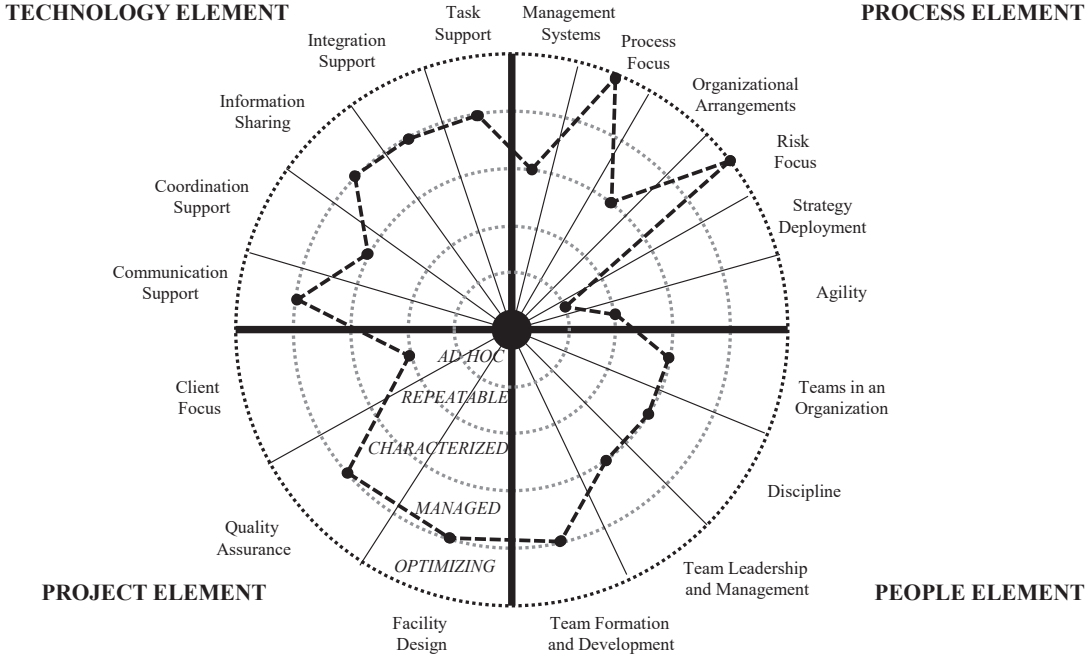

Figure C.3 Respondent # 3

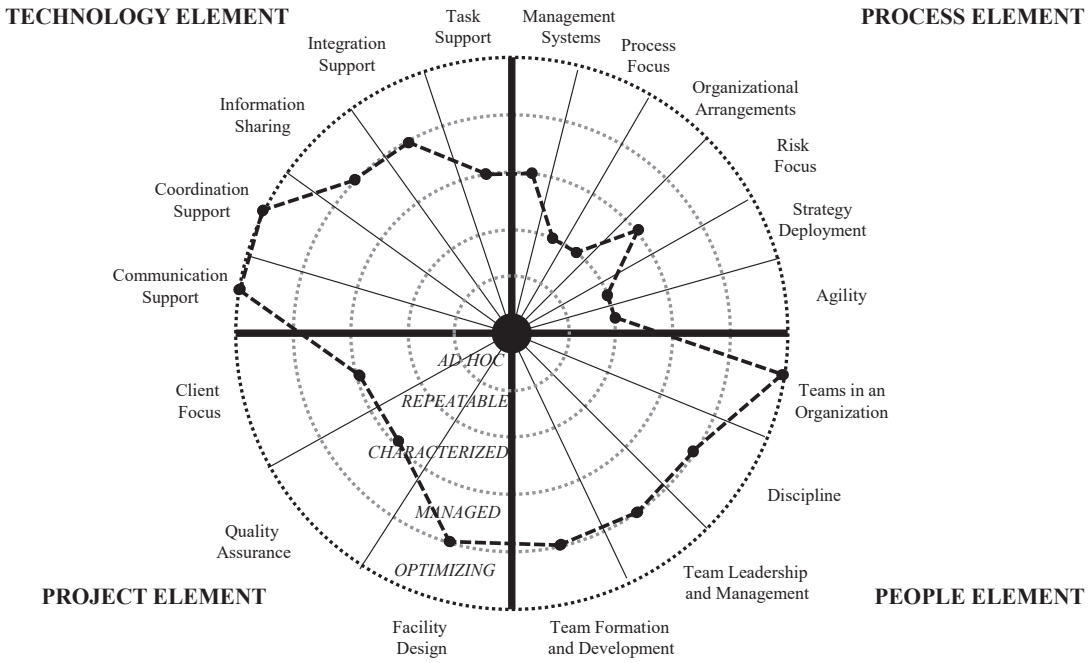

Figure C.4 Respondent #4

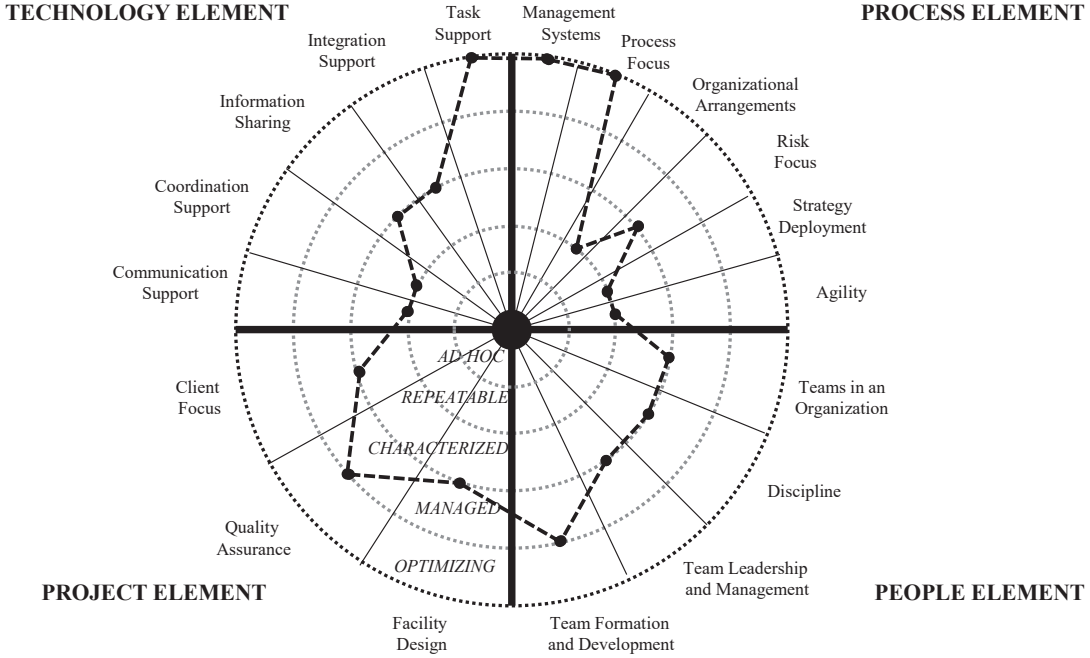

Figure C.5 Respondent #5

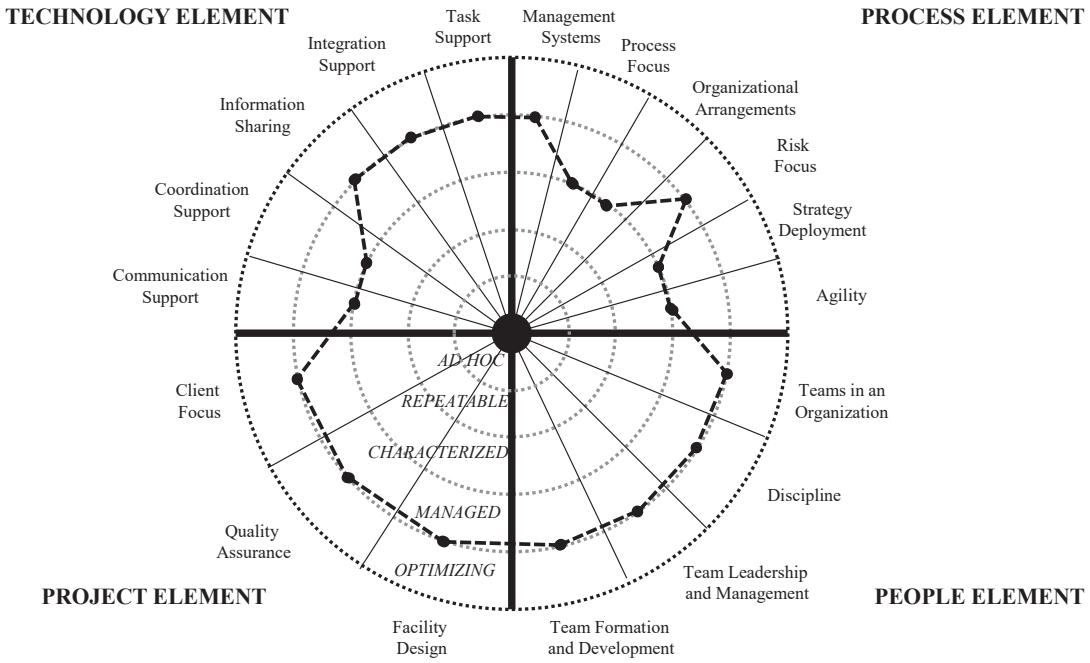

Figure C.6 Respondent #6

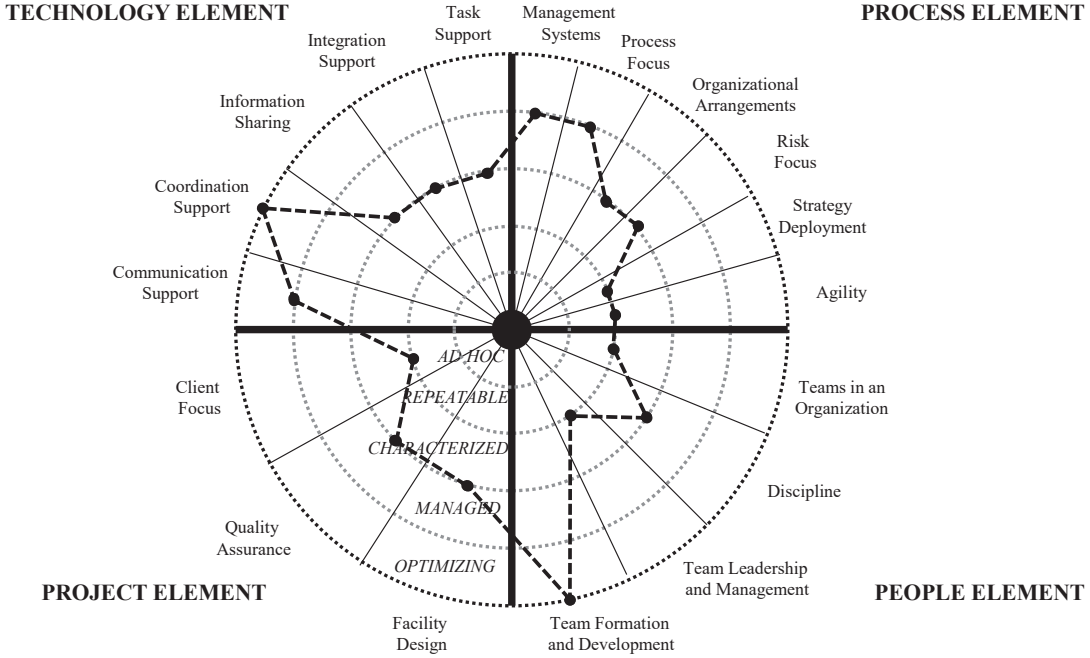

Figure C.7 Respondent #7

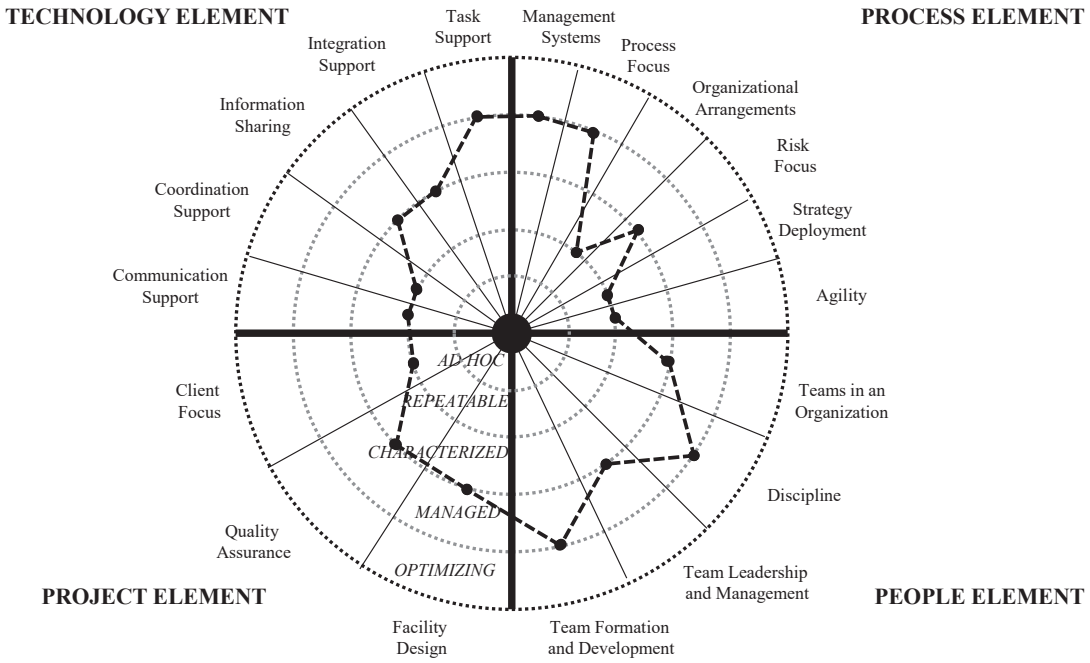

Figure C.8 Respondent #8

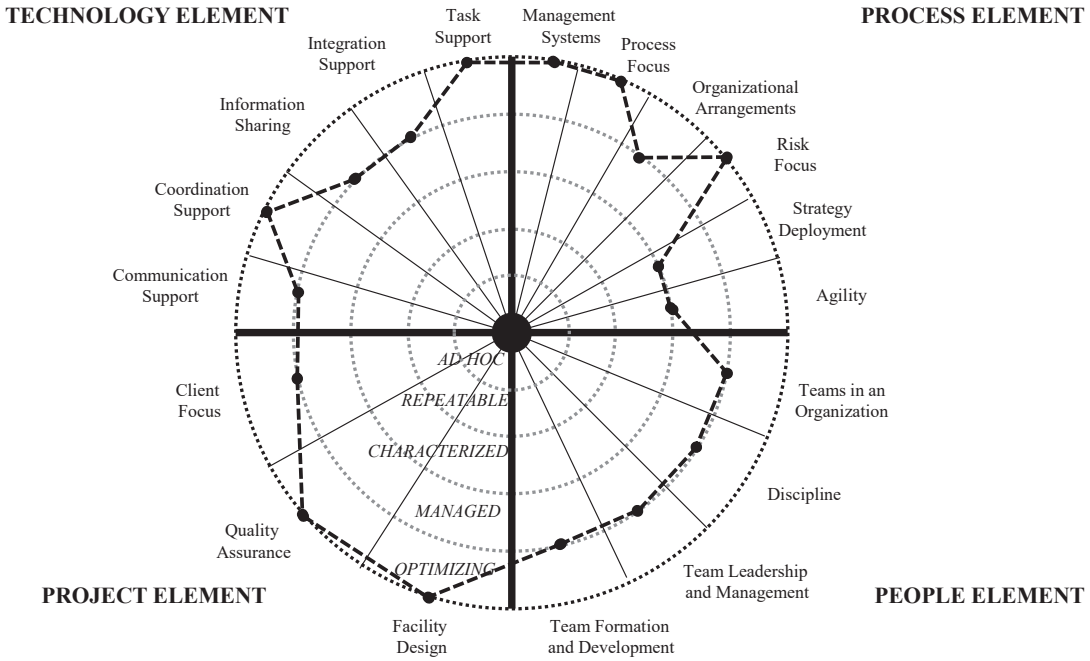

Figure C.9 Respondent #9