Optimizing Construction Knowledge Integration in Offshore Wind Projects

M.Sc. Thesis – Construction Management and Engineering | TU Delft

Harsh Soni | August 2019

TU Delft

Van Oord

Optimizing Construction Knowledge Integration in Offshore Wind Projects

Thesis Report (CME 2001)

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12th August 2019 | Delft

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Van Oord Marine ingenuity

Colophon

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Graduation internship Duration: 1st February 2019 to 19th August 2019
Kick-Off: 11th March 2019
1st Mid-term: 7th May 2019
2nd Mid-term: 6th June 2019
Greenlight: 19th July 2019
Thesis Defense: 19th August 2019

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Preface

*This is the **Master's thesis report** as a part of the M.Sc. program in **Construction Management and Engineering** at the Civil Engineering Faculty of **TU Delft, The Netherlands**. The thesis has been carried out in collaboration with **Van Oord**, a renowned marine construction and dredging company with a global outreach. The core objective is to optimize integration of construction knowledge in the project processes of 'Offshore Wind' projects and consequently add value to projects. The thesis has been completed in a period of 29 weeks, starting on the 1st of February, 2019.*

*This thesis has constructively gained from the inputs and involvement of various individuals throughout the process. First and foremost, I would like to thank **Ir. Jeroen Meijs** and **Ing. Nico Cats** for providing and eagerly supervising the research opportunity at **Van Oord**. It has been an absolute pleasure working with you and the company. I would further like to thank **Dr. Afshin J. Sohi** for his patient and enlightening academic inputs to the research and content of the report and being approachable throughout. Last but not the least, I would like to thank **Prof. Dr. Marcel Hertogh** and **Ir. Jeroen Hoving** for their expert insights which gave a direction to the research and refined it further.*

Finally and above all, I want to thank my parents who have been a constant source of motivation and energy throughout the master's program. Without their support and hard work, this master's program would not have been possible. In the end, I am also thankful to my brother, my sister-in-law and my dear friend Asmeeta for providing ever needed support during the entire master's program.

Wishing you a pleasant read!

“**Research is creating new knowledge**”

– Neil Armstrong

Executive Summary

Global demand for renewables is increasing day by day as people across the globe are getting more aware of climate change and contribution of non-renewables to it. One dominant source of energy, at least in Europe – Offshore wind, is the subject of this research. Offshore wind energy is set to quadruple in the next decade (19GW to 70GW). These are mega-projects with high lead times and costs reaching hundreds of millions of dollars. These projects are growing in technical and logistical complexity by the day as larger turbines and deeper waters are being pursued. Further, competitiveness of the market is increasing with more companies entering the sector and government's having moved towards zero-big (zero subsidy) tenders. Hence, there is a need to optimize project value.

A major part of the overall project costs in OW sector is spent on executing the 'Balance of Plant' items which includes components like offshore cable, offshore substation, foundation, installation etc. These can account for anywhere between 23% to 45% of the total project costs. Within these foundations are the costliest with over 40% of BoP cost. As 'Engineered to Order' (ETO) components, these are designed inhouse or externally and fabricated by specialized contractors. Initial research & exploratory interviews suggested that there is **limited integration of construction knowledge in realization of offshore wind projects which can also impact project value.** This is the primary problem being addressed through this research. Construction knowledge is the requisite knowledge needed for construction work to effectively and efficiently take place. For e.g., it can be added insights on the labor, materials, equipment, space, logistics and techniques required to build or the opportunities and challenges of executing various design details. When these insights are amalgamated (included) in the project processes across business entities, it is integration of construction knowledge. Hence the **research objective is to optimize the construction knowledge integration (CKI) in the project processes of offshore wind projects and consequently add value.** This was achieved through a set of sub-objectives which included exploring the concepts related to CKI , assessing the CKI regime in OW projects, findings the key issues hindering CKI and addressing these issues. The scope of this research is limited to the foundation component under BoP items in EPC OW projects from the perspective of the primary contractor, here Van Oord. To fulfil the main and sub-objectives mentioned above, data was collected through literature study and case studies of recently completed/ ongoing OW projects and then analyzed for devising recommendations. The research was conducted over a period of 6 months under the guidance of three supervisors from TU Delft and two supervisors from Van Oord.

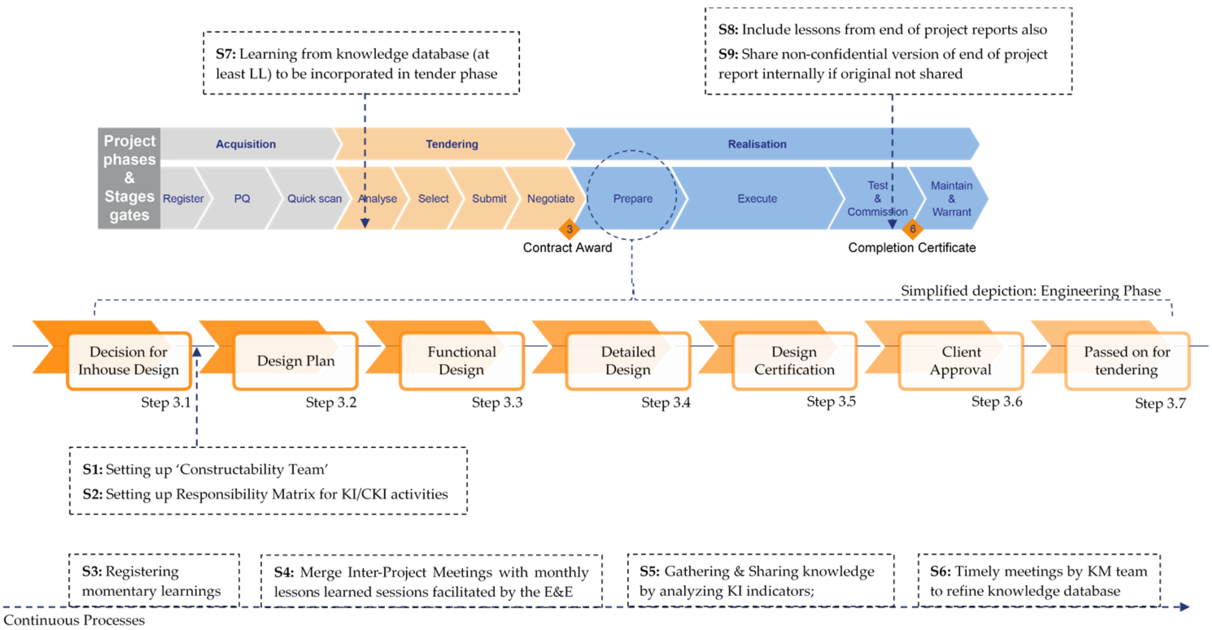
The first step after framing the research design was to study past researches and literature relevant to the subject. The literature study was done mainly to explore the concepts of and related to construction knowledge integration. Covered in detail in chapter 2, **the literature study provided key insights on the context, benefits, sources, obstacles and methods to achieve CKI.** The theoretical definition, which has already been covered in the previous paragraph, helps communicate the concept aptly to the reader. Knowledge integration is a cyclical process with 5 stages namely locating and accessing, capturing/storing, representing, sharing and creating new knowledge. These are the function that the system needs to fulfil to integrate knowledge. These steps also help assess the precise effect of an issue or a solution for KI. It was found that construction knowledge integration offers many benefits (detailed list in **Table 3**) like reduction in contract variations, quality improvements, cost and time reduction, increase in safety etc. and consequently, owner satisfaction. The study also highlights that construction knowledge should be integrated in early phases of the project for higher benefits and that construction knowledge can be gathered from varied sources like in-house experts, construction management consultants, contractors and even formalised knowledge database/ management systems. An elaborate list of generic obstacles was also compiled to increase awareness of issues that can come up during KI/CKI. One of the main contributions of literature study was provide exposure to various procedures that aid in KI. Hence, a comprehensive list of tools and processes was compiled like constructability/design reviews, knowledge database, hypermedia, responsibility matrix etc. This study provided a theoretical base for the empirical part of this research.

Since it is a practice oriented research, the dynamics and existing regime (system/ set of procedures) of construction knowledge integration had to be explored in the context of offshore wind projects. For this, case studies were pursued in which data was collected through interviews and supported by documented data. **The three chosen cases were Deutsche Bucht BoP, Deutsche Bucht MBF and Borselle 3&4. A total of 12 semi-structured interviews were carried out (4 per case) of around 60 minutes each. The subjects covered in the interviews were key project management challenges in OW projects, understandability of CKI,** tools/practices for KI/CKI used in the projects, issues faced, positive measures in place for KI/CKI, suggestions for improvement, KI indicators and impact on value. The key PM challenges stated by the respondents were time constraints and managing extensive number of project participants, communication, interfaces and information. All the respondents aligned with the concept of CKI and ascertained its need in OW projects. A total of 15 different tools or practices were found on combing the all responses on this subject. However the most commonly stated tool or practices in use are lessons learned register/ sessions, inputs from inhouse experts and progress/design reviews. Similarly, the list of issues was compiled in which the most commonly stated issues are lessons learned register being inconvenient and unstructured, difficult to retrieve knowledge, less inhouse experts for fabrication, quality management etc., high time constraints (note: same as 1 of key PM challenges) and no formal work protocol for KI/CKI. Even with some issues, the respondents were positive about increasing focus on lessons learned sessions and developments in the register, existence of standard templates, 'ROC' drills and physical mock-ups during execution and the organic nature of communication within the company. Suggestions to improve the KI/CKI regime were gathered in which the key suggestions were to formalize the KI/CKI processes, early involvement of project participants (mainly fabrication/ installation experts), integrated knowledge database and to fill missing competencies inhouse like fabrication experts. As indicators for CKI/KI in the project, most dominant responses were 'Non Conformance Report (NCR)' and 'Technical Query (TQ)'. It is also interesting to note that the effect on CKI on value (cost, time, quality and safety) recognized by interviewees was in line with the literature findings, that is construction knowledge integration reduces cost and time while improving quality and safety. The purpose here is not to present these most common responses as findings but to show the dynamics and context of construction knowledge integration in OW projects.

The above findings from case studies were used to assess the existing regime for CKI in OW projects. The tools and practices in use (combined with key positives in the system) helped construct decipher the current regime. It was observed that most of the tools and processes in use were structurally informal, meaning that either it were not considered as contributing to knowledge integration or were not executed in pre-planned intervals. The only formal mention in the standard work practice for knowledge integration was to gather, register and share the lessons learned after project completion.

In terms of the KI steps, it was concluded that the current regime fulfilled all the steps but only using the lessons learned data/ sessions which implied there is scope for improvements. It was also concluded that there was limited integration from crucial knowledge sources like fabrication, installation, lessons learned, ongoing projects etc. After analysing the current regime, the task at hand was to find the key issues in the regime so that it could be tackled. For this, the list of issues had to be screened further to find the issues which cause the biggest hinderance to CKI in OW projects. It was observed during analysis that causal and correlational relationships existed within and between issues and suggestions. These were assessed and combined to see which issue was causing or correlated to other issues in the list. The analysis revealed that the lack of a standard formal work protocol for KI/CKI activities and the lack of an efficient and effective integrated knowledge database were the key issues in the regime.

The final step was to address the key issues. The straight-forward solutions to the key issues were to formalise the KI/CKI regime and develop or assist the development of an effective and efficient knowledge database. The recommendations were made for each of the issues that were related to the key issues, which made the recommendations more specific and effective. Recommendations were also made keeping in mind that it remedies the KI steps affected by the issues. Further the recommendations for formalizing the KI/CKI process were refined in the context of existing project processes. Both, the recommendations and process model were validated in an expert panel session with 9 experts from Van Oord representing various domains like project management, construction management, engineering management, project controls, quality management and knowledge management. The feedback was gathered individually in writing and was critically assessed and incorporated in the recommendations. Overall the feedback was positive and convincing. The validation provided another step of improvement for the recommendations. **The final set of recommendations of this research can be seen in detail in Section 5.3, *Table 17*.** The recommendations for the first key issue, lack of standard KI protocol, have been mostly depicted in the process model below (same as **Figure 21** from main text):



The recommendation for an integrated knowledge database were essentially features and processes to ensure in a knowledge database for effectiveness and efficiency. While the detailed recommendations are in *Table 17*, some recommendations to give an idea are using advance data & text mining algorithms for better knowledge retrieval, filtering knowledge using usage analyses, feedbacks or screening sessions, standard tags and contact of knowledge entrant etc.

The research findings have certain limitations. The CKI regime and issues have been assessed only from the primary contractor's side and does not empirically cover the perception of other project participants. Further, the regime and issues are assessed using data from one organisation, while findings may vary depending on organisations. The research does not empirically prove the effect of CKI on project value or the effect on KI steps. Lastly, the research does not cover the behavioural aspect of people in integrating knowledge. The limitations also create room for further research, which is essential for scientific research. Hence, there is scope for further research in understanding perspective of other project participants and organisations on CKI, effect of CKI on project value and lastly, how behavioural science can add to construction knowledge integration in projects.

In conclusion, this research presents a positive proposal to achieve more constructible offshore wind components/projects. Where it strongly adds to the literature is by exploring the concept of construction knowledge integration in the realm of offshore wind projects, which had not been amply researched. The key recommendations to remember in the end are that KI/CKI needs a symbiotic mix of tools and practices, relevant sources of knowledge should be identified and integrated in early stages of the project and people in the sector should be made aware of the benefits of KI/CKI and formalize the procedures int his regard.

1. Introduction

1.1 Context and Relevance

With the world rapidly shifting towards sustainable energy alternatives, the global demand for off-shore wind power is increasing. **Off-shore wind farms** (hereon OWF's) are extremely efficient as they are exposed to higher and more consistent wind flow and easier land procurement than onshore wind farms. Offshore wind energy is expected to show even higher growth trends as it is expected to cover 10% (70 GW) of EU's electricity demand by 2030 (Wind Europe, 2017). At the end of 2018, total offshore wind capacity in EU was about 19 GW (Wind Europe, 2018), implying an expected 3.5 fold increase in the next 12 years. Parallelly, the Levelized Cost of Energy (LCOE) for OWF energy has dropped sharply over the past few years: from €140/MWh in 2013 to almost €50/MWh in 2016 (LEANWIND, 2017). The sharp reduction in LCOE implies increased price competition in the sector and technological advancements in construction. However, this also implies lesser revenue per MWh of construction. Even then, offshore wind power is much more expensive than power from non-renewables (Leary, 2018). These are made feasible through government subsidies, which indirectly effects all power users. As the governments across the globe aspire to end these subsidies (PwC, 2018), there is an increasing need to optimize costs while addressing other challenges.

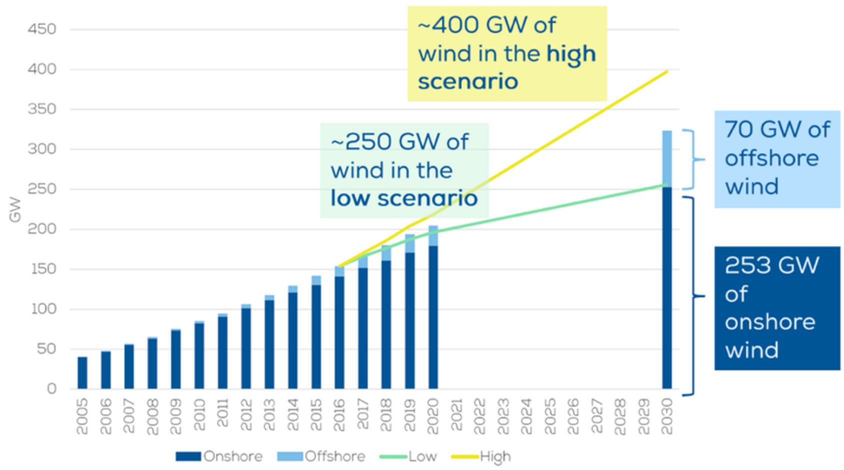


Figure 1 – Wind Energy growth trend in EU (Wind Europe, 2017)

The OWF projects also face the challenge of high lead times due to various factors. An offshore wind turbine (hereon OWT) comprises of numerous specialized ETO (Engineered to Order) products which face moderate to severe supply constraints (The Carbon Trust, 2008). Further, the installation of these components rely on many external risks like weather, sub-sea conditions, availability of specialized vessels and the components to be installed. Not to forget, an OWF project has to go through extensive administrative clearances to be constructed and operated (EWEA, 2010). All these factors cause high lead time and create immense engineering, forecasting and project management challenges.

Apart from the cost and time challenges, the market is dealing with increased technical and logistical complexity (LEANWIND, 2017) (due to the increasing number and sizes of OWF's) and a competitive market. Hence, the sector needs to evolve with the market dynamics and contracting companies need to further optimize the cost, time, quality and safety (collectively – 'Value') of the OWF projects. This addition would not only ensure more competitive bids but also delivers higher value to the contractor, client and even the end user (LEANWIND, 2017).

1.2 The Problem

Engineering and procurement of various **ETO products** lies at the core of planning an OWF project. These components also collectively termed as 'Balance of Plant (BoP)' components can constitute around 23% to 45% of the total project costs (depending on type of foundation used) (NREL, 2017). The BoP components do not include the turbine (including tower), and hence include the foundations, offshore substation, cables and onshore electricals. Out of this, foundations account for almost 40% of the cost. Components like foundations, layout etc. are designed by the engineering company and not the end fabricator. The relation between the engineering company/primary contractor and fabricator/sub-contractor is the similar to the relation between the designer and the contractor in a traditional design bid build project.

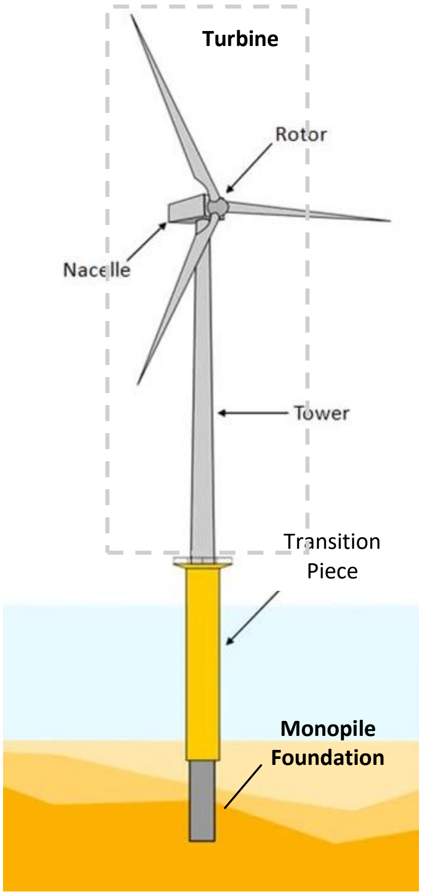


Figure 2 – Components of a standard Offshore Wind Turbine (OWT) installation (EWEA, 2010)

Several researchers and practitioners have repeatedly observed that there exists a knowledge gap between the designer and the construction/production body. The knowledge being referred to is relevant for efficient and effective construction, also termed as construction knowledge (elaborated in Ch. 2). Arditi & Kale (2002) state that **construction knowledge** is a crucial design/ engineering input and is often missed due to designer's lack of construction knowledge which can lead to scheduling problems, cost and time overruns and even disputes in the process. Song et. al. (2009) analyzed researches like Construction Industry Institute's best 14 practices, 44 Value Management Practices and IPA's Value Improving Practices to conclude the common underlying virtue of construction knowledge and experience as the key reason for performance enhancement of **construction and engineering projects.** This implied that the issue of missing construction knowledge in project processes is valid across sectors in the entire construction industry.

Initial literature review, like Kolman (2014) and exploratory interviews from staff in the offshore wind industry (mainly the collaborating organization) reaffirmed the issue of limited construction knowledge integration in its project processes. This is the prime focus of this research, since the research is based on the offshore wind energy sector. **Hence, the main underlying problem being addressed in this research is the limited integration of construction knowledge in realization of offshore wind projects.**

1.3 Research Objective

An objective defines the structure of the research and its constituent set of actions, to be carried out as a part of the research. The research objective will clarify the expectations and limitations of the research results. The objective is constructed by combining the unmistakable contribution of the research project to the problem being addressed and how the contribution would be provided.

Hence, in response to the context and problems explained in the previous chapters, the objective of this research is: **'To optimize construction knowledge integration during the project processes of offshore wind projects and consequently add value (minimize cost and time, maximize quality and safety) to the projects.'** To fulfil this objective, the following sub-objectives have been devised:

1. To explore the concept of construction knowledge integration
2. To assess the current construction knowledge integration regime in OW project processes
3. To find the key issues hindering construction knowledge integration in OW projects
4. To address these key issues hampering construction knowledge integration

1.4 Research Scope

The scope or extent of the research is crucial to be determined so that more focused knowledge can be generated with the available resources for the research. This research is being carried out in collaboration with Van Oord (VO) Offshore Wind and for a targeted duration of 23 weeks (with 40 hours work per week). Most projects in the OWF sector are tendered as EPC contracts for Balance of Plant items and separate contract for turbine. This implies more scope of construction knowledge integration lies with the EPC contractor owing to their responsibilities throughout the project lifecycle. Hence, the focus on this research is on EPC projects. Foundations cover a major part of the BoP components as they cost around 14% to 34% of the total project (60-79% of the BoP cost) (NREL, 2017) and the engineering responsibility is often held by the EPC contractor. Therefore, for this research the assessment and interventions for construction knowledge integration would be focused on foundations of OWF projects. Van Oord Offshore Wind with its extensive experience in designing or managing the design of foundations, provides ample data to study. While the focus here is on one BoP component, it would also be reviewed if the findings can be applicable to other BoP components as well. The scope refinement is summarized in Figure 1 & 2 below:

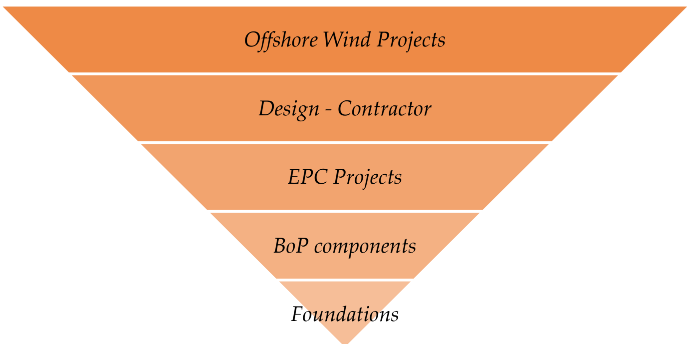


Figure 3 – Research Scope screening(1)

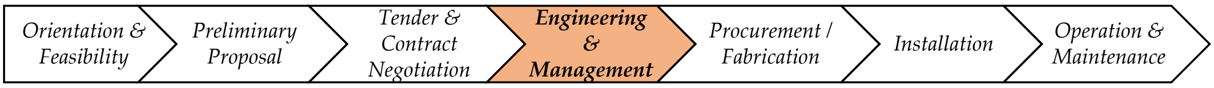


Figure 4 – Project Processes in OWF. Highlighted processes are the scope of this research

The above figure (2) shows the generic processes/ phases in project's lifecycle. While project phases can be divided into more sub-phases, the above categorization into 7 broad phases is to communicate the scope of this research. Focus of this research is on the highlighted project phase, that is engineering and management, in which research would be pursued.

1.5 Research Question(s)

Carrying forward from the research objective and scope mentioned above, the main research question can be framed as: **"How can construction knowledge integration be optimized in the engineering processes of Offshore Wind projects?"**

The main research question can only be answered with in depth research into the related sub-aspects, which have been covered by the following sub-research questions:

1. **What is construction knowledge, its integration, benefits, sources and ways to achieve it?**
2. **What is the current construction knowledge integration regime in engineering processes for OW projects?**
3. **What are the key issues hindering construction knowledge integration in OW projects?**
4. **What are the applicable process interventions to address the key issues hindering construction knowledge integration in OW projects?**

1.6 Research Design

1.6.1 Research Approach & Strategy

Research Approach refers to the broad procedure or idea of methodology and yield of the research. Different literary sources term research approaches in different headings but a broad common idea can be extracted. Here the four different research approaches namely **descriptive, explanative, remedial and methodological** were reviewed and a rational choice of an approach for this topic is chosen. With the research objective to increase knowledge integration in engineering processes for higher value generation, improvements in the current regime are core to the process. This is the main driver here to choose the research approach. A descriptive study does not aim to solve a problem, an explanatory study reveals the cause of the problem but does not attempt to solve it while the methodological study focuses on testing or devising new research methods. **Hence, the clear choice is a remedial study which would not only critically reflect on the current construction knowledge integration regime but also suggest remedial measures to enhance it.**

1.6.2 Research Strategy

The Research strategy explains the coherent body of decisions concerning the way research is going to be carried out in detail, like explaining the tools and types of information that would support the research. Before selecting the necessary tools for research, it is crucial to reflect on the following questions (Verschuren & Doorewaard, 2013):

- **A Broad or Deep research?** This question addresses the outreach of the research on virtue of whether the research yield is generic to the problem or specific to a context. While the research outcome would be based on a narrow context (monopile component), the **results would be targeted for a generic outcome so that it can be implemented flexibly. Further, the outcome aspires to reach out to other 'Balance of Plant' components where construction knowledge integration is desirable.**

- **Quantitative or Qualitative?** This question addresses the type of data that the analysis and results would be based on. Analyzing the existing regime of construction knowledge integration would be based on mostly qualitative project data backed by some quantitative inputs. This does not make it a quantitative research but the analysis of quantitative data would still need to be done. Further, tackling challenges and improving construction knowledge integration would be through qualitative remedies. Hence, overall this research would be based on mixed inputs.

- **Empirical or Desk research?** This question addresses the source of data, whether it would be collected by the researcher (empirical) or be taken from other researches. Again, this would be a mixed strategy for the source as some data would be collected from existing project data and professional interactions within the company (empirical data) while some theories and arguments would be based on the literature study (desk research).

Empirical research can be achieved by a series of methods, but the data sourcing constraints should be reviewed before selecting them. Since the research is in collaboration with a renowned OWF contracting company (Van Oord), it was dependent on detailed project data, expert insights and other resources available within the company. Empirical data collection can be broadly classified into 4 tools: **Survey, Experiment, Case Study and Grounded theory approach** (Verschuren & Doorewaard, 2013). The rationale of choosing or rejecting the use of these tools is given below:

- *Survey* – This tool implies to gathering empirical information from a large sample set of people when doing a broad study. Since this study sources most of its data from a collaborating organization, survey is not the chosen tool. Rather the focus is on gathering insights from specific set of experts. **Hence, survey is not the chosen tools for this research.**

- *Experiment* – This tool implies experimenting a new theory, approach or product to come up with results. While this research does intend to innovate on knowledge integration, time required for actual testing or simulation is difficult within the available research duration and other resources. **Hence, this is not a chosen tool for this research.**

- ***Case study*** – This tool, as the name suggests, focuses on collecting and analyzing data from relevant cases/ projects. Since, one of the first sub-objective and research question is to analyze the existing state of construction knowledge integration in planning of OWF projects, analyzing actual OWF projects would be ideal. Since the collaborating company has many completed projects in this sector, **Case studies would be undertaken for this research.** Past projects are preferred to ongoing projects as they offer data on the final performance/ outcome.

- *Grounded theory approach* – This tool implies a theory-oriented research, which in relation to construction knowledge integration would have meant focusing on people's thought behind knowledge theories. Since the focus of this research is not to work towards a new theoretical setup of relation which is why the **ground theory approach is not a chosen tool.**

Desk research – This involves taking insights from existing research or literature in relatable and necessary sectors. Since research on project management challenges in OWF sector is limited, often comparison to research based on other construction projects is necessary. For instance, the focus on knowledge integration practices is tried in parallel construction sectors but unheard of in the OWF sector. This means desk research essential for this research.

1.6.3 Data Collection, Analysis & Validation

As elaborated in the previous chapter (section 4.2), methods within the realm of **surveys, case studies** and **desk research** would be the main source of data collection for this research. Since, the collected data and consecutive analysis would be the basis for answering the research questions, it is imperative to define precise methods for each sub-research question. This is defined in the table below:

Table 1 – Data collection methods for sub-research questions

S.No.	Sub-research question	Data Collection method
1.	**What is construction knowledge, its integration, benefits, sources and ways to achieve it?**	*Desk research / Literature study*
2.	**What is the current construction knowledge integration regime in engineering processes for OW projects?**	*Case studies on completed EPC projects at Van Oord (Interviews & document analysis)*
3.	**What are the key issues hindering construction knowledge integration in OW projects?**	*Case studies on completed EPC projects at Van Oord (Interviews & document analysis)*
4.	**What are the applicable process interventions to address the key issues hindering construction knowledge integration in OW projects?**	*Combining findings from literature study and case studies*

As mentioned in section 4.2, this research is going to be based on qualitative as well as quantitative data. Based on the data collection methods corresponding to research questions (Table 1), it can be said that most of the data is going to be qualitative in nature. This classification largely impacts the analysis methodology. This is elaborated below:

- **Quantitative data**
  This research is mainly qualitative in nature. The only quantitative data used in this research is in commonality analysis of responses from literature and case studies. Also in the validation assessment, quantitative data guided the selection of findings. This data is much simpler that studies which are dominantly quantitative in nature.

- **Qualitative data**
  Unlike quantitative data which is objective in nature, qualitative data non-quantifiable (unless converted). Qualitative data analysis is a continuous process whose interpretation goes on throughout the project starting with data collection itself. It is an inductive, iterative and reflexive process. The following 5 listings summarize the techniques for qualitative data analysis.(CIRT) These techniques co-exist in this research.
  - Data collection and documentation
  - Categorizing data into concepts
  - Connecting data to show how concepts may influence others
  - Legitimizing by evaluating alternative explanations and negative cases
  - Reporting the findings

1.7 Report Structure

Chapter 1 shed light on the broader context and relevance of research in the OWF sector followed by the main problem being focused on in this research. Then the chapter presented the research design constituting research objective, scope, question(s), approach, data collection strategy and planning. This set course for the future activities in the research. Chapter 2 presents the literature review on the main subject of this research, construction knowledge integration. It is followed by research methodology in Chapter 3. The case data and analysis are presented in Chapter 4. This is followed by framing the recommendations from this research and its validation, elaborated in Chapter 5. The main text end with discussion, conclusion and limitations of this research in Chapter 6. The report ends with a list of references, glossary and some added information in Appendices, mainly appendix A which contains the raw case study data and Appendix B which contains validation data.

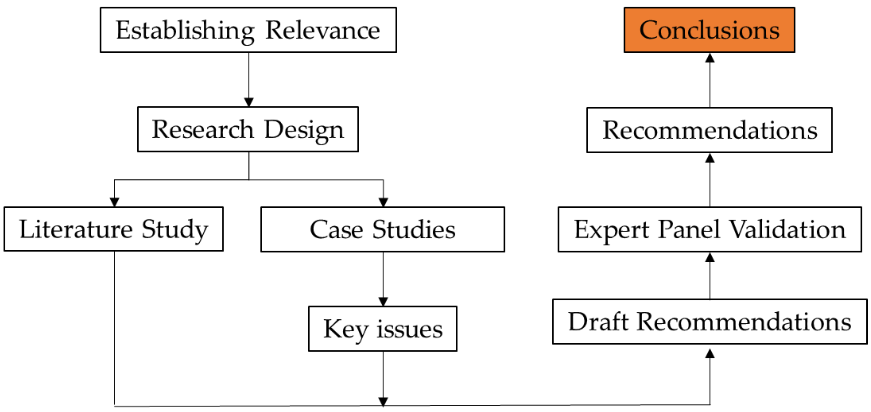


Figure 5 – Research Structure

“Knowledge has a beginning but no end”

– Geeta Iyenger

2. Literature Review

This chapter elaborates on the key concepts and terms that form a base for this research, it reviews the past research findings and literature on the key concepts and analyses the opportunities and challenges[1]. The chapter begins with explaining the concept of construction knowledge integration and its relevance. It then covers the main benefits of construction knowledge integration and its appropriate source. The next sections shed light on the obstacles faced and the tools/ practices which various researches advocate for increasing construction knowledge integration. The last section presents the key takeaways from the literature review.

2.1 Construction Knowledge Integration (CKI)

Before aiming for integration, it is important to understand what is knowledge and what this research refers to as 'construction knowledge'. Knowledge is the 'acquired' information, skill or perspective about something gathered through various sources. Construction knowledge, simply put, is the knowledge and experience of construction/ fabrication/ installation processes and dynamics, which might stretch over multiple phases in the project. ***"It is the requisite knowledge needed for construction work to effectively and efficiently take place"*** (Gambatese, Pocock, & Dunston, 2007). For example, it can be the added insights on the labor, materials, equipment, space, logistics and techniques required to build or the opportunities and challenges of executing various design details (Gambatese et al., 2007).

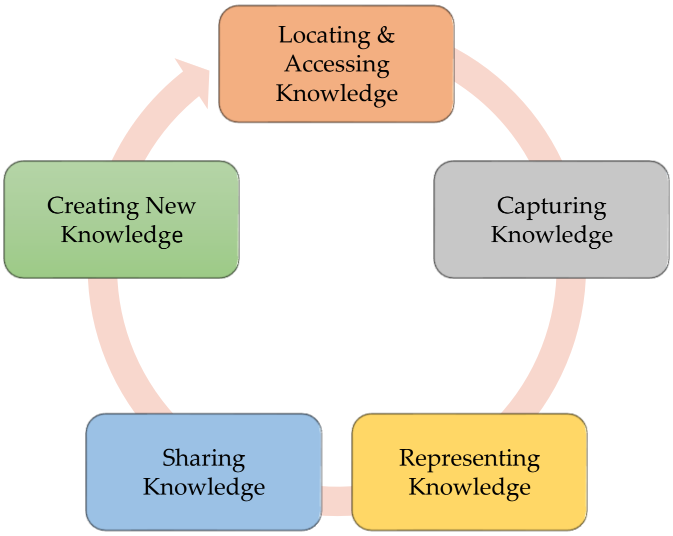


Figure 6 – Steps of Knowledge Integration & Management *(Ruikar, Anumba, & Egbu, 2007)*

When these insights are amalgamated in planning, executing and reviewing various activities in the project lifecycle, it integrates the construction knowledge and experience into project processes. *Grant (1996)* and *Andreu & Seiber (2005)* stated that knowledge integration is the process of combining

[1] It is worth noting that construction knowledge integration finds its prime use in the well-researched practice of 'Constructability'. Constructability is defined as the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve project objectives (Construction Industry Institute, 2009). Hence construction knowledge integration is at the core of the constructability. Further due to lack of direct literature on managing construction knowledge, literature on constructability has been a major source for the literature review. Concepts and arguments directed towards knowledge integration have been screened through researches on constructability.

knowledge across business entities, for e.g. across teams, business units, departments and organizations in order to enhance organizational capabilities (Kapofu, 2014). Its primary objective is to achieve a net learning effect in the organization. The core of knowledge integration is in being able to apply and improve the available knowledge. Here a link can be made to the 5 steps of KM/Integration proposed by few studies (Anumba, 2008; Ruikar et al., 2007). The 5 steps, also shown in ***Figure 6***, include locating and accessing, capturing and storing, representing, sharing and creating new knowledge. The third step of representing knowledge can be very broad to address in mega projects like offshore wind. This is because it deals with several types of knowledge which can be represented in distinct formats. Hence, assessing it has been kept out of scope of this research. This research then adds learning to the organization (by facilitating locating & accessing, capturing, sharing and creating new knowledge). Khan (2015) cited integration to be an 'invisible asset.' Several researches advocate for the integration of construction knowledge and experience into as many activities during the project, right from feasibility to completion (Khalfan, Kashyap, Li, & Abbott, 2010; Khan, 2015; Kifokeris & Xenidis, 2017; Pheng, Gao, & Lin, 2015; Stamatiadis, Goodrum, Shocklee, & Wang, 2012), to name a few.

While such integration sounds imperative, it has been a major challenge for the construction industry (Othman 2011; Gambatese et. al. 2007; Fisher 2007; Pulaski et. al 2005 etc.), also established in Section 1.2. It has been specially challenging for the construction industry because of its fragmented nature, uniqueness of each project, disparate project teams/ stakeholders and requirements of specialized skills (Ruikar et al., 2007). Low/ no knowledge integration in construction projects leads to many problems (Gambatese et al., 2007; Song, Mohamed, & Abourizk, 2009), some of which are mentioned in the list below. The problems have been presented with the project participants affected by it (in case of EPC projects) so that it makes a case for these participants to invest in knowledge integration measures:

Table 2 – Problems due to low/ no construction knowledge integration in projects and project participants affected by it (in case of EPC projects)

Problems	**Affected Project Participants (in EPC)**
Lack of adequate relevant information with project participants (both a cause & consequence)	*All participants (client, (sub)contractor) unless knowledge withheld for strategic gains*
Design errors, rework, wastage (material, labor etc.)	*Main Contractor*
Poor quality documentation (e.g. drawings), project specification	*Main Contractor*
Poor communication/ disputes	*All participants*
Unrealistic schedules / project planning	*Main Contractor*
Inaccurate estimates & even bids. Cost overruns as a consequence of problems in the list	*Main Contractor*

It is interesting to note that direct indicators of lapses in construction knowledge integration can be seen in the form of Request for Information (RFI's), Non-conformity reports (NCR's), Rework requests etc. (Khan, 2015; Song et al., 2009). Such added communication can directly impact the schedule and cost of activities as added coordination consumes resources (like time and money).

The use of construction knowledge integration in projects is known and researched for decades and has benefited other sectors of the construction industry (Stamatiadis et al., 2012; Trigunarsyah, 2004). However, **the research on integration is more relevant now more than ever** because of the sheer increase in complexity of construction projects, innovation needs, chaotic and ambiguous amount of information, new stakeholder relationships, disproportionate implementation and competitiveness (Kifokeris & Xenidis, 2017). Further, it is worth noting that the type of integration process/ strategy is dependent on the project type and contracting environment (Gambatese et al., 2007), and **the offshore wind sector** (the focus of this research) **has been severely unexplored in this regard** which can be inferred from lack of past researches on the subject.

2.2 Benefits of CKI

The problems mentioned in the previous section give a sense of what could be the possible benefits of effective construction knowledge integration in projects. Several researches advocating on this subject show a positive relation between construction knowledge integration and overall project performance (Kifokeris & Xenidis, 2017; Motsa, Oladapo, & Othman, 2008; Othman, 2011b; Pheng et al., 2015; Pulaski & Horman, 2005; Ruikar et al., 2007; Song et al., 2009). Many quantitative and qualitative parameters have been used to evaluate project performance in these researches like cost, time, quality, safety and client requirements. The following table lists the main benefits:

Table 3 – Benefits of construction knowledge integration

Type	Benefits	Authors				
		Arditi & Kale, 2002	Pocock et al., 2006	Motsa et al., 2008	Othman, 2011b	Khan, 2015
Quantitative Benefits	Enhances project quality		✓	✓	✓	✓
	Reduces project cost		✓	✓	✓	✓
	Minimizes contract variation orders & disputes	✓	✓	✓	✓	✓
	Reduces project duration		✓	✓	✓	✓
	Increases Safety		✓			✓
	More effective construction planning			✓	✓	
	Reduces maintenance costs					✓
Qualitative Benefits	Better design	✓		✓	✓	✓
	Improved site/ logistics management			✓	✓	✓
	Efficient management of waste problems			✓	✓	
	Increases construction flexibility					✓
	Increased job satisfaction	✓		✓	✓	
	Better communication		✓	✓	✓	✓
	Provision of feedback for future projects			✓	✓	
	Increases owner satisfaction	✓		✓	✓	✓
	Enhances partnering & trust among project teams	✓	✓			✓

Quantitative benefits make a good case for organizations to invest in knowledge integration efforts (Ruikar et al., 2007). While the three famous project drivers are cost, time and quality, the fourth driver gaining consideration in modern projects is 'safety'. Collectively, the four drivers (cost, time, quality, safety) are collectively reflect on the added or lost 'Value' of a project (Ref. Glossary for detailed definition). Since construction knowledge integration positively correlates to all four drivers, it can be hypothesized that construction knowledge integration adds to **value of a project**.

While construction knowledge integration has many benefits, it is strictly dependent on the time at which integration efforts are executed. Past researches suggest that construction knowledge should be integrated in all project phases because of its ability to improve performance of processes (Othman, 2011a). However, an empirical research revealed that 83% of construction professionals preferred or focused the integration before the start of construction (Pocock, Kuennen, Gambatese, & Rauschkolb, 2006). In continuation to this, several researches on the subject strongly stress on starting knowledge integration practices/efforts as early as possible in the project lifecycle or in pre-design phases (AASHTO, 2000; Khan, 2015; Othman, 2011a; Pocock et al., 2006; Pulaski & Horman, 2005). Early efforts to integrate knowledge would help resolve key issues and choose more appropriate alternatives for the design/ project without adverse costs to the project.

It is known that changes brought in the later stages of the project require more effort and cost and have lesser influence. This is shown in the figure below, visualized in ASCE's white paper on constructability (Khan, 2015). It shows that the maximum potential to influence project performance and outcomes is through interventions in the early stages of the project. Finally, it comes down to the project delivery strategy as it decides the duration of involvement of project participants. Notably in DBB as well as EPC projects, the contractors and the sub-contractors respectively are mostly signed after the design stage. While this thesis does not focus on project delivery interventions, the way forward depends on sources of construction knowledge and practices/ tools to integrate which has been elaborated in the next section.

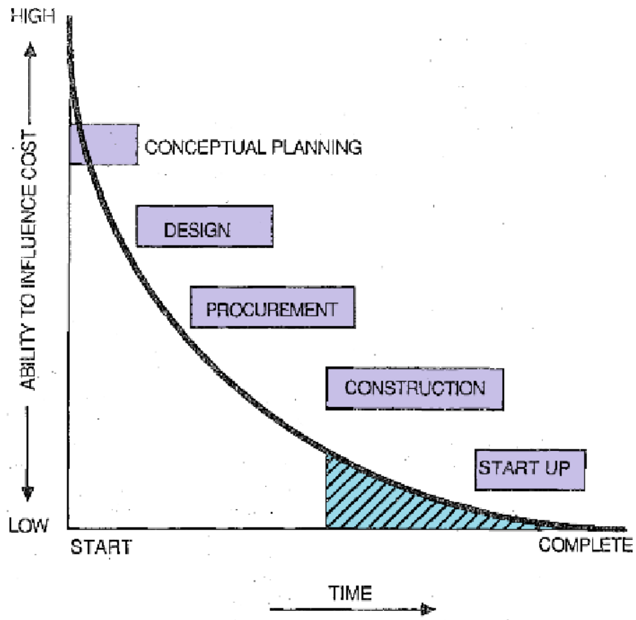


Figure 7 – Project phases and influence potential *(Khan, 2015)*

2.3 Sources of Construction Knowledge

One of the key steps before the actual process of knowledge integration is determining the source of knowledge. Determining this knowledge source has been a common issue in the construction industry (Song et al., 2009). Since projects continue to grow in size and complexity, the necessary construction knowledge is not held by a single type of design professional. Song et al. (2009) grouped the resources of construction knowledge into four broad categories:

- In-house expertise of designers (engineers) and owners
- Construction management consultants
- General or specialty contractors
- Formalized knowledge management systems

While Song et al.(2009) and Othman (2011b) through their research advocated for contractors to be the **best** and **essential** source of construction knowledge, Othman (2011b) showed that general/ specialty contractors are used the least, as a source of construction knowledge. Pulaski (2005) advocate for knowledge management software as being more reliable than reviews conducted by project participants (Pulaski & Horman, 2005).

The specialised designers and engineers form an obvious and irreplaceable part of the project as they initiate the processes. However, irrespective of the professional group they belong to, the key is also to involve experts from different sources/ processes in the sector. Such a visualization of construction knowledge integration is presented below:

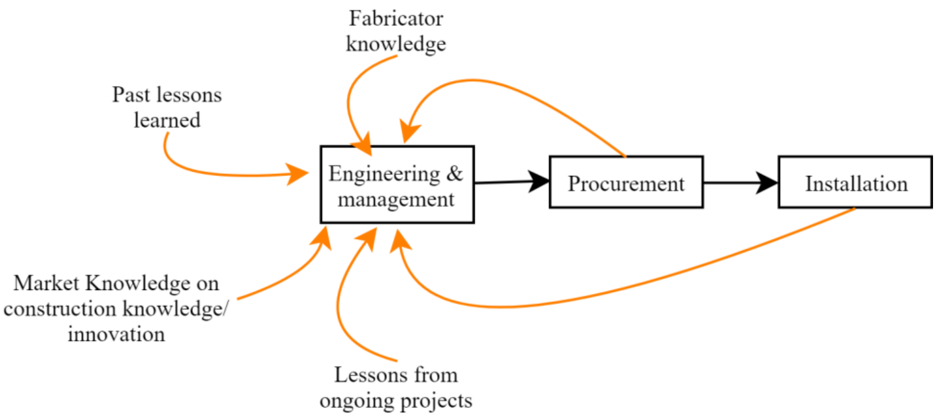


Figure 8 – Construction Knowledge Integration from various sources

The choice of project participants or other mediums as sources of construction knowledge largely depends on the **project context, scale, resources, client's encouragement, participant's willingness** and most importantly, the **project delivery method** (Othman, 2011b; Trigunarsyah, 2004). While a single type of source would be insufficient to address the complexity and innumerable interfaces of modern day mega-projects, **the way forward might be to find a right balance between the various knowledge resources by assessing the factors like project context, resources, delivery method etc.**

2.4 Obstacles in CKI

Many past researches on the subject have framed a set of obstacles/ barriers which inhibit the integration of construction knowledge in the projects. CII (Construction Industry Institute) categorized constructability barriers into general, owner, designer and contractor barriers (Othman, 2011a). Since this categorization sums up the important actors in a project, it has been used to present the barriers for construction knowledge integration. They have been summarized below (Kifokeris & Xenidis, 2017; Othman, 2011b; Pocock et al., 2006; Ruikar et al., 2007)[2]:

General Barriers

- **Uncritical satisfaction with the existing state of affairs**
- **Disbelief in utility of knowledge integration initiatives**
- **Inadequate sources of construction knowledge**
- **Reluctance for innovation**
- **Discontinuity of key participants in project team**
- **Varying focus and priorities of project participants (e.g. Owner, contractor)**
- **Lack of resources (time, money) for knowledge integration initiatives**
- **Highly competitive sector**
- **One-off nature of projects**
- **Project delivery methods**
- **No documentation of lessons learned**
- **Failure to search out problems and opportunities**

Owner Barriers

- Lack of awareness and resistance to formal knowledge integration programs
- Perception that knowledge integration programs delay project schedule
- Reluctance to invest additional money and/or effort in early project stages
- Lack of genuine commitment
- Insistence in separating design & construction management operations
- Lack of construction experience
- Lack of team-building or partnering
- Disregard of knowledge integration in selecting contractors and consultants
- Contracting difficulties in defining knowledge integration scope
- Misdirected design objectives and performance measures
- No financial incentive for participants
- Standard gold-plated specifications
- Limitations of lump-sum competitive contracting
- Unreceptive to contractor innovation

[2] These researches showed convergence in their listing for integration obstacles. This is why a combined list of obstacles is presented instead of separate research specific lists.

Designer Barriers

- False perceptions of construction knowledge integration
- Lack of awareness of knowledge integration concepts and benefits
- Lack of construction experience/technology awareness/ qualified staff
- Setting company or personal goals over project goals
- Lack of mutual respect for other project participants
- Perception of increased designer liability
- Construction input is requested too late to be of value
- Faulty, ambiguous, or defective designs
- Incomplete specifications and budgetary limitations

Contractor Barriers

- Reluctance of field staff to offer preconstruction advice
- Poor timeliness of input
- Poor communication skills
- Lack of awareness of knowledge integration concepts and benefits
- Lack of involvement in tool and equipment development
- Outdated construction methods and techniques
- Inadequate construction experience
- Lack of qualified and skilled manpower
- Lack of resources for skill training

2.5 Tools/Practices for KI

The previous sections explained the concept of construction knowledge integration, its need, benefit, source and obstacles. Here we discuss the methods of integration i.e. locate and access-capture-share-create new. Specific interventions need to be made for locating and accessing, capturing, sharing or creating construction knowledge, thus enabling its integration. These interventions have been categorized as process/policy based tools, modelling tools and technology based tools.

To prepare a consolidated list of tools/ practices, all important tools suggested by literature were recorded (which specifically focus on knowledge integration) and further divided into the respective categories. Since this research focuses on the engineering phase and not the pre-preparation or execution phases, screening was done based on the phase. Also, certain researches mentioned the overarching concept of a tool/ practice, while some used a different name or detailed the concept further. For example: a research specifies the importance of CAD, while another mentions the name of a CAD software or CAD optimization, both eventually root for CAD. **It is also worth noting that no one tool or practice can solve all obstacles, but rather a combination is needed which will drive the combined knowledge integration strategy** (Fisher, 2007). The list of tools/ practices for construction knowledge integration is presented below:

Table 4 – Tools/ Practices for construction knowledge integration

Type	Tools/ Practices	KI step addressed				Authors[3]						
		L&A	CAP	SH	NEW	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Policy/ Process based	Policy & Objective statement		●	●		✓						
	Constructability Team **	●		●	●	✓						
	Suggestion form			●	●	✓						
	Partnering	●		●	●	✓						
	Contractor determined schedule					✓						
	Implementing responsibility matrix	●	●	●		✓						
	Team building	●		●		✓						
	Constructability engineers **			●	●	✓						
	Formal implementation processes **	●	●	●		✓						
	Community of Practice (CoP) activities **	●		●	●		✓					✓
Modelling based	Constructability coordinator	●		●					✓			
	Post-construction reviews			●	●							✓
	Project constructability agreement **		●	●		✓						
	Agency constructability checklists		●	●		✓					✓	
	Brainstorming			●	●					✓		✓
	Value engineering**			●	●	✓						
	Best Practices /Idea /Lesson learned log	●	●	●	●	✓		✓	✓			
	Critical path method **			●	●	✓						
	Cost/benefit analysis			●	●	✓						
	Constructability resources **	●	●	●		✓						
	Constructability/ Design reviews			●	●	✓			✓	✓	✓	
	Feedback system			●	●					✓		
	Surveys & interviews of professionals**		●					✓				
	Special Interest Groups for tasks **	●	●	●	●		✓					
	Trainings/ Seminars/ Conferences/ Discussion forums	●		●	●							✓

[3] **(1)** - (Fisher, 2007); **(2)** - (Khalfan et al., 2010); **(3)** - (Kifokeris & Xenidis, 2017); **(4)** - (Langkemper, Al-jibouri, & Reymen, 2003); **(5)** - (Othman, 2011b); **(6)** - (Pocock et al., 2006); **(7)** - (Ruikar et al., 2007)

Type	Tools/ Practices	KI step addressed				Authors[3]						
		L&A	CAP	SH	NEW	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Technology based	CAD/ BIM		●	●		✓		3D, 4D, 5D BIM ,CO KE **				
	Hypermedia/ Multimedia/ Hypertexts **		●	●		✓		✓				✓
	Knowledge Databases	●	●	●		✓		✓ CPP MM **				✓
	Artificial Neural Networks	●	●	●		✓		✓				
	Integrated groupware solutions **			●	●							✓
	Intranet/ Extranet	●	●	●								✓
	Data & Text mining software	●	●	●		✓						✓

**Refer Glossary for definitions

2.6 Discussion

This chapter elaborated on the key concept of construction knowledge integration, its relevance, benefits, sources, obstacles and tools and practices for integration. This section analyses and presents the key findings based on literature study and what it contributes to the research. The final recommendations would be a mix of the practices found below and case study findings (chapter 4).

Section 2.1 presents the problems that arise in construction projects if there is less or no integration of construction knowledge in products. Noticeably all these problems (except if information is held for strategic reasons) adversely impact the EPC main contractor. These problems reduce the profitability of projects for the contractor which is why it is important for the main contractor of EPC projects to invest time and other resources for construction knowledge integration.

Further, the list of benefits of this integration, with validation from 5 different literature sources revealed the most dominant recurring benefits. **(**While the improvement in safety does not make it to the most dominant benefits, but literature study still shows positive correlation between higher construction knowledge integration and safety. Safety is important for discussion as it is taken as the 4th pillar of **'Value'** (Ref. Glossary). In the list below, the 1st benefit of reduction in contract variation orders and disputes is seen in all sources reviewed in the literature study. The other 6 benefits are listed in 4 out of 5 sources referred. Benefits scoring less than 4 were not considered.

1. Minimizes contract variation orders and disputes
2. Enhances project quality
3. Reduces project cost
4. Reduces project duration

5. Improves designs
6. Improves communication between project participants
7. **Increases owner satisfaction**

Section 2.3 presented the various sources of knowledge but went on to conclude that a single source of knowledge might not suffice for the complexity and scale for modern day projects. The way forward is a mix of sources and from various processes in the project life cycle. Moving to the obstacles in knowledge integration, the list presented in section 2.4 is quite explicit but may not seem of big virtue on its own. However, these will be correlated with findings from the sector specific case studies in the next chapter to derive concrete recommendations.

Finally, the literature review presents the key tools/ practices, summarized from 7 literature sources which explicitly talk about them for construction knowledge integration. They were presented in the same manner as that of benefits, but due to the different tools/strategies suggested by different literature, the repetition was less. Again with analyzing the most listed in literature, the following list of dominant tools/ practices were compiled:

1. Constructability/ Design reviews by experts
2. Lessons learned/ Best practices/ Idea log
3. Hypermedia/ Multimedia/ Hypertexts
4. Knowledge Databases

It is to be noted that this is not the final list being prescribed as it needs to be compared and streamlined with the findings of the case study. Lastly, it is also worth noting that elaboration of construction knowledge integration and its related concepts like benefits, steps, sources, tools and practices to achieve etc. answers the first sub-research question as well.

2.7 Conclusion

To conclude, this chapter presented a detailed review of past researches on the concepts related to construction knowledge integration, fulfilling the first objective (and research question) and establishing an essential base for exploring the regime of construction knowledge integration in practice. Starting with the definition, it clarifies what can or cannot be expected out of construction knowledge integration. The theoretical steps of knowledge integration are locating and accessing, storing, sharing and creating new knowledge, provide aspects on which the recommendations can be assessed. Literature study reinstates the importance of integrating relevant sources of knowledge, like fabrication knowledge, and that too in early stages (pre-design) of the project life cycle. Among the main contribution of the literature study is insights into precise tools and processes that have been used in other researches or sector for accentuating construction knowledge integration. Even if findings from case study process do not present concrete solutions to issues, the literature findings in section 2.5 provide a base to fall back on. **In conclusion, this chapter having explored the core concepts of this research, would impart theoretical reliability to the arguments and findings of this research.**

3. Research Methodology

The previous chapter introduced the concept of construction knowledge integration, its benefits, sources, obstacles and tools and practices which aid in integration. The information presented by the previous chapter was based on existing literature/ researches on the subject. The chapter also stated that the integration process/ strategy depends on the project type and that the offshore wind energy sector is largely unexplored in this regard. Hence, it is imperative to delve into the construction knowledge integration regime in the sector. **One of the methods to study the existing regime is through case study of offshore wind energy projects.** The choice of this research tool is elaborated in section 1.6. Hence, this chapter elaborates on the case study process followed in the research like case selection, data collection methodology, case description and analysis methodology.

3.1 Case Selection

The case selection process is crucial as empirical findings depend on the case details and unrelated or incomparable cases would yield unreliable results. The cases are screened on criteria like **physical context, scale, complexity, project delivery method, implementation progress etc.** The selection criteria of case type/ sector is not mentioned as the entire research is focused for the OWF projects and cases from the sector are an obvious choice. **The intent is to select 'Typical' cases, meaning cases which represent descriptive features of a broader set of cases.** This would help to relate and imply the research interventions on a broader context by the readers. The following table elaborates on the selection criteria and the chosen parameters along with reasoning:

Table 5 – Case selection criteria

Selection Criteria	Parameters	Rationale
Context	**In and around Europe**	Offshore wind industry more evolved in Europe. Further, similar geographical, economic and cultural factors into play
Scale	**Mega-project. Cost > 300 mn. $**	Bigger projects have more interfaces and project participants, creating extra difficulty for knowledge integration
Project Delivery Method	**EPC**	Integrated project delivery methods were devised to integrated project disciplines. How this plays out in the sector can be seen through EPC projects
Technical Complexity	**High**	High technical complexity creates more need for knowledge integration
Implementation progress	**Recently completed engineering and planning phase (less than 1 year ago)**	OWF is a rapidly evolving industry. Findings should be relatable and useful for future projects. Further, gathering tacit insights from project participants easier with recently completed projects
Project Performance	**Similar project performance. No major cost or time delays**	Hence no adversities affecting knowledge integration in the project

The cases are selected using the above parameters from a pool of **projects available with the partnering company, Van Oord** which has many Offshore wind projects in its portfolio. There is a need to analyze multiple cases so variation in knowledge integration regime could be compared across projects and generalizations for knowledge integration regime could be extracted. Considering the duration of the research, **the number of cases has been limited to <u>three</u>, which are as follows:**

1. **Deutsche Bucht Balance of Plant** (tag: DBU BoP)
2. **Deutsche Bucht Mono-bucket foundation** (tag: DBU MBF)
3. **Borssele 3 & 4** (tag: BOR)

Notably, the 1st and 2nd cases are related. The latter is a major sub-package of the former. Since the team, contract, challenges and other dynamics were different, it has been considered as a separate case to be studied. They would be elaborated in section 3.3.

3.2 Data Collection Methodology

In this research, interviews and documented information has been used to collect case related data (as also described in section 1.8). This thesis presents a cross-sectional study as the data collection time is much smaller than the actual spread of knowledge integration activities in the project. Interviews yields insights from the staff involved in the project while the documentation cross-verifies and adds to the findings from the interviews. The data collection methods are explained below:

Interviews

The interviews conducted are semi-structured in nature, meaning that specific concepts/questions are put forward to the interviewee but are not limited to the same. Other interview approaches like unstructured and fully structured do not give direction to extract information or do not give room to uncover rich personal experiences of the participant respectively.

The people to be interviewed are key in extracting reliable data. Although the research mainly deals in knowledge integration in the engineering phase, this knowledge itself depends on inputs from diverse disciplines involved in the project aligned for effective and efficient construction. This is why the intent has been to interview staff performing different professional roles in the project. **A total of 12 interviews have been conducted, that is 4 per case where each lasted between 40-60 minutes.** The interviews were conducted in 2 rounds. Firstly, 4 design managers were interviewed as they had the responsibility of integrating various disciplines in design. Preliminary analysis of the 1st round hinted that opinions towards construction knowledge integration may vary as per professional roles/ background which also motivated in interviewing as many different roles as possible in the stipulated time. In the second round, 8 interviews were conducted with staff members like project manager, project director, supply chain manager and procurement manager. The main subjects covered were:

- General context, interviewee's role, background
- Need for construction knowledge integration
- Current integration regime in BoP components
- Construction knowledge Integration and 'Value'
- Tools/ Practices for construction knowledge integration

The interviews followed a protocol to cover the main subjects but left room for additional questions to be asked based on response. These interviews were recorded with the interviewee's permission and the information shared was summarized in a short, meaningful and unaltered manner. The interview protocol can be seen in Appendix A. The core concepts stated by interviewee's have been analysed and tabulated in the next chapter, in section 4.1.

Documents

Along with interviews, a set of documents were also reviewed from the case database shared by the managers. The intention was to cross verify and review the broader context of the case like organisational structure, project planning, knowledge database etc. A set of documents was requested for each case from respective staff members. While most of the documents are generic in understanding the case setting, the request for lessons learned files and TQ/ NCR registers were only made after preliminary analysis of the first round of interviews as it was revealed through analysis that such documents exist in the company. The list of documents collected for each case is mentioned below:

- Lessons learned files
- Team structure for the project/ Organogram
- Work Breakdown structure/ Network breakdown structure
- Project planning, Stage gates, Coordination/ Review meetings planned
- Overview of design reviews / project progress reviews/ analysis
- Proof of knowledge integration hurdles like TQ's, NCR's, quality reviews etc.

3.3 Case Description

The cases selected for this research according to the parameters listed in section 3.1 are **Deutsche Bucht BoP**, an OWF project off the coast of Germany, **Deutsche Bucht MBF** – a major sub-package of the Deutsche Bucht project and **Borssele III & IV**, off the Dutch coast. This section describes the background of these cases, emphasizing the uniqueness of each case. The data collected and analysis thereof is presented in the next chapter.

3.3.1 Deutsche Bucht BoP, Germany

Deutsche Bucht is an offshore wind farm located more than 100 km off the coast of Germany in North Sea. The wind farm is owned by a Canadian power company, Northland Power. Deutsche Bucht is its third wind farm in the North Sea. The EPC contract for the Balance of Plant (BoP) components of the project was assigned to Van Oord in August 2017. Van Oord is responsible for the design, engineering, procurement, construction and installation of the foundations, inter array cables and offshore substation, as well as the transport of the wind turbines. While the contract was awarded then, the internal works on engineering of components was already on-going.

The wind farm will have a grid connection capacity of 269 MW produced by 33 wind turbines of 8.4 MW each. Built at a CAPEX of €1.4 billion, the power generated will provide for nearly 328,000 households with sustainable energy annually. The 33 wind turbines are supported on 31 monopiles (plus transition pieces) and 2 mono-bucket foundations (part of next case). The installation of 31 foundations (monopiles) started in September 2018. By the end of January 2019, all monopiles with TP's were installed. Currently, the offshore substation is also installed and the mono-bucket foundations are under fabrication. The project is expected to be commissioned by the end of 2019.

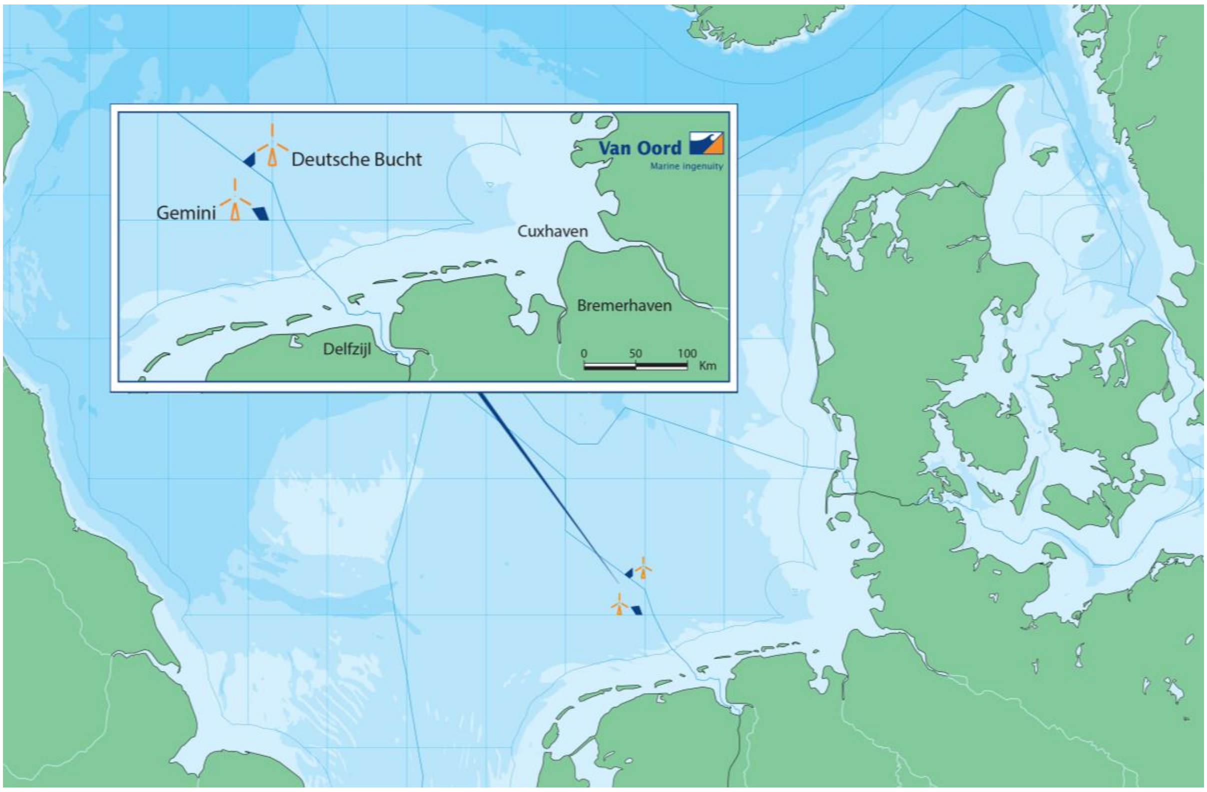


Figure 9 – Deutsche Bucht Location (source: Van Oord)

As mentioned before, 4 professionals from the contractor's (VO) side were interviewed per case. The list below summarizes the background and role of the interviewees:

- **DBU BoP 1 – Supply Chain Manager/ Project Engineer**
  The interviewee has been working for 5 years in Van Oord, out of which 3.5 years has been in the OWF sector. The interviewee was in charge of supply chain of the transition pieces for the foundation, positioned at the fabrication site for monitoring and supervising the fabrication process and communicate to the package manager and the client.

- **DBU-BoP 2 – Design Lead/ Manager**
  The interviewee has been working with VO for over 4 years and with its subsidiary for another 4 years. The interviewee was the design manager of the foundations Deutsche Bucht BoP project. While the detailed foundation design was done by Ramboll, the interviewee was responsible for all coordination, from foundation design to necessary coatings, electricals etc and was also involved for coordination of details during fabrication & consultation during transportation and installation to ensure the integrity of designed component.

- **DBU-BoP 3 – Interface Manager**
  The interviewee has been working at VO for 8 years. As interface manager for this project, the interviewee's focus has been on the process, to bring people from all packages together and clarify responsibilities and interfaces and monitor project interfaces in the later stages.

- **DBU-BoP 4 – Package Manager**
  The interviewee has been working at Van Oord for over 19 years in diverse roles and sectors. The interviewee was the package manager of foundation & Wind Turbine Generators at Deutsche Bucht BoP project, involved in all phases, from procurement till installation.

3.3.2 Deutsche Bucht MBF, Germany

Figure 10 – Mono-bucket foundation *(source: Universal Foundations)*

Deutsche Bucht, as stated in the previous case description also, is an offshore wind farm located more than 100 km off the coast of Germany in North Sea. The wind farm is owned by a Canadian power company, Northland Power. Deutsche Bucht is its third wind farm in the North Sea. The EPC(I) contract for the Balance of Plant (BoP) components of the project was assigned to Van Oord in August 2017. Hence, the contract implies EPCI of the foundations, inter array cables and offshore substation, as well as the transport and installation of the wind turbines. The wind farm will have a grid connection capacity of 269 MW produced by 33 wind turbines of 8.4 MW each. Built at a CAPEX of €1.4 billion, the project will power nearly 328,000 households annually. Out of the total 33 wind turbines, 2 are supported by mono-bucket foundations, which is the scope of this project. The 33 wind turbines are supported on 31 monopiles (plus transition pieces) and 2 mono-bucket foundations. Deutsche Bucht will be the first wind farm worldwide to test this new type of foundation structure under commercial operating conditions.

Mono 'suction' bucket

The Mono Bucket foundation consists of a 'suction bucket', a single steel cylinder on which a shaft is mounted. A transition piece and an 8.4-megawatt wind turbine will be installed on the shaft. The suction bucket structure becomes firmly embedded in the sea floor by its own weight and vacuum pressure, eliminating the need for pile driving and consequently for noise mitigation measures such as big bubble curtains. The new structure therefore benefits the environment because it causes less disruption to local porpoise populations and can be completely decommissioned at the end of its lifetime. The suction bucket installation responsibility vests with Universal foundations (the patented designer of the system). Further, the fabrication itself is done by three different parties (TP, Shaft & The Bucket), hence adding to its complexity.

For this case also, 4 interviews were conducted. Background and roles of interviewees is stated below:

- **DBU MBF 1 – Design Lead/Manager**
  The interviewee has been working for almost 2 years at Van Oord and for 7 years in total in the civil engineering industry. The interviewee is the design lead of the mono-bucket foundations used in Deutsche Bucht, also being involved in the design certification and contract negotiations with the client as well as the sub-contractors/ fabricators.

- **DBU-MBF 2 – Procurement Officer**
  The interviewee has been working since 2006 (13 years) in the offshore wind industry. He has worked as a superintendent at the vessel 'svanen', followed by working as a contracts manager. He has been working at Van Oord for the last 6 years and has been involved full time as the procurement officer for Deutsche Bucht project for the past 1.5 years.

- **DBU-MBF 3 – Package Manager**
  The interviewee has been working at Van Oord for 2 years and in the offshore wind industry for over 10 years. The interviewee is the package manager at Deutsche Bucht MBF project, involved in all phases of mono-bucket foundation, right from pre-tendering to design, fabrication and installation.

- **DBU-MBF 4 – Project Director**
  The interviewee has over 22 years of experience in the civil engineering industry with over 18 years on various projects at Van Oord. The interviewee is the project director of Deutsche Bucht project, in charge of the entire project team executing the EPCI contract for Deutsche Bucht, including the BoP and MBF part.

3.3.3 Borssele III & IV, Netherlands

Borssele 3 & 4 are offshore wind farms located in the Dutch North Sea, 22km off the coast of Zeeland in The Netherlands. The combined tender for two sites was awarded to the BLAUWWIND consortium in December 2016. A total of 26 bids were received from 7 parties/ consortia. The BLAUWWIND consortium partners are Partners Group** (45%), Shell (20%), DGE*** (15%), Eneco Group (10%) and Van Oord (10%). Shell and Eneco Group have also secured 15-year Power Purchase Agreements (PPAs) from the Consortium, under which each will buy 50% of the power generated by the wind farms. Van Oord will execute the "Balance of Plant" for the project, consisting of the engineering, procurement and construction of the foundations and inter array cables. The offshore substation Borssele Beta will be designed and constructed by TenneT. The project would be constructed at a capex of €1.3 billion. The project bid boasts a low subsidy application of 5.45 cents/kWh or €0.3 billion, excluding grid connectivity.

The project will have a grid capacity of 731.5 MW, produced by 77 wind turbines of 9.5 MW each. Total expected production is 3,000 gigawatt hours (GWh) per year, enough to power about 825,000 households. The 77 turbines would be fixed on monopile foundations (without transition pieces). The main installation work is due to start in the fourth quarter of 2019, with commercial production expected in early 2021. Currently , the second mock-up monopile has been installed.

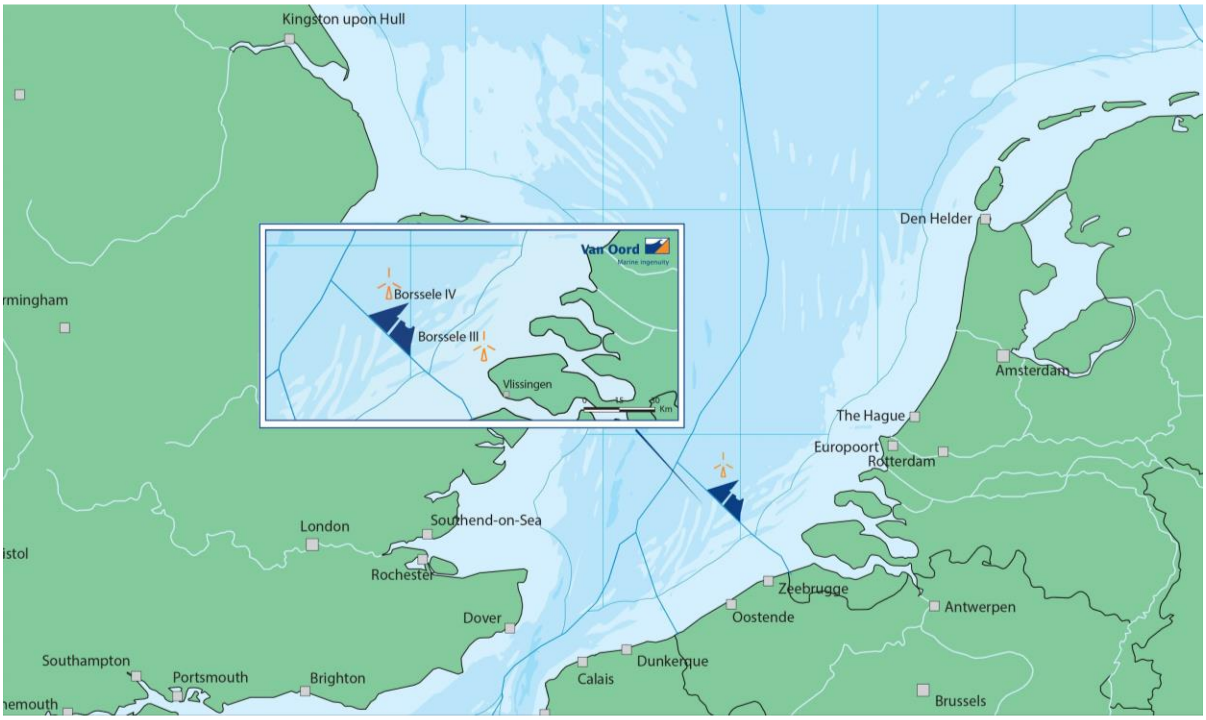


***Figure 11 – Borssele III & IV Location** (source: Van Oord)*

The list below summarizes the background and role of 4 interviewees which stated data for this case:

- **BOR 1 – Design Lead/Manager**
  The interviewee has over 10 years of experience in the offshore wind industry. The employee started to work at Van Oord in 2007 as a trainee. The interviewee is working on Borssele 3 & 4 as the design manager during the engineering phase.

- **BOR 2 – Design Lead/Manager**
  The interviewee has been working at VO for the past 6 years and in the current role for about 2 years. The interviewee is responsible for managing technical queries from all project participants, systems engineering and document control for the project, design management during the fabrication & installation phases.

- **BOR 3 – Package Manager**
  The interviewee has been working at offshore wind segment of the company for over 6 years. The interviewee is the package manager of foundation supply for the Borssele 3 & 4 project, involved in mainly managing the fabrication and supply of the monopile foundations in the project. There is a different package manager for the design and installation phases.

- **BOR 4 – Project Director**
  The interviewee has been working at Van Oord for over 10 years. The interviewee is the project director of Borssele 3&4 project and is responsible for supervising the entire project across disciplines and phases.

3.4 Data Analysis Methodology

Step 1
Inputs on various subjects like issues, positives, suggestions etc. were simplified, refined & merged with similar responses within the same case. This gave case wise lists of inputs on various subjects.

Step 2
Inter-case comparison was carried out on inputs on similar subjects. For e.g. issues cited by respondents from DBU BoP were compared with issues cited by respondents from other two cases. Many similarities were observed, analyzed & highlighted.

Step 3
Combined result on question about applicability of concepts (about tools/ practices/ issues/ positives) revealed that these are applicable to other components & even other projects within the company. Hence, combination of concepts was possible.

Step 4
This prompted the combination of results from step 2 & a comprehensive list of tools/ practices in use, issues & suggestions was compiled. This reflected on the regime of CKI in projects. These findings were assessed & arranged hierarchically based on commonality within responses from 12 interviewees. The remaining subjects like key PM challenges, positives etc. were arranged based on simpler commonality analysis, straight from step 2.

Step 5
The current regime was analyzed & presented not only in terms of the current order or system of CKI, but also in terms of the KI phases catered to by the regime & the sources of knowledge integrated.

Step 6
Next, to find the key issues, the issues from step 4 had to be streamlined further. For this intra & inter linkages between issues & suggestions from step 4 were evaluated.

Step 7
The previous step enabled reassessing the commonality of issues as some were ascertained by linkages with suggestions. This revised list of commonality yielded the key issues.

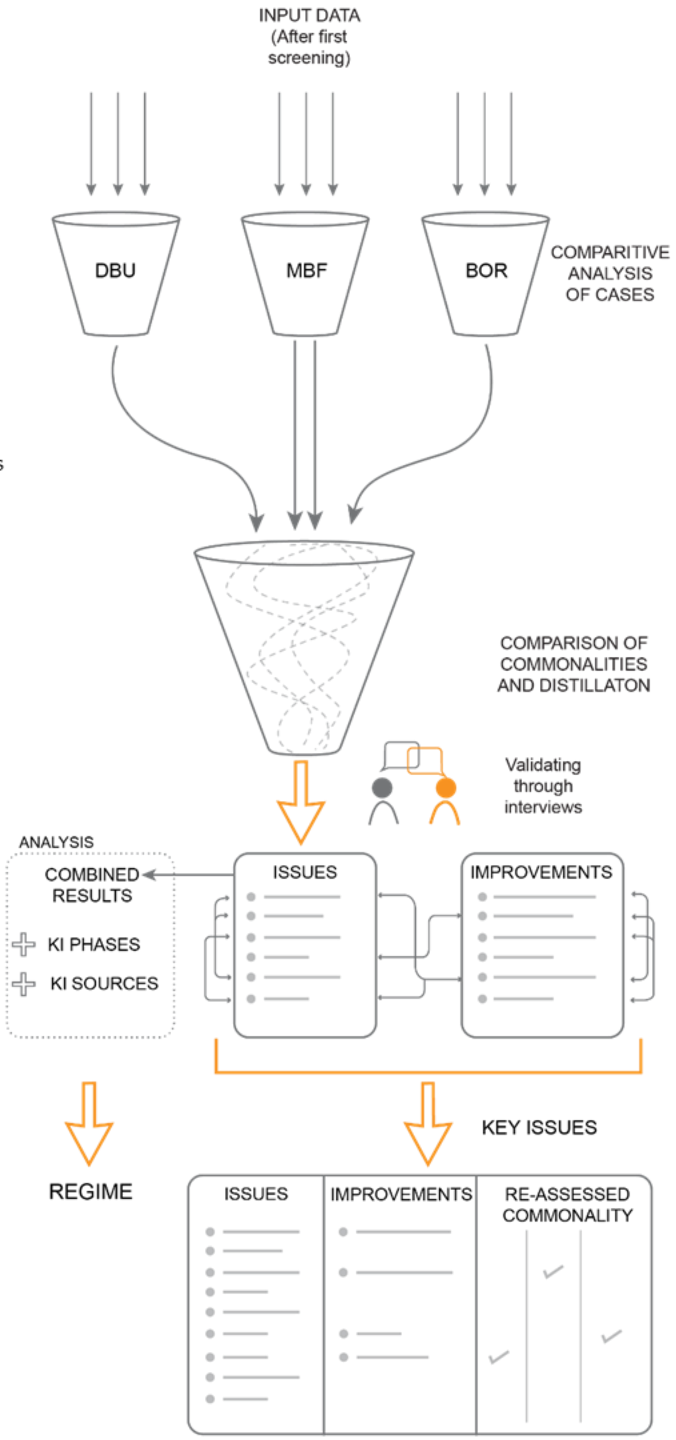


Figure 12 – Steps followed to analyze case data

The figure above summarizes the case analysis methodology followed in the next chapter.

4. Case Data & Analysis

In line with the case study methodology elaborated in the previous chapter, this chapter dives into analysing the 3 aforementioned cases, Deutsche Bucht BoP, Deutsche Bucht MBF and Borssele 3&4. The chapter is divided into two main parts. The first describes case data (through interviews) while the second analyses it in detail complying with the structure presented in section 3.4. This chapter deciphers the current regime of CKI in OW projects and also finds the key issues in the regime, further fulfilling two sub-objectives of this research. The latter finding also sets the course to devise recommendations for optimizing construction knowledge integration in the sector.

4.1 Case Data

This section presents case data gathered through interviews. The interview data is presented first in each sub-section followed by the respective first-level screening of the data. Some clarifications are pre-stated below to increase the readability and understandability of the interview tabulations in the following sub-sections:

- Some phrases may seem to be repeated. This is only in cases where the same core concept was being described by the interviewees. It should be noted that it is not an exact transcription but instead an analytical summary of their core concept.
- Due to the semi-structured nature of the interview and the modification in the protocol after the first round, certain questions were not posed to some interviewees. Those have been shown as 'N/A' (not applicable).
- An attempt has been made to arrange the interviews in ascending order of seniority or broadness of scope in the project. For e.g. a project director would be to the right of design manager

4.1.1 Deutsche Bucht BoP, Germany

The first subject in the table below shows the main project management challenges in OWF projects according to the interviewees. Since inputs from 2 out 4 interviewees are available, it does not converge sharply. The reason why analyzing project management challenges is important as these can also be inferred as direct obstacles for construction knowledge integration. In conclusion, top project management challenges based on staff from this case are:

- Time constraints in execution
- Communication between the project participants and the client
- Extensive documentation/ tests for client approval

Table 6 – DBU BoP – Project Management challenges in OWF projects

Subject	DBU BoP 1	DBU BoP 2	DBU BoP 3	DBU BoP 4
General				
Main project management challenges	Communication between the project participants and the client;	Time constraints in execution; Extensive documentation/ tests for client approval;	N/A	N/A
Construction knowledge integration – concept & importance				
Initial perception on construction knowledge integration	Implementing all the knowledge from design into the fabrication process;	The interviewee was not sure of the term & asked for explanation but agreed completely to the elaboration;	Using the knowledge, practices from a certain work package to another;	Activity of sharing information/ knowledge from different projects to use in developing other projects
Is CKI an issue for OWF sector?	Yes, as it is difficult to get all the requirements applied during the design & fabrication. Some are forgotten or ignored;	Yes, as it is difficult to get timely input from all participants;	Yes, an issue in the sector to a certain extent as knowledge often available but difficult to find; still integration is important to do;	Yes, in the company, due to inexperienced staff, lack of foresight in engineers & rapidly evolving industry
Importance of knowledge integration in project management?	Very important as improper design would not get certified & hence not go for fabrication;	N/A	Important, as it helps in executing the project as per design, standards & requirements;	Important, as it helps manage client expectations, contracts, design responsibilities, processes etc.
Current CKI regime				
Current steps followed in knowledge integration	Design certification helps in KI; List of requirements through systems engineering docs.; Time allotted in weekly meetings for lessons learned discussion with sub-contractors; Monthly progress meetings with client, VO reps. & sub-contractors;	Referring to similar projects in past; Inputs from inhouse experts; Design reviews including installation staff & other experts;	Informal consultation to inhouse/ external experts, mostly reactive to problems; Lessons learned database; Contacting/ referring to similar/ relevant past projects; Feedback to corporate engineering dept. through end-of-works reports;	Organic interactions with inhouse or external experts; Lessons learned sessions; 'Trelo' was used as an exclusive groupware software to plan and share info within the team;
Issues in construction	No integrated knowledge database;	Lack of sources for fabrication knowledge. Experts	Actions associated with project	Missing realization of long-term effects and risks of

Subject	DBU BoP 1	DBU BoP 2	DBU BoP 3	DBU BoP 4
knowledge integration	No software for interface/ quality management; Working with lessons learned not defined as standard work practice; Difficult to obtain info from lessons register as they are not straight-forward; Design certification severely underestimated in terms of time & resources required due to lack of awareness of process Certain standard templates missing like for quality inspections;	hired externally when needed; Inputs hard to get due to time crunch; Inputs hard to adopt when received at a later stage;	processes are informal in nature; The competencies of quality mgmt., fabrication knowledge, noise mitigation & electrical are weak for foundations; Lessons registered are very project/ circumstance specific; Difficult to retrieve knowledge from lessons database; Difficult to describe complex information in database; Opportunity lost to moderate designs when engineering is sub-contracted;	decisions & context like soil conditions, component design in engineers; Poor inter-project learning; knowledge stays within respective teams; teams start afresh every project; Lessons learned database unstructured, unfiltered, not merged well, feels like an obligation; Using lessons learned not defined as standard work practice; Missing fabrication specialists/ knowledge;
Positive KI tools/ practices/ steps in current regime?	Continued involvement of design manager in the fabrication phase Fixed templates for correspondence with client, sub-contractor Design was fully complete before fabrication; Structured weekly meetings; ROC drills;	N/A	Current size of company/ dept. still makes informal acquaintances possible; Offshore project teams located in a single building also helps in knowledge sharing; Efforts to formalize KI & feedback to corporate dept.;	Semi-organic interaction can maximize staff creativity, enthusiasm, resourcefulness & provide new insights & opportunities; Lessons learned sessions at end of package/ project are useful;
Steps for knowledge integration improvements	Information/ knowledge/ scope to be shared with all participants;	Proactive to gather inputs from experts; When design is outsourced, there is more time for integration. When design is inhouse, design or integration are neglected;	Training/ involving engineers to consider impact of their decisions on constructability, other drivers; Formalize Knowledge Integration Process;	Mix junior & senior staff in sub-teams to maximize intra team learning; A convenient knowledge database for core concepts, standards, best practices, lessons, templates for monitoring & reporting etc.;

Subject	DBU BoP 1	DBU BoP 2	DBU BoP 3	DBU BoP 4
			Pro-active involvement rather than reactive;	Formalizing pre-requisite information & steps for engineering processes, preparation works, knowledge sharing etc. Use 4D BIM & modernize engineering processes; Integrated groupware solutions, same for entire organization;
Integration scenario generic to entire project?	All concepts/ suggestions are generic to the project across components;	Overall Similar. Issues for foundations increase with complexity/ no. of interfaces like TPs	N/A	All concepts/ suggestions are generic to OWF projects in the company;
Indicators for gaps in knowledge integration	High product & process NCR's; High TQ's;	High TQ's, NCR's etc. but No.'s can be misleading	Process NCR's (not product).	High Remedial works, costs register; TQ's & NCR's. Analysing can show which questions/ issues repetitive;
Less construction knowledge integration would impact project 'Value':				
Increase Cost	Yes, due to re-work	Yes	Yes	Yes
Increase duration	Yes, due to re-work	Yes	Yes	Yes
Reduce Quality	Yes, obviously	Yes	Yes	Yes
Reduce Safety	Yes	Yes	Yes	Yes
Tools/ Practices for construction knowledge integration				
Tools/ Practices for construction knowledge integration	Quality management software like 'Relatics'; Integrated groupware solutions which increase communication, option of questions open to all; People should be able to feed lessons	Formalize design review and learning processes; Strengthen fabrication knowledge; Show senior management that knowledge integration benefits entire project;	The systems engineering approach depending on team's experience (more experienced team need less systems engineering); Early involvement of corporate experts, experienced staff, all relevant disciplines;	In addition to suggested improvements, identify weak spots/ areas/ competencies and develop KPI's for knowledge integration;

Subject	DBU BoP 1	DBU BoP 2	DBU BoP 3	DBU BoP 4
	whenever they realize it & not wait for sessions to register;	Technology based tools only useful in clash detection. Only meetings help resolve them		

DBU BoP – CKI Concept & Importance

The next step evaluated the respondents' understanding of the concept of construction knowledge integration and then validated its need in the OW sector. Firstly, interviewee's perception on construction knowledge integration was gathered and then, if it deviated largely from the definition used in this research, the latter was discussed. Out of the 4 interviewees, 3 stated their perception and 1 refrained. If compared with the theoretical definition of CKI, the 1st respondent's definition did not specify multi-disciplinary integration of knowledge which is used for designing the component. The respondent simply pointed to integrating design knowledge for fabrication. Further, the 3rd respondent did not specify that knowledge to be integrated has to be aligned for effective construction. Lastly, the 4th respondent did not specify CKI for the ongoing project, but mainly for future projects. The theoretical definition of CKI was discussed with the 2nd interviewee after which he understood the concept. It was observed that the interviewee had knowledge of the concept but could not quickly associate with the term.

All 4 respondents unanimously agreed that construction knowledge integration is an issue for the company, but 3 chose to state it for the OWF sector as well. However, all respondents had different reasons to state like difficulty in managing requirements, find inputs or the engineers missing foresight. All 3 interviewees unanimously agreed that knowledge integration is an important part of project management as it helps fulfil project objectives.

DBU BoP – Current CKI Regime

For the <u>current tools/ practices</u> in use for knowledge integration, the following list is concluded (depending on different types of tools/ practices stated in the answers).

- List of requirements through systems engineering docs.
- Lessons learned sessions/ register
- Inputs from inhouse/ external experts
- Referring to past projects
- Progress meetings/ Design reviews
- Feedback through end-of-works reports
- Integrated groupware solutions
- Design certification

After understanding the current practices, focus was shifted to discussing <u>issues</u> in construction knowledge integration. Finding the key issues is one of the main outcomes expected from the case study process and similar to the method above, the following list of issues is compiled:

- The competencies of quality mgmt., fabrication knowledge, noise mitigation & electrical are weak for foundations
- Lessons learned database unstructured, unfiltered, not merged well, feels like an obligation, difficult to retrieve knowledge
- Working with lessons learned not defined as standard work practice
- Lessons registered are very project/ circumstance specific
- Difficult to describe complex information in database
- No integrated knowledge database
- No software for interface/ quality management
- Poor inter-project learning
- Certain standard templates missing like for quality inspections
- Inputs hard to get due to time crunch
- Inputs hard to adopt when received at a later stage
- Actions associated with project processes are informal in nature
- Opportunity lost to moderate designs when engineering is sub-contracted
- Missing realization of long-term effects and risks of decisions & context like soil conditions, component design in engineers
- Lack of awareness of resources required for design certification (case specific)

A new question was added after the first round of interviews, which asked the interviewees to state positive tools/ practices for knowledge integration which they would like to preserve. It is often easier to state bad things rather than good and hence this question probed the interviewees to reflect more on the current knowledge integration regime and state its advantages and disadvantages. The following list of good practices is compiled:

- Lessons learned sessions at end of package/ project are useful
- Continued involvement of design manager in the fabrication phase
- Fixed templates for correspondence with client, sub-contractor
- Design was fully complete before fabrication (DBU BoP)
- Structured weekly meetings
- ROC drills
- Current size of company/ dept., proximity to other project teams
- Efforts to formalize KI
- Feedback to corporate dept.
- Organic interaction

The consequent question investigated the possible improvements in the regime. The respondents highlighted the ideal practices and gaps which yielded an extensive list of improvements. Since this question conceptually matches with the last question of the interview, the results of both these questions will be combined to generate more reliable suggestions for improvement. The same will be done for the next two cases as well.

The next question was aimed at understanding the applicability of the issues/ practices on other components or the sector. All interviewees stated that the concepts shared by them are generic to the project as a whole and applicable to other components as well. One of the interviewees stated that issues can increase for foundations with increase in technical complexity, but arguably, this can also be applicable to other components.

Additionally, in an attempt to gauge the status of KI in a project, the interviewees were asked for key indicators of knowledge integration lapses in the project. The list and frequency of indicators stated are:

- High no. of **Technical Queries (TQs)** – 4/4
- High no. of **Non Conformance Reports (NCRs)** – 3/4
- High no. of **Process NCRs** – 1/4
- High no of entries in **Remedial works register** – 1/4

DBU BoP – Impact of CKI on 'Value'

The next subject covered construction knowledge integration's impact on value (cost, time, quality and safety) of the project. As can be seen in **Table 6**, all (4 of 4) respondents agreed that less construction knowledge integration would cause an increase in cost and project duration while reducing the quality and safety aspects of the project.

DBU BoP – Suggestions for CKI Improvement

The last subject of discussion was on the possible tools/ practices that would help in construction knowledge integration. The research considers these tools/ practices/ measures as the key to optimizing knowledge integration. This list was further combined with diverse list of improvements suggested before and is shown below:

- A single efficient knowledge database for core concepts, standards, best practices, lessons, templates for monitoring & reporting etc.
- Formalizing pre-requisite information & steps for engineering processes, preparation works, knowledge integration etc.
- Information/ knowledge/ scope to be shared with all participants
- Training engineers to develop foresight of decision impacts on project objectives;
- Mix junior & senior staff in sub-teams to maximize intra team learning;
- Use 4D BIM & modernize engineering processes
- Quality management software like 'Relatics'
- Convenient register for spontaneous lesson additions
- Strengthen fabrication knowledge
- Increase awareness to benefits of CKI to company/ senior management
- Early involvement of corporate experts, experienced staff, all relevant disciplines;
- Identify weak spots/ areas/ competencies and develop KPI's for knowledge integration
- Proactive to gather inputs from experts
- Outsource design activities

Certain improvements/ tools/ practices suggested like Integrated groupware solutions and systems engineering approach are already undergoing major developments in the company, but have come up in the list maybe because of unavailability at the time when the project was being executed.

4.1.2 Deutsche Bucht MBF, Germany

Table 7 – DBU MBF – Project Management challenges in OWF projects

Subject	DBU MBF 1	DBU MBF 2	DBU MBF 3	DBU MBF 4
General				
Main project management challenges	Time constraints in execution; Lower cost margins; Sub-contractors/ fabricators pre-selected by client for DBU MBF;	To control the project within budget; Overruns can be caused by certification/ fabrication delays, poor estimation/ planning etc.	Managing various technical & commercial risks;	Extensive no. of project participants (stakeholders, suppliers, sub-contractors); Lot of information to be managed;
Need for construction knowledge integration				
Initial perception on construction knowledge integration	Using multiple specialized input in project;	Integrating/ storing knowledge from experience & use it for future projects; Often knowledge exists but is not used or carried over;	Respondent was unclear at first. After elaboration, interviewee grasped the concept & cited multi-project environments as a reason;	To have more integrated engineering, planning, budgeting considering construction/ fabrication activities;
Is CKI an issue for OWF sector?	Yes, as expert input required from several project participants	Not really an issue but big scope for improvements & important to be done in project;	Cannot be said for sector but certainly for the company as improvements are constantly needed;	Not much of an issue but should be a key focus;
Importance of knowledge integration in project management?	N/A	Important as helps in project decisions;	Very important as it helps to avoid past mistakes & preserve knowledge for future use	Important, as a lot to be gained when design is integrated with fabrication;
Current CKI regime				
Current steps followed in knowledge integration	'Lessons Learned' database; Document sheets (stage feedback) Inputs from inhouse experts; Formal notices/ queries like TQ's	Knowledge centralized by creating specialized teams like cables, foundations etc. Lessons learned register; End of project/ package discussions; Information lunches; Using past data to assess or detail tender invitations;	Lessons learned sessions before start of project works; Face to face meetings with inhouse experts/ team members; Face to face interactions with team members of past relevant work packages; Action-trackers were created & followed;	Lessons learned sessions, register & monthly lessons learned flashes that are released; Webinars about ongoing projects within company along with interactive discussions – open to project/ package managers; Intranet;

Subject	DBU MBF 1	DBU MBF 2	DBU MBF 3	DBU MBF 4
		Discussions with sub-contractors/ fabricators during tendering process can help in design optimization;		
Issues in construction knowledge integration	Lessons learned database not referred; Troublesome when inhouse expertise unavailable; Sub-contractors not contacted for inputs due to mis-trust; Lack of staff with sub-contractor for coordination;	Learning happens in moments & difficult to record these moments; Lessons learned database inefficient in screening required knowledge; Staff gives less time to register knowledge due to time constraints; End of project/ package reports not openly shared maybe due to confidentiality; Electrical/ SCADA knowledge missing; Full access of documents prepared should be provided even to youngest staff for reference;	Lessons listed in registers are either too long or short; Lack of fabrication knowledge; Difficult to communicate tacit knowledge/ experience through writing; only face to face interactions or physical involvement work; Time constraints hindering personal interactions;	Current designers are ambitious & lack foresight of influence in fabrication; Difficult to extract information from listed knowledge due to different type of input – lessons are broad or deep; The company did not raise alarm on constructability of mono-buckets due to inexperience & late involvement; Incomplete design was passed on to company due to financial close; Risks have been underestimated for mono-bucket due to inexperience; Diverse geographical locations of the team members hindered knowledge sharing;
Positive KI tools/ practices/ steps in current regime?	N/A	Lessons learned sessions;	Monthly lessons learned sessions by E&E department; Standard templates like for DPR's;	Standard forms/ templates like risk registers, trade-off matrices etc.;
Steps for knowledge integration improvements	Refer to lessons learned; Regular sessions for design/ process improvement with project participants including design	Weekly/ Bi-weekly lessons learned sessions instead of monthly; Register knowledge/ lessons in a smart	Make lessons learned sessions by E&E more accessible digitally for live participation from other locations; Formalize & make participation in	Involving all participants like planners, suppliers, fabricators for regular design optimization during the phase;

Subject	DBU MBF 1	DBU MBF 2	DBU MBF 3	DBU MBF 4
	certifier, fabricator, installation experts; Data management in contracts;	standardized structure; Tender/ project managers should be obliged to absorb past lessons learned; More resources can be put to create/ enhance specialized knowledge/ engineering depts.;	lessons learned sessions mandatory;	Lean knowledge – considering only top lessons, risks; Lessons should be stated in broad manner to make people think; Keep removing lessons after stipulated period;
Integration scenario generic to entire project?	Similar issues;	Concepts stated so far are generic to components & projects within the company;	Concepts stated generic to all components & even projects within the company;	N/A
Indicators for gaps in knowledge integration	High TQ's, NCR's, fabrication support	High questions raised during certification/ negotiation process; review sheets can be referred for this;	More no. of things gone wrong; High NCR's.	More no. of TQ's as it shows lesser alignment & unclear subjects between project participants;
Less construction knowledge integration would impact project 'Value':				
Increase Cost	Yes	Yes, largely;	Increased risk;	Yes, obvious;
Increase duration	Yes	Yes, largely;	Increased risk;	Yes, obvious;
Reduce Quality	**No**, Independent body certifies quality	Yes, largely;	Increased risk;	Yes, obvious;
Reduce Safety	Yes, (installation works)	Yes, largely;	Increased risk;	Yes, obvious;
Tools/ Practices for construction knowledge integration				
Tools/ Practices for construction knowledge integration	All relevant people to be involved at an early stage; Formalize process to involve experts at pre-decided/ relevant intervals; Sending out document sheets to all participants together;	Responsibilities should be set for knowledge integration activities; Not only major lessons, but smaller lessons should also be recorded in standardized format;	Increase no. of interactive sessions; Improve integration of past project data for tendering, estimation, project controls; Pre-arranging team of technical experts to address technical complexity;	Webinars or inter-project sessions should be extended to maximum team members; Lessons learned sessions should be accessible even to travelling members; Fabrication knowledge should be built by inducting experts in company;

DBU MBF – Key PM Challenges

The top project management challenges based on staff from this case are:

- Excessive information to be managed
- Time constraints in execution
- Extensive no. of project participants
- Managing various technical & commercial risks
- Controlling the project within budget;
- Lower cost margins;

DBU MBF – Need for CKI

The next subject was to evaluate respondents' understanding of the concept of CKI and then validating the need for it in the OW sector. As mentioned in the previous case, here also the perception was asked first and if it largely varied from theory, it was discussed for reference. Out of the 4 interviewees, 3 stated their perception and 1 refrained. The 4th interviewee's perception was same as the theoretical definition of construction knowledge integration. There was slight difference in the definitions of 1st and 2nd interviewees from the 4th/ theoretical as the former did not state the alignment of varied disciplines to effective construction and the latter did not specify CKI for the ongoing project, but mainly for future projects. The theoretical definition of CKI was discussed with the 3rd interviewee as he refrained from stating his perception at first. After the discussion, the interviewee immediately understood and stated multi-project environment as a possible cause for gaps in CKI.

Two of four interviewees agreed that construction knowledge integration is an issue for the company (not the sector). The dissenting respondents, however, stated that there is a huge scope for improvement and important to be done in a project. In similar lines, the next question focused on whether knowledge integration forms an important part of project management. All 3 responses stated it to be very important, although reasons for importance varied from enabling project decisions to avoiding mistakes and prevent knowledge for future use. Noticeably, even the 3rd interviewee who was not able to state the definition of CKI at first, confirmed its importance in a project in the next two questions, confirming that the concept of CKI was well absorbed in the discussion.

DBU MBF – Current CKI regime

For the current tools/ practices in use for knowledge integration, the following list is concluded (depending on different types of tools/ practices stated in the answers).

- 'Lessons Learned' sessions/ database
- Monthly lessons learned flashes
- End of project/ package discussions/ feedback (Document sheets)
- Inputs from inhouse/ external experts/ team members(face to face meetings preferred)
- Formal notices/ queries like TQ's
- Using past data to assess or detail tender invitations
- Discussions with sub-contractors/ fabricators during tendering process
- Face to face interactions with team members of past relevant work packages;

- Action-trackers were created & followed
- Webinars with interactive discussions – open to project/ package managers
- Intranet
- Information lunches

The following list of issues is compiled after analysing respective case data:

- Lessons learned database not referred
- Difficult to extract information from listed knowledge due to different type of input – lessons are broad or deep
- Troublesome when inhouse expertise unavailable
- Sub-contractors have different drivers & lack staff for coordination (also verified by lessons learned register)
- Hassle to record momentary learnings
- Knowledge registering hindered due to time constraints
- End of project/ package reports not openly shared maybe due to confidentiality
- Fabrication/ Electrical/ SCADA system knowledge missing
- Hassle to arrange documents for reference by younger staff
- Difficult to communicate tacit knowledge/ experience through writing
- Time constraints hindering personal interactions
- Current designers lack foresight of influence in fabrication
- Diverse geographical location of the team members hinders knowledge sharing (case specific)
- The company did not raise alarm on constructability of mono-buckets due to inexperience & late involvement; Incomplete design was passed on to company due to financial close (case specific)
- Risks have been underestimated for mono-bucket due to inexperience (case specific)

Positive tools/ practices according to the interviewees is stated below. Quite visibly, the list received for positives from 3 responses is much smaller as compared to the previous case. This question was added after the first round of interviews.

- Lessons learned sessions
- Standard forms/ templates like risk registers, trade-off matrices, DPR's etc.

The next question was about possible improvements in the regime, having gathered insights on existing tools, issues and positive practices. Like the previous case, owing to diverse list of responses and similarity to the last question in the protocol, it would be more reliable to combine these responses with the responses for the last question.

The next question was aimed at understanding the applicability of the issues/ practices listed till now on other components or the sector. All 3 responses received mentioned that the concepts shared by them are generic to the project as a whole and applicable to other components as well. However, it is worth noting that certain project specific issues might be exclusive and not dominant in other projects.

Responses on key indicators of knowledge integration gaps in the project and their commonality in responses is stated below:

- High no. of **Technical Queries (TQs)** – 2/4
- High no. of **Non Conformance Reports (NCRs)** – 2/4
- Extra sanctions requested as **Fabrication Support** – 1/4
- High no of questions in **Review Sheets** – 1/4

DBU MBF – Impact of CKI on 'Value'

The next subject covered construction knowledge integration's impact on value (cost, time, quality and safety) of the project. As can be seen in the table above, all respondents agreed that construction knowledge integration has an impact on the cost, duration and safety aspects of project value. Where 3 out of 4 respondents stated a large inverse correlation (low CKI reducing value aspects) for cost, duration and safety, one respondent stated it increases the risk of inverse correlation as some projects get lucky and overcome poor knowledge integration. 3 out of 4 respondents also stated inverse correlation for quality (again 1 out of 3 cited increased risk), but 1 respondent dissented saying quality is assured by an independent certifier which assures quality of end product.

DBU MBF – Suggestions for CKI improvement

The combined list of suggested tools/ practices for CKI and improvements in the regime is stated below:

- Regular sessions for design/ process improvement with all project participants including design certifier, fabricator, planners, installation experts etc. starting at early stages
- Weekly/ Bi-weekly lessons learned sessions instead of monthly
- Register knowledge/ lessons in a smart standardized structure
- Lessons should be stated in broad manner to make people think
- Not only major lessons, but smaller lessons should also be recorded in standardized format
- Keep removing lessons after stipulated period
- Lean knowledge – considering only top lessons, risks
- Fill missing competencies inhouse like fabrication, electrical, quality
- Enable remote participation for lessons learned sessions by E&E
- Webinars or inter-project sessions should be extended to maximum team members;
- Formalize process to involve experts at pre-decided/ relevant intervals, can be mandatory, increase no. of sessions;
- Responsibilities should be set for knowledge integration activities;
- Improve integration of past project data for tendering, estimation, project controls;
- Sending out document sheets to all participants together;
- Data management in contracts

Certain improvements/ tools/ practices might contradict or may seem unconventional for inclusion in the system, like one respondent saying lessons registered should be broad, more lean while other is suggesting inclusion of smaller lessons as well. An argumentation to conclude the majority views has been presented in the discussions section.

4.1.3 Borssele III & IV, Netherlands

Table 8 – BOR – Project Management challenges in OWF projects

Subject	BOR 1	BOR 2	BOR 3	BOR 4
General				
Main project management challenges	Time constraints in execution. Hence preparation should be perfect; Several project participants & interfaces to manage; Lack of experienced staff as industry is relatively new;	Time constraints in execution. Hence preparation should be perfect; Increasing technical complexity of components & the sector;	N/A	Extensive no. of stakeholders & project participants. They have changing requirements through the project; Projects with government subsidies have to comply with extra legislations;
Need for construction knowledge integration				
Initial perception on construction knowledge integration	The interviewee felt the term was a bit vague at first but stated that there is a lot of specialized knowledge to be integrated in the projects.	The experience one gains from science or past projects to improve future projects;	Integrating knowledge required to fabricate, install components in the project. Like knowledge on material, welds, practices, tools etc.;	Using all knowledge from design, market & participants in the project;
Is CKI an issue for OWF sector?	Yes, as it is difficult to integrate design-fabricator-installation inputs;	Yes, as technical complexity is increasing. Integration would support competitive & efficient projects;	Quite Evident as it can be seen in a lot of hassles faced during the project;	Not an issue but there is much scope for improvements;
Importance of knowledge integration in project management?	N/A	N/A	Important, as it affects decision-making in the project	Important since it can prevent mis-happenings in the project;
Current CKI regime				
Current steps followed in knowledge integration	Pre-tendering coordination with fabricators; Design reviews, formal queries; Physical mock-up of components; Inputs from inhouse experts;	Lessons learned log by team & board members; Monthly lessons learned lunch sessions; Bi-weekly project team meetings (all participants including	Involving installation experts (OCM's)in tender & design stages; Inputs from inhouse & external experts; Monthly lessons learned lunch sessions;	Systems engineering documents impart client requirements; Lessons learned sessions/ register; Coordination meetings to manage interfaces;

Subject	BOR 1	BOR 2	BOR 3	BOR 4
	Referring to similar projects in past;	fabricator); Weekly engineering meetings; Physical mock-up of components;		ROC drills (drills of installation processes) & physical mock ups; takeaways concluded in report; Operational meetings within package managers for inter-project learning;
Issues in construction knowledge integration	Hard to focus because of time crunch Troublesome when inhouse expertise unavailable; Late fabricator selection & late involvement of installation experts delays integration, causes rework; Lessons learned database is inconvenient & unstructured; Company feels early fabricator involvement reduces bargaining advantage; makes fabricator specific design	No single platform for interface management; Diverse geographical locations of project participants/ suppliers; Lack of experienced staff as industry is relatively new; knowledge will increase with experience;	Lack of standard system/ protocol for knowledge integration (the who, how, what, when of knowledge source); lack of awareness, newness of sector & affinity to flexibility are main reasons; Team members not aware of major decision making processes, like choice of foundation type etc.; Difficult to know which specific experts to contact; Designers lack practical & commercial knowledge; Listing/ referring to lessons learned is a hassle; lessons lost since only registered monthly; no incentive to list lessons as no info received in return; No steps to facilitate inter project learning	Lack of awareness of existing knowledge & sourcing methods; Past discussions/ decisions in project difficult for new members to grasp due to poor storage; Difficult to screen knowledge from lessons register due to no. of lessons; Improper descriptions of lessons, hence calling the person directly is preferred; Every knowledge type has a different database/ type like systems engineering, lessons learned, templates etc. Fabrication experts, quality inspectors & electrical experts are limited of missing in-house;
Positive KI tools/ practices/ steps in current regime?	N/A	N/A	Increasing focus on lessons learned sessions/ register;	ROC drills & mock-ups are good initiatives. Help optimize interfaces & prevent issues in

Subject	BOR 1	BOR 2	BOR 3	BOR 4
			Intranet (news flashes) give company updates; Periodic review meetings among project directors; Required expertise is sanctioned; Company staff is helpful;	implementation/ installation;
Steps for knowledge integration improvements	Share virtual model developed inhouse with fabricator to save latter's effort; Develop system for inter-project learning; Integrating expert knowledge early in the process, like installation input;	Training programs like technical traineeships for inhouse engineers for rapid knowledge gain;	Lessons learned sharing/ registering should be formalized/ refined & made convenient to note at shorter voluntary intervals; Inter-project reviews/ sessions to increase inter-project knowledge;	Single more interactive and accessible knowledge database;
Integration scenario generic to entire project?	Concepts described on basis of foundations; similar for rest BoP	Concepts described on basis of foundations; similar for rest BoP	Concepts described generic to all components, only technical knowledge differs;	Concepts describes above are generic to the project except missing competencies which are foundation specific;
Indicators for gaps in knowledge integration	High NCR's etc.;	High TQ's High NCR's etc. but No.'s can be misleading;	High TQ's, High NCR's List of contract variations;	High process & product NCR's; Long-list of lessons learned;
Less construction knowledge integration would impact project 'Value':				
Increase Cost	Yes (Indirectly)	Yes (hard to measure)	Yes	Yes, definitely;
Increase duration	Yes	Yes	Yes	Yes, definitely;
Reduce Quality	Yes	Yes	Yes	No. Makes quality inspection difficult.
Reduce Safety	No	Yes (hard to measure)	Yes, during installation mainly;	No, since safety norms mandatory;
Tools/ Practices for construction knowledge integration				
Tools/ Practices for	Component physical mock-ups;	Employees find it challenging to	Standardized & convenient,	Review meetings with representation

Subject	BOR 1	BOR 2	BOR 3	BOR 4
construction knowledge integration	Method statements (feedback system), design reviews; Formalize integration process; Trade-off (cost-time-quality-safety benefits) matrices to motivate teams & management to invest in knowledge integration efforts;	conclude lessons learnt. Casual sessions to discuss them helps conclude learnings, like monthly lunch sessions in Borssele; Imparting responsibilities like concluding lessons learnt would help; Continue to participate in industry wide knowledge sharing platforms like JIP's (Joint Industry Practices);	integrated knowledge database of knowledge, lessons learned, list experts etc. instead of excel database; Intranet to be detailed further; Detailed organograms with precise expertise listed; Standardized protocol for project processes, like how to handle a TQ;	from all project participants; External experts should justify their inputs; Quality inspectors should be hired by the company;

BOR – Key PM Challenges

The top project management challenges based on staff from this case are stated below. Data from 3 out of 4 interviewees is available for this question.

- Time constraints in execution
- Extensive no. of project participants, interfaces & their requirements to be managed
- Lack of experienced staff in sector
- Increasing technical complexity of components/ sector
- Project may face extra legislations/ scrutiny due to govt. subsidies

BOR – Need for CKI

The next subject was to evaluate respondents' understanding of the concept of construction knowledge integration and then validating the need for it in the OW sector (**Table 8**). Firstly, interviewee's perception on construction knowledge integration was gathered and then, if it deviated largely from the definition used in this research, the latter was explained. All 4 respondents attempted to sum up their perception of construction knowledge integration. The definition of 3rd respondent was fully in line with the theoretical version. The 3rd interviewee even went on to state examples of specific knowledge areas for foundations/ steel works like welds, material, machine tools, etc., which makes it even closer to the definition in section 2.1. The 1st, 2nd and 4th respondents had slightly different perceptions. The 1st and 4th respondent did not explicitly state that knowledge integration here is aimed at increasing construction efficiency. The 2nd respondent did not state that the integrated knowledge can also be used for ongoing projects and not only future ones.

Three of four respondents agreed that construction knowledge integration is an issue for the company and the sector due to difficulties in integrating certain competencies and increasing complexity in the sector. The 4th respondent did not see it as an issue but mentioned that there is room for improvement.

The 3rd and 4th respondent also stated that knowledge integration in itself is important for project management as it helps in decision making and avoiding mistakes. Noticeably the 4th respondent did not see it as an issue but confirmed its importance, reinstating the need for optimization of CKI.

BOR – Current CKI regime

For the current tools/ practices in use for knowledge integration, the following list is concluded (depending on different types of tools/ practices stated in the responses).

- ROC drills (drills of installation processes) & physical mock ups
- Lessons learned sessions/ register, maybe monthly
- Pre-tendering & design coordination with fabricators/ installation experts (OCM's)
- Inputs from inhouse & external experts
- Formal queries
- Design reviews
- Referring to similar projects in past
- Design reviews/ Weekly engineering meetings/ Bi-weekly project team meetings (all participants including fabricator)
- Systems engineering documents impart client requirements
- Operational meetings within package managers for inter-project learning

The following list of issues is compiled after analysing respective case data:

- Lessons learned database is inconvenient & unstructured, difficult to retrieve knowledge, fill momentary lessons
- No incentive to list lessons as no info received in return
- No single platform for interface management
- Every knowledge type has a different database/ type like systems engineering, lessons learned, templates etc.
- Diverse geographical locations of project participants/ suppliers
- Lack of experienced staff as industry is relatively new
- Lack of standard system/ protocol for knowledge integration (the who, how, what, when)
- Late fabricator selection/ installation team formation delays integration
- Team members not aware of rationale behind major decisions/ changes
- Designers lack practical & commercial knowledge
- No steps to facilitate inter project learning
- Lack of awareness of KI benefits, existing knowledge & sourcing methods
- Troublesome when inhouse expertise unavailable
- Fabrication experts, quality inspectors & electrical experts are limited of missing in-house
- Time crunch

Positive tools/ practices according to the interviewees is stated below:

- Increasing focus on lessons learned sessions/ register
- Intranet (news flashes) give company updates
- Periodic review meetings among project directors

- Required expertise is sanctioned
- Company staff is helpful
- ROC drills & mock-ups

The next question was about possible improvements in the regime, having gathered insights on existing tools, issues and positive practices. Like the previous case, owing to diverse list of responses and similarity to the last question in the protocol, it would be more reliable to combine these responses with the responses for the last question.

On applicability of the issues/ practices stated so far on other components or the sector, all interviewees stated that the concepts shared by them are generic to the project as a whole and applicable to other components as well. The 3rd and 4th interviewees went on to add that the technical knowledge and missing competencies differ across components.

Responses on key indicators of knowledge integration gaps in the project and their commonality in responses is stated below:

- High no. of **Non Conformance Reports (NCRs)** – 4/4
- High no. of **Technical Queries (TQs)** – 2/4
- High no. of questions in **Contract Variations** – 1/4
- High no. of **Lessons registered** – 1/4

BOR – Impact of CKI on 'Value'

The next subject covered construction knowledge integration's impact on value (cost, time, quality and safety) of the project. As can be seen in the table above, all 4 interviewees agreed that poor knowledge integration in a project would directly or indirectly cause increase in project cost and duration. 3 out of 4 interviewees stated that knowledge integration is proportional to quality but the 4th respondent dissented stating that quality is assured by an independent body. However the 4th respondent went on to state that poor knowledge integration makes quality inspection difficult, citing the case of unreachable welds in certain secondary steel detailing in Borssele 3&4. Citing mandatory safety norms, 2 out of 4 interviewees dissented to knowledge integration's effect on safety of the project.

BOR – Suggestions for CKI Improvement

The combined list of suggested tools/ practices for CKI and improvements in the regime is stated below:

- ROC drills & Physical mock-ups
- Method statements (feedback system)
- Formalize knowledge integration processes
- Trade-off (cost-time-quality-safety benefits) matrices to motivate teams/ management for KI
- Monthly lessons learned sessions
- Imparting responsibilities for 'lessons learned' efforts
- JIP's (Joint Industry Practices), industry wide participation/ sharing
- Standardized & convenient, integrated knowledge database of knowledge, lessons learned, list experts etc. instead of excel database
- Intranet to be detailed further

- Detailed organograms with precise expertise listed
- Quality inspectors should be hired by the company
- Share virtual model developed inhouse with fabricator to save latter's effort
- Develop system for inter-project learning
- Integrating expert knowledge early in the process, like installation input
- Training programs like technical traineeships for inhouse engineers for rapid knowledge gain

This list concludes the description of the case data. Analytically breaking down statements from the interviews has given lists of tools/ practices, issues, improvements etc. The correlation of the cases and listed findings is crucial and is taken up in the next sections.

4.2 Discussion

The previous section covered the case data gathered through interviews, covering various subjects essential to fulfil the research objective. This section analyses the case data collected to extract the core findings from the data. The analysis has been divided into three parts where first the effect of generic case attributes like location, complexity etc. on CKI is evaluated. This is followed by analyzing and presenting the combined results of various subjects covered in the interviews. This sheds light on the existing regime of CKI in offshore wind projects and is in line with the second objective of this research. Lastly, the analysis is directed to find the key issues which is in line with the third objective of this research.

4.2.1 Case Attributes

As mentioned above, this section aims to evaluate the effect of generic case attributes on construction knowledge integration. The attributes considered for analysis are physical context/location, scale and complexity, project delivery, organizational structure and project processes. Most of these attributes were also the basis for case selection (elaborated in section 3.1). This analysis highlights if cases are subjected to exclusive conditions and what effect it has on the CKI in that project.

Geographical Context

The project sites of Deutsche Bucht (BoP & MBF) and Borssele III&IV are both located in the North Sea, German and Dutch respectively. The sites for offshore projects are obviously distant from the mainland which creates logistical challenges for communication and knowledge sharing. However, since these issues are common to most (if not all) marine construction projects, they do not create any exclusive difference in knowledge integration of these cases. However, the locations of the suppliers and other project participants who need regular visit plus the location of the team members itself can be an issue. Diverse geographical locations of team members and other project participants is an issue stated by respondents from BOR and more strongly for DBU MBF. As stated by the project director of DBU MBF, the team members itself were at different locations, varying at least between Hamburg, Gorinchem and Belfast (and an upcoming fabrication subcontract in Denmark). For the other projects, the project teams were based at the main offshore wind office of the company in Gorinchem. These, according to the respondent were exclusive challenges that the project (DBU MBF) faced and created extra difficulties in knowledge integration activities.

Project Scale and Complexity

The next attribute to review is project scale and complexity. The statistics on cost and scale of the cases can be rather confusing as there is a large parity between the cases. The DBU BoP plus DBU MBF are being built with a combined CAPEX of €1.4 billion which includes 31 standard 'monopile (with transition piece) foundations and 2 'mono-bucket foundations.' The 3rd case, Borssele 3& 4 has 77 WTG's implying 77 foundations being built with a CAPEX of €1.3 billion. This is where the technical complexity comes in. A major reason for the CAPEX being comparable is that the former is over 5 times farther to the shore than the latter. Further, the former is testing a completely new technology at this scale (to support an 8.4 MW WTG). While technical advancements also have a role to play in lower bids with time, the comparable duration of these cases presents an interesting fact. The planned duration of DBU BoP is around 2 years, DBU MBF is around 2 years 8 months and Borssele 3&4 is about 3 years. The significant duration of just two mono-bucket foundations gives a clear idea of its technical complexity. With all this said, the aim here is to assess the impact of these dynamics on knowledge integration of the projects. However, when assessing the impact of these dynamics on KI in projects, it was observed that the most case specific issues were stated for the DBU MBF project. Two of the three specific issues were about risk underestimation and delay in raising an alarm over design/ technology. Both of it can be directly attributed to the high technical complexity and the newness of the project rendering the company inexperienced in assessing or modifying the design at an early stage. Hence, it would not be wrong to say that high technical complexity (and not the project scale) can accentuate knowledge integration gaps in the project.

Project Delivery

As mentioned in the project scope, the cases being analyzed are EPCI contracts to the company (VO). Here again, with respect to project delivery details, within the EPCI contract, attempt was made to extract different situations (if any) that the projects had to face. Interestingly, the MBF part of the DBU project was given as a separate contract to Van Oord but the client had already chosen the sub-contractors (designer and fabricator) which then the main contractor (VO) had to work with. Further the main contractor was involved much later in the process and possibility to influence the design got more diluted due to lack of experience. To top it all, the financial close of the project, in time according to DBU BoP, shifted the design responsibility to the main contractor, as the design was not fully complete (design needs to be complete for financial close). Hence such a situation created an extra burden for the contracting company, which possibly added to delay as the project is still under fabrication and delayed by at least 6 months from the initial plan. The client did not focus on construction knowledge integration and involved Van Oord considerably late in the process to influence the design or choice of technology. Thus, an opportunity was missed in construction knowledge integration which is now creating trouble for most project participants, all of it due to project delivery dynamics. To add some perspective, the standard procedure, also followed for DBU BoP and BOR 3&4, is to prepare the design and release a tender to select the fabricator and suppliers.

Organizational Structure

The organizational structure of the project team is also an important attribute to consider as it governs the manner in which decisions and information flow in the project team. The team structure of all three cases is functional in nature but the difference is in hierarchy. The DBU BoP and DBU MBF were organized with a single package manager per BoP component, responsible for the entire scope of work from design, fabrication, transportation and installation. Owing to past lessons learnt (as stated by an interviewee), the structure was changed to separate package managers for separate tasks of the same component, implying a different package manager responsible for design, different for fabrication and vice versa. In other words, the hierarchy was diluted.

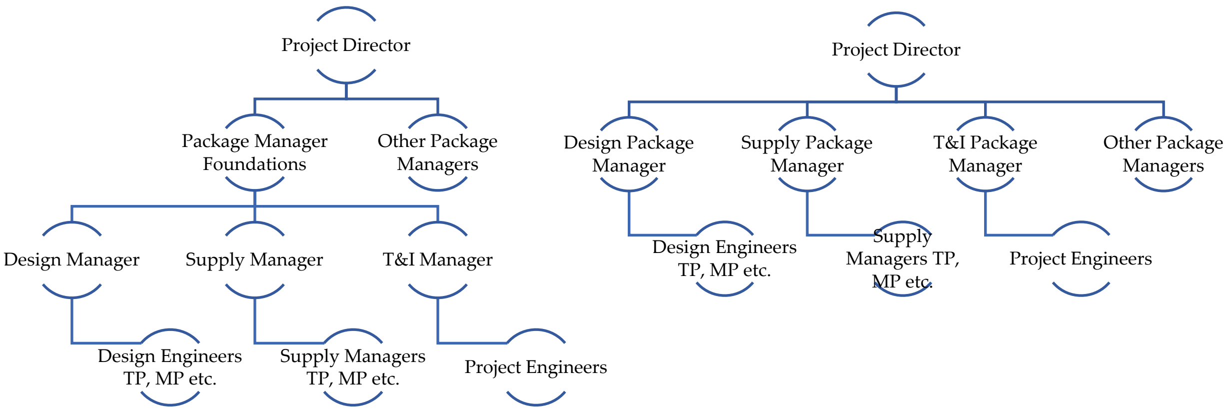


Figure 13 – Organizational structure differences, DBU BoP & MBF (left), BOR (right)

Interestingly, 2 opposite opinions were gathered from staff working in these projects. The proponent of the change stated that with one package manager only focused on the fabrication of the foundation, he/she does not have to worry about the arrangements for transportation and installation. Similarly, the package manager for T&I does not have to worry about the interfaces working in fabrication and can prepare well in advance for T&I. This detailed preparation is beneficial for the project. The opponent of the system stated that staff working in these individual packages do not get the full picture and work in their own frame. Further, due to multiple package managers for a single component supervised straightaway by the project director is too big a hierarchical difference to resolve communication hurdles between these packages. This interviewee felt that added package managers were hindering information flow and might increase knowledge integration gaps. The aim here is not to propagate one team structure over the other, but to highlight the fact that construction knowledge integration can be affected by the organizational structure.

Project Processes

While we know the broader packages that are enclosed in an EPCI contract for BoP components of an OWF, there are formal and informal stages or processes to achieve these packages. The aim here was to evaluate if all three cases under consideration went through the same set of processes and what these processes were. The company (VO) has a standard set of stage gates that all projects go through which covers processes right from acquisition till realization. A simplified version of the actual stage gate system is given in the figure below. Under three broad phases of acquisition, tendering and realization, 11 main processes or stages have been identified. The DBU BoP and BOR followed the standard acquisition process and hence went through the respective stage gate system. However, DBU MBF was not acquired in the standard manner as it belonged to the same client as DBU BoP and was handed over straight in the realization phase. This obviously means that any formal or informal measures for CKI that exist in the acquisition and tendering phases (if any) would have been missed in DBU MBF.

Since the scope of this research is primarily in the engineering and management phase (Ref. Section 1.4), examining the standard stages within it is also crucial. A simplified depiction of standard processes involved in engineering and design of the BoP component is presented in the figure below. Except DBU MBF, both other cases were monitored through the aforementioned processes during the engineering phase of their foundations. Since some extent of design was completed and then handed over to VO for further coordination, it hampered knowledge integration in the early stages of engineering.

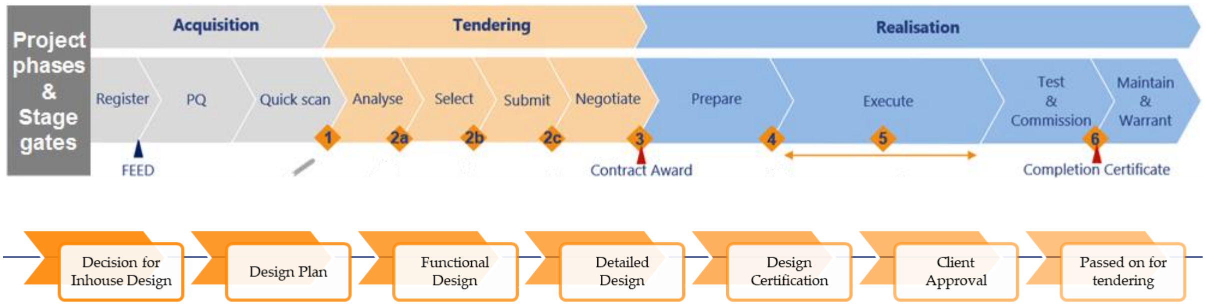


Figure 14 – Stage gate process (above); Standard processes during engineering phase (below)

The aim here was to cover the standard processes that projects within the collaborating company go through. The broader depiction of stage gates and sub-stages during the engineering phase also provide an essential base model to show the existing and recommended regime of CKI, which will be taken up in the upcoming sections/chapters. Depiction on this base model would not only be relatable for the company but the field in general as stage gates and engineering stages are generic in nature.

4.2.2 Combined Case Results

The previous section focused on highlighting and analyzing the project attributes which could impact construction knowledge integration in those projects. It was also concluded from interview data that almost all concepts shared under various subjects are applicable to all projects within the company (if not the industry as a whole). This prompted the combination of results which are presented in this section. The combined results are derived through a series of steps, as also elaborated in Section 3.4. Subjects which are more relevant in concluding the current regime or towards key issues have been assessed in more detail.

Key PM Challenges

Responses from all cases were compared (Refer Appendix A) and combined. Their commonality was assessed which helped in identifying the key project management challenges in offshore wind projects. In the comparison, three challenges were clearly more common in responses than the rest:

1. Time constraints in project execution
2. Managing extensive no. of project participants, their communication, interfaces & requirements
3. Extensive processes/ information to be managed

Noticeably, the 1st, 2nd and 3rd challenges logically create an extra burden for knowledge integration. However, since a separate question regarding issues in knowledge integration exists, the top 3 challenges would not be carried over.

Need & Perception of CKI

The next subject focused on understanding the perception and need of construction knowledge integration. It was important to ensure that interviewees understood the concept of CKI, without which the responses on its existing regime in projects would have been unreliable. Analyzing it with respect to the theoretical concept provides a base for comparison and discussion. A total of 10 responses were received (out of 12) on interviewee's perception of CKI. Noticeably, 2 out of 10 responses were exactly same as the theoretical definition. Comparing with the theoretical concept, 4 respondents did not explicitly say that the knowledge should be construction specific. 3 respondents perceived construction knowledge integration as something for future projects. The first difference in staff definition and theory is important as it is the primary difference between knowledge integration and construction knowledge integration (both concepts might overlap but that is for later evaluation). The second difference is however not critical as CKI or KI is an ongoing process and is a case of changing reference points in time, for example what's future today will become present tomorrow. It is interesting to see that multiple responses deviated along similar notions. Notably, even the interviewees who did not state their perception, completely understood and agreed to the elaboration by the interviewer. This was important for further questioning. **While judging the responses in comparison with theoretical definition might seem strict at first, it is essential to establish the difference between construction knowledge integration and knowledge integration since this research mainly focuses on the former. The 2nd deviation (on CKI for ongoing projects) was also important to discuss since it resonates with the company's current efforts on KI. The deviation was acknowledged by all respondents which validates the need to consider their initial definitions as slightly deviated.**

Having covered the perception of interviewees, it was important to validate the need. While summaries from individual cases have been stated in previous sections, the result is even more empowering when combined and are summarized below:

- **Nine interviewees strongly agreed** on CKI being an issue for the company;
- **Three interviewees disagreed**, **but** went on to state **its importance** and **big scope to improve**;
- **Eight** (of Eight) also strongly confirmed its importance in project management processes;

Tools/ Practices in Use

This topic and the rest to follow, namely issues, positives and suggestions were questioned to infer the existing regime of construction knowledge integration in the cases studies. Finding the existing CKI regime is the primary reason for choosing the case study method for data collection. The comparison of responses from each case regarding this and the topics to follow is described in Appendix A. As mentioned in the case analysis methodology, these topics have been analysed in more depth than the preceding subjects of PM challenges and CKI understandability.

The tools/ practices in use currently in the projects/company are analysed in the table below. Upon analysis, the top 3 tools/ practices used in the projects are listed below. The 4th finding on the list can be arguably similar to the second listing as past project data itself would be gathered from inhouse data or staff, which is what the 2nd listing essentially talks about. This is highly similar to using inhouse knowledge. Hence it has been left out from the 'key' list, which summarizes **the top 3** (below):

1. **Lessons learned register/ sessions/ flashes**
2. **Inputs from staff/inhouse/external experts**
3. **Progress meetings/ Design reviews**

Table 9 – Key tools/practices used for KI in OWF projects at VO (hierarchically arranged)

No.	Tools/ Practices in use for CKI	DBU BoP				DBU MBF				BOR			
		1	2	3	4	1	2	3	4	1	2	3	4
1	Lessons learned register/ sessions/ flashes	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓
2	Inputs from staff/inhouse/external experts		✓	✓	✓	✓	✓	✓		✓		✓	
3	Progress meetings/ Design reviews	✓	✓							✓	✓		✓
4	Referring to past project data/ staff		✓	✓				✓		✓			
5	End of package discussions/ feedback (document sheets)			✓		✓	✓						
6	Inputs from fabrication/ installation specialists during pre-tendering phase						✓			✓		✓	
7	ROC drills & Physical Mock-ups									✓	✓		✓
8	Systems engineering docs. (list of req.)	✓											✓
9	Formal queries/ notices					✓				✓			
10	Integrated Groupware Solutions				✓								
11	Webinars with interactive discussions (open to package managers)								✓				
12	Intranet								✓				
13	Operational meetings within package managers for inter-project learning												✓
14	Setting Action trackers							✓					
15	Design Certification	✓											

Issues hindering CKI

Finding issues hindering CKI is extremely crucial as it sets course for the results of this research and helps improve the CKI regime. More emphasis was given to this question during the interviews and the respondents were driven to think of as many issues as possible. The analysis is similar to the table above, that is assessing the commonality of the responses. This step was preceded by comparing and merging issues (whichever necessary) stated across cases, listed in **Table 21**, Appendix A. **The table below reveals the most commonly stated issues by the interviewees.** Since there is a tie in commonality of 3rd and 4th issue in the list, for now the top 4 issues have been concluded:

1. **Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format**
2. **Less/ no inhouse experts for fabrication, quality mgmt., electrical**
3. **High time constraints – no time for CKI**
4. **No standard work protocol for KI/ CKI**

It is interesting to note that the 3rd most commonly stated issue of time constraints is also the most commonly stated PM challenge in the sector, validating how PM challenges affect CKI in a project.

Table 10 – Key issues hindering CKI in OWF projects (hierarchically arranged)

No.	Issues hindering CKI	DBU BoP				DBU MBF				BOR			
		1	2	3	4	1	2	3	4	1	2	3	4
1	Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format			✓	✓	✓	✓	✓	✓	✓		✓	✓
2	Less/ no inhouse experts for fabrication, quality mgmt., electrical		✓	✓	✓		✓	✓					✓
3	No standard work protocol for KI/ CKI	✓		✓	✓							✓	
4	High time constraints – no time for CKI		✓				✓	✓		✓			
5	Designers lack practical & commercial foresight/ impact of decisions				✓				✓			✓	
6	Late involvement of fabrication/ installation specialists		✓						✓	✓			
7	No integrated database for all available knowledge (lessons, best practices, templates, standards, req., protocol)	✓											✓
8	No steps for inter-project learning of entire team				✓							✓	
9	No software for interface/ quality mgmt.	✓									✓		
10	Diverse geographical locations of project participants								✓		✓		
11	Troublesome when inhouse expertise busy/ missing					✓				✓			
12	Lessons are project/ situation specific	✓		✓									
13	Difficult to describe complex information in database			✓									✓
14	Lack of awareness of KI benefits, knowledge available & sourcing methods											✓	✓
15	Missing templates like quality inspection	✓											
16	Lack of awareness of resources needed for design certification	✓											
17	Difficult to moderate designs when sub-contracted			✓									
18	Sub-contractors have different drivers & lack staff for coordination					✓							
19	End of package reports not openly shared						✓						
20	Documents unavailable as references						✓						
21	Difficult to transfer tacit knowledge through databases							✓					
22	No incentive to list lessons as no info received in return											✓	
23	Lack of experienced staff as sector is new										✓		
24	Knowledge behind major decisions not shared											✓	

Positive integration processes in the regime

After finding the key issues, the focus was shifted to understanding what is positive in the system according to the project team members. The responses on this question were compared across cases and is presented in **Table 22**, Appendix A. Since the quantum of responses received for this question was less, analysing the key positive concepts does not need further analysis. The key positives in the regime are the top 4 listings in **Table 22**, which are common across two or more cases. To cross check, the commonality of the listings was assessed which led to the same result. Higher commonality in perception of positive processes implies the importance and need for these processes to be preserved in the regime. The key positive tools/ processes for CKI in the current regime are:

1. **Increasing focus on lessons learned sessions/ register**
2. **Standard formats/ templates for correspondence, risk registers, DPRs etc.**
3. **'ROC drills' & 'Physical Mock-ups'**
4. **Organic communication/ helpful staff**

Suggested tools/ processes/ improvements

Table 11 – Key tools/processes/improvements suggested by interviewees (hierarchically arranged)

No.	**Suggestions for CKI**	**DBU BoP**				**DBU MBF**				**BOR**			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	Formalize knowledge integration/ certain engineering communication processes		✓	✓	✓	✓				✓		✓	
2	Early involvement of all relevant parties including fabrication/ installation			✓		✓			✓	✓			✓
3	Single structured & convenient database for all knowledge/ information available				✓		✓					✓	✓
4	Fill missing competencies of fabrication, quality & electricals inhouse		✓				✓		✓				✓
5	Lessons learned sessions/ meetings					✓	✓			✓			
6	Setting responsibilities for KI processes						✓	✓		✓			
7	Develop systems for inter-project learning, e.g. webinars accessible to all							✓		✓		✓	
8	Increase awareness of CKI need & benefits to senior management/ teams		✓							✓			
9	Enable remote participation for lessons learned sessions by E&E							✓	✓				
10	Quality management software	✓		✓									
11	Proactive to gather inputs from experts		✓	✓									
12	Training engineers to develop foresight for practical & commercial implications			✓							✓		
13	Information/ knowledge/ scope to be shared with all project participants	✓											
14	Mix junior & senior staff in sub-teams to maximize intra-project learning				✓								
15	Use 4D BIM & modernize engineering processes				✓								

No.	Suggestions for CKI	DBU BoP				DBU MBF				BOR			
		1	2	3	4	1	2	3	4	1	2	3	4
16	Identify weak spots/ areas/ competencies and develop KPI's for KI				✓								
17	Outsource design activities		✓										
18	Momentary leanings should be added to preserve knowledge	✓											
19	Lessons should be stated in broad manner to make people think								✓				
20	Not only major, but smaller lessons also need to be recorded in standard format						✓						
21	Keep removing lessons after fixed period								✓				
22	Lean knowledge – considering only top lessons, risks								✓				
23	Improve integration of past project data for tendering, estimation, project controls							✓					
24	Sending out document sheets to all participants together					✓							
25	Data management in contracts					✓							
26	ROC drills & Physical mock-ups									✓			
27	Method statements (feedback system)									✓			
28	JIP's (Joint Industry Practices), seminars, industry wide participation/ sharing									✓			
29	Intranet to be detailed further											✓	
30	Detailed organograms with precise expertise listed											✓	
31	Share virtual model developed inhouse with fabricator to save latter's effort									✓			

As also mentioned in the previous sections, the improvements suggested by the interviewees has been combined with the tools/practices suggested by them for optimizing construction knowledge integration in OW projects. A comparison of responses across cases on this topic can be seen in **Table 23**, Appendix A. Following this, the commonality of listed concepts is assessed, presented in the table below. Since 3rd and 4th on the list have a tie in commonality, the top 4 improvements are:

1. **Formalize knowledge integration/ certain engineering communication processes**
2. **Early involvement of all relevant parties including fabrication/ installation**
3. **Single structured & convenient database for all knowledge/ information available**
4. **Fill missing competencies of fabrication, quality & electricals inhouse**

Key Indicators for CKI lapses

The list of dominant indicators of knowledge integration lapses/ hassles in a project is given below. It was derived by combing all interview responses on this question.

- **'Non-Conformance Reports' or 'NCRs' –** stated by **9 of 12** respondents
- **'Technical Queries' or 'TQs' –** stated by **8 of 12** respondents

The above figures clearly show NCRs and TQs as the key indicators for CKI lapses. Several other indicators were suggested like 'Process NCRs, Remedial works register, Fabrication support, Review Sheets, Contract Variations and High entries in Lessons learned database'. All these indicators had a commonality of **1** in **12**.

Impact on project value

The interviewees were also asked how CKI impacts project value (cost, duration, quality and safety). There was high similarity in the responses as evident from the results below:

- Less CKI **increases project cost** – 11 of 12 agreed
- Less CKI **increases project duration** – 11 of 12 agreed
- Less CKI **decreases project quality** – 9 of 12 agreed
- Less CKI **decreases project safety** – 9 of 12 agreed

One of the respondents stated Less CKI increases the risk for cost and time overruns while reducing quality and safety of the project. It is worth noting that the same relation between construction knowledge integration and project value was established through literature review in section 2.2. **Hence, it can be concluded that the influence of less CKI on project value is recognized by interviewees/ company staff.** Since it has not been quantitatively derived by this research, it has not been presented as a scientific finding of this research, though its effect on value are strongly indicative.

This concludes the combined results of all subjects covered in the interviews. The combined results are more reliable and usable than individual cases. Further, the fact that these concepts are applicable to other projects within the company, increases its relatability. These analyses and results shed light into the condition/ regime of the projects which is elaborated in the next section.

4.2.3 Current CKI Regime

In this section, conclusions on the existing regime are made based on case data analysed so far. This is in line with the second sub-objective of this research and has been the sole purpose of choosing the case study methodology. A 'regime' in simple terms, is a system or ordered way of doing things. This system can be formal or informal. Such a system can be inferred from the **tools and processes** (practices) **currently in use** in the cases studied. This can directly be derived from two questions asked during the interviews, firstly about tools/ practices in use and secondly about the positive steps in the system that need to be preserved. Hence, combining these showed the order in which construction knowledge is being integrated. Issues and suggestions can be seen as a review of the CKI system but these do not specify the order of use. Further, it is analysed **which steps of knowledge integration** (Ref. ***Figure 6***) and **sources of knowledge** are catered in the current regime.

Since construction knowledge integration (if being done) is a sub-process within a project, hence it exists in context to several other processes which constitute the project. Considering this, here the regime has been presented in context to the existing stage gates and standard steps in the engineering phase (see figure above). This makes the depiction more relatable. After analysing the case data, there were certain formal and informal processes that could be shown in a framework and can be seen in the figure below. **It is important to note that the continuous processes are not formalised in the current regime, meaning they are not defined objectively for knowledge integration within the company and are not conducted in pre-planned intervals.** The only formal mention is of lessons learned register to be completed and integrated in database after project completion. **No formal mention of using lessons learned database/system in earlier stages officially permits project team members to skip it.** The ROC drills and mock ups are not recognized as activities which aid in communication.

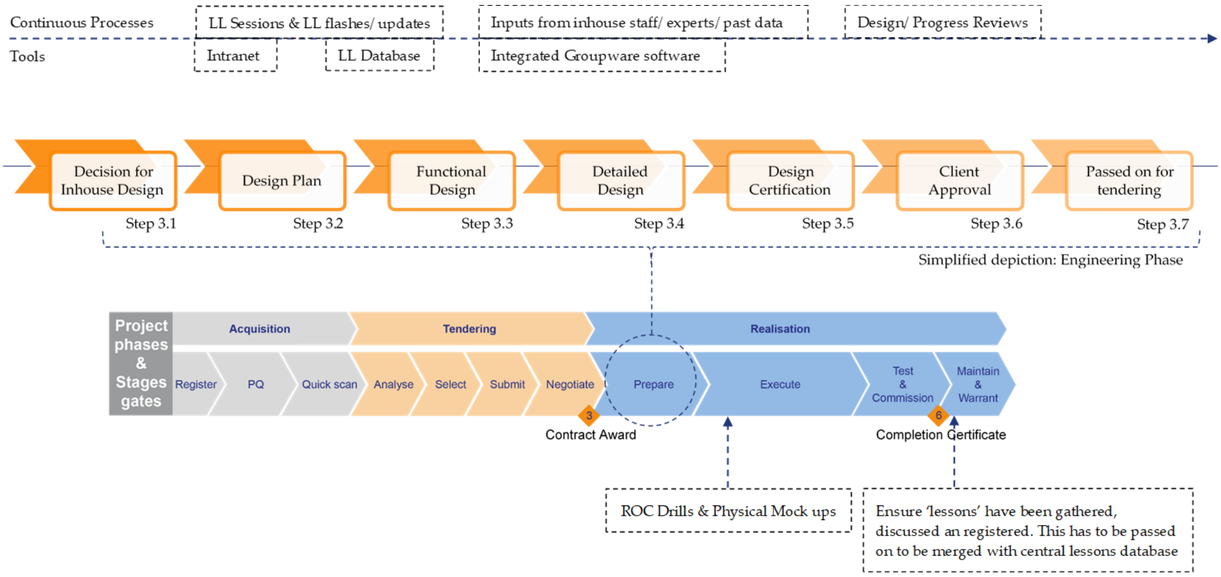


Figure 15 – Current regime of CKI in OW projects reviewed

Here it can be seen that formal and informal processes mainly make use of lessons learned from projects. As stated in the literature study, section 2.5, these contribute in all four steps of knowledge integration namely locating and accessing, capturing, sharing and creating new knowledge. This itself implies that all four steps of KI are catered through the current regime. But since the tools/ practices in current regime are fairly limited and strong issues are stated with the lessons learned database/ system itself, knowledge integration has large scope of improvement. Since quantitative measurement of KI is not part of this research, the extent of KI steps catered cannot be stated and is indicative.

The last analysis to elaborate on the regime is on sources of knowledge catered through the current system. As mentioned in section 2.3, there are many sources and types of construction knowledge that need to be integrated in the project. Hence, it is important to analyse what sources of construction knowledge are integrated through the current regime, only after which any improvements (if needed) can be suggested. The sources currently integrated was revealed through list of most commonly stated tools/ practices in use. Further, the issues in the regime and suggestions for improvement (***Table 10*** and ***Table 11***, section 4.2.2) revealed the sources which are not or challenging to integrate. The figure below shows the sources that the current regime integrates or misses out (or partially integrates). The former is connected through continuous arrows while the latter is through dotted arrows. For instance, integrating past lessons learned is substantiated by the 1st and 7th most commonly stated issue and the 3rd most commonly stated suggestion. Similarly, integration of fabrication, procurement and installation knowledge is substantiated by the 2nd, 6th and 2nd, 4th most commonly stated issues and suggestions respectively. There are lapses in learning from ongoing projects within the company shown by issues and suggestions raised for inter-project learning in the company. Summarized in fig. below:

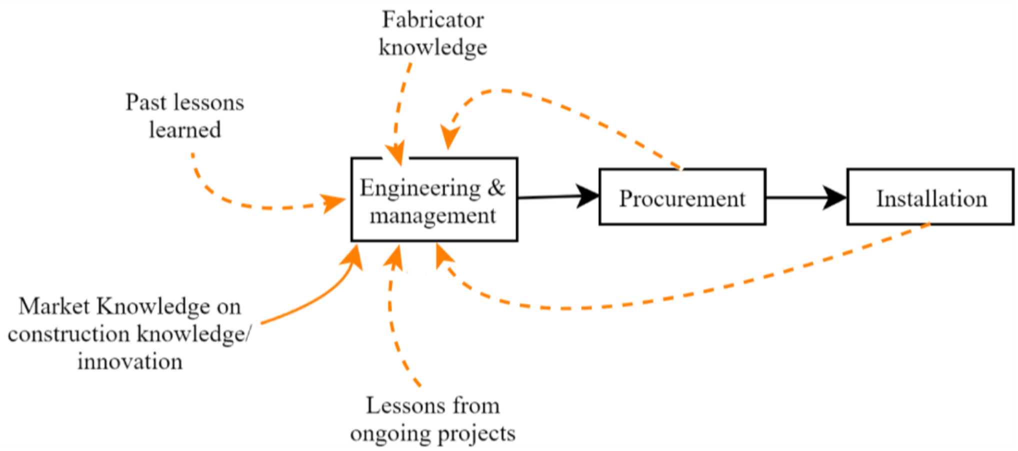


Figure 16 – Construction Knowledge sources optimally used by the current regime

4.2.4 Key Issues hindering CKI

The previous sub-sections analyzed various case attributes and also presented the combined results of interview data. The latter along with some more analysis on KI steps and knowledge sources influenced, provided for an elaborate description of the current regime. This fulfilled the second research objective and one of the main objectives of choosing case study as a research approach. Another objective of choosing this approach was to find the key practical challenges posed by OW projects to construction knowledge integration. This also is in line with the 3rd sub-research objective and is the root to the next sub-objective of devising recommendations for the regime. The list of issues achieved through combined analysis of interview data (***Table 10***) is 24 issues long with top 4 derived by higher commonality. This section aims to streamline the issues and derive the key issues which have the biggest impact on construction knowledge integration in the regime.

It was observed during interviews and case analysis that certain issues can be the underlying cause for other issues. For instance an interviewee explicitly stated that the obligatory use of lessons learned database in the early phases is missing in the standard work practice and hence is not used. Hence, there arose a need to decipher intra-linkages within issues to find the key underlying issues. Another observation was that some suggestions corresponded to certain issues in the findings. This prompted the analysis of deciphering inter-linkages between issues and suggestions from section 4.2.3. Since an improvement or a suggestion can only exist if there is an issue in the system, it is justified to compare and analyze these findings together. With this being said, the intra and inter linkages within list of issues and suggestions are explained in this section below.

Intra-linkages within issues & suggestions

It has already been established above that intra linkages within list of issues would help to find the underlying cause of these issues. In similar lines, it was observed that some suggestions are subordinate to bigger suggestions in the list. This prompted the analysis being extended to intra-linkages within the list of suggestions as well. The analysis and the key observations from it are shown below:

- The third issue on the list states the lack of a standard work protocol for KI/CKI, which means there is a lack of formal processes indicating when and how to integrate construction knowledge. Fisher (2007) states that a formal implementation process clearly defines steps and procedures to be followed and formalization assures that certain steps and issues will be addressed and that too in a systematic manner. Issues 1,4,6,8,11,19,22 and 24 point towards a KI/CKI tools or practice not being executed properly. It was seen through document analysis and interviews (hence the current regime) that no standard directions exist to use these tools or practices. Hence, use of these tools and processes is discretionary. This is the first link to a broader issue, no. 3, that is the lack of standard protocol for KI/CKI. The intra-linkages are further supported by more specific arguments below:

- As stated earlier in this section, lack of formal KI processes does not make it obligatory for staff to invest time in CKI efforts. This is the reason why use of lessons learned register is often avoided in early stages of the project (stated by interviewee, BOR 3). Further, if the standard work protocol does not indicate procedures to be followed, staff is not obligated to reserve time for KI activities (interviewee: DBU MBF 2). Under an informal setting KI activities are then avoided due to time constrains (DBU MBF 2). This establishes intra-link between issue 1 and 4 to issue 3.
- The current regime established the missing competencies in the system (issue 6). It was further stated that representatives from certain competencies like installation phase might change during the course of the project causing difference of opinion and further hassles. Also they stated that it is troublesome when required competencies or experts are missing (issue 11). Since the CKI process is mostly informal (as concluded in section 4.2.3), there are no formalised backups. This is again due to lack of formalization. Some interviewees also stated that inter-project learning is not formalised and hence missed (BOR 1, BOR 3). These arguments further link issues 6,8 and 11 to issue 3.
- Issue 19 and 24 imply ambiguity in the system to share or withhold certain information and documents. Document analysis and interviews did not reveal any specific guidelines which decide this, implying lack of formal protocol. Issue 22 implies people have a choice to not participate in the CKI process, implying responsibilities and obligations have some ambiguity. All these again indicate lack of a standard protocol.

Conclusively, issues 1,4,6,8,11,19,22 & 24 are caused by the lack of standard protocol for CKI, (issue 3).

- Another issue which intra-links to many other issues is number 7 on the list, stating the lack of a standard knowledge database. This intra-relation is not causal, like the previous. Here, issues like 1,12,13 and 21 indicate lack of a standard system and infrastructure for storing and sharing knowledge, which is what issue 7 essentially states. Further, the former issues named are essential considerations in devising an effective knowledge database. For example, lessons learned database (issue 1) is a small part of what the knowledge database entails (as it contains best practices, templates etc.). Further, issue 12 and 13 essentially imply he lack of a system for storing knowledge. A knowledge database cannot be created without a system in place for storing knowledge. Lastly, issue 21 states an extra challenge that an ideal knowledge database needs to resolve and hence if issue 21 is solved, it creates a stronger database. With these arguments, the intra-link between these issues towards issue 7 is inferred.

- Similar to the intra-relations within issues, the list of suggestions was evaluated. It was observed that many suggestions were intra-related with the most common suggestion of formalizing CKI processes and the third suggestion of a single efficient knowledge database. Suggestions intra-linked to suggestion 1 mainly pointed towards the necessary steps or features that a formal protocol for CKI should entail for full coverage. Similar to this, the 3rd suggestion was inferred to be intra-related with suggestions 18-22, 24 and 29 as these stated features that are necessary for an effective database and solve issues related to it. Hence most specific suggestions were directed towards achieving a standard KI/CKI protocol or a structured and efficient knowledge database.

No.	Issues hindering CKI
1	Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format
2	Less/no inhouse experts for fabrication, quality mgmt., electrical
3	No standard work protocol for KI/ CKI
4	High time constraints – no time for CKI
5	Designers lack practical & commercial foresight/impact of decisions
6	Late involvement of fabrication/installation specialists
7	No integrated database for all available knowledge (lessons, best practices, templates, standards, req., protocol)
8	No steps for inter-project learning of entire team
9	No software for interface/quality mgmt.
10	Diverse geographical locations of project participants
11	Troublesome when inhouse expertise busy/missing
12	Lessons are project/situation specific
13	Difficult to describe complex information in database
14	Lack of awareness of KI benefits, knowledge available & sourcing methods
15	Missing templates like quality inspection
16	Lack of awareness of resources needed for design certification
17	Difficult to moderate designs when sub-contracted
18	Sub-contractors have different drivers & lack staff for coordination
19	End of package reports not openly shared
20	Documents unable as references
21	Difficult to transfer tacit knowledge through databases
22	No incentive to list lessons as no info received in return
23	Lack of experienced staff as sector is new
24	Knowledge behind major decisions not shared

No.	Suggestions for CKI
1	Formalize knowledge integration/certain engineering communication processes
2	Early involvement of all relevant parties including fabrication/installation
3	Single structured & convenient database for all knowledge/information available
4	Fill missing competencies of fabrication, quality & electricals inhouse
5	Lessons learned sessions/meetings
6	Setting responsibilities for KI processes
7	Develop systems for inter-project learning, eg. webinars accessible to all
8	Increase awareness of CKI need & benefits to senior management/teams
9	Enable remote participation for lessons learned sessions by E&E
10	Quality management software
11	Proactive to gather inputs from experts
12	Training engineers to develop foresight for practical & commercial implications
13	Information/knowledge/ scope to be shared with all project participants
14	Mix junior & senior staff in sub-teams to maximize intra-project learning
15	Use 4D BIM & modernize engineering processes
16	Identify weak spots/areas/competencies and develop KPI's for KI
17	Outsource design activities
18	Momentary leanings should be added to preserve knowledge
19	Lessons should be stated in broad manner to make people think
20	Not only major, but smaller lessons also need to be recorded in standard format
21	Keep removing lessons after fixed period
22	Lean knowledge – considering only top lessons, risks
23	Improve integration of past project data for tendering, estimation, project controls
24	Sending out document sheets to all participants together
25	Data management in contracts
26	ROC drills & Physical mock-ups
27	Method statements (feedback system)
28	JIP's (Joint Industry Practices), seminars, industry wide participation/sharing
29	Intranet to be detailed further
30	Detailed organograms with precise expertise listed
31	Share virtual model developed inhouse with fabricator to save latter's effort

Figure 17 – Analysing intra-linkages within issues (left) & suggestions (right)

<u>Inter</u>-linkages between issues & suggestions

The third step in streamlining list of issues was to analyse the inter-relationships between issues and suggestions. The key difference here with the first step in this section is that suggestions and issues can be conceptually combined, if a suggestion is essentially resolving a specific issue, it also reinstates the existence of that specific issue. This is what prompted the inter-linkage analysis which is shown in detail in the figure below. Notably, only direct linkages have been considered and **not** the intra-linkages derived from the step 2 analysis. The key observations from the analysis are listed below:

- The 3rd most commonly recognized issue of no standard work protocol for KI/CKI corresponds to the most common suggestion made for improvements by the interviewees, that is to formalize the KI/CKI processes. This linkage further emphasises the lack of standard process protocol for knowledge integration in the projects and the company.
- Noticeably, the most common issue has no direct link in the list of most common suggestions. The 5th most common suggestion is to keep continuing the practice of lessons learned sessions but does not shed further details for it. If the intra-linkages within the issues is considered, as explained in the previous page, then it would indirectly relate to suggestion 1 and 3 on the list.

- The 6th most common issue of late involvement of necessary competencies in the project correlates with the 2nd most common suggestion. Both ascertain the problem with late involvement and the need for early involvement of relevant project participants. This divide in commonality of responses shows that while interviewees feel the importance of a certain issue, they often miss including it in the responses. Combining results is beneficial since it includes the important concepts missed in the responses of specific questions.
- Similar to the 6th most common issue, the 7th on the list correlates with the 3rd most common suggestion of the need for a single/ structured knowledge database.
- The other correlations were between the 8th and 9th issues on the list with 7th and 10th suggestions respectively. These inter-relations were relatively similar in the respective hierarchies.
- The figure also shows a contradiction between 17th issue and 17th suggestion as the former states the issue of less control in outsourcing design while the latter advocates for it.

The above list does not cover all the inter-linkages but tries to cover the main observations.

No.	Issues hindering CKI
1	Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format
2	Less/ no inhouse experts for fabrication, quality mgmt., electrical
3	No standard work protocol for KI/ CKI
4	High time constraints – no time for CKI
5	Designers lack practical & commercial foresight/ impact of decisions
6	Late involvement of fabrication/ installation specialists
7	No integrated database for all available knowledge (lessons, best practices, templates, standards, req., protocol)
8	No steps for inter-project learning of entire team
9	No software for interface/ quality mgmt.
10	Diverse geographical locations of project participants
11	Troublesome when inhouse expertise busy/ missing
12	Lessons are project/ situation specific
13	Difficult to describe complex information in database
14	Lack of awareness of KI benefits, knowledge available & sourcing methods
15	Missing templates like quality inspection
16	Lack of awareness of resources needed for design certification
17	Difficult to moderate designs when sub-contracted
18	Sub-contractors have different drivers & lack staff for coordination
19	End of package reports not openly shared
20	Documents unavailable as references
21	Difficult to transfer tacit knowledge through databases
22	No incentive to list lessons as no info received in return
23	Lack of experienced staff as sector is new
24	Knowledge behind major decisions not shared

No.	Suggestions for CKI
1	Formalize knowledge integration/ certain engineering communication processes
2	Early involvement of all relevant parties including fabrication/ installation
3	Single structured & convenient database for all knowledge/ information available
4	Fill missing competencies of fabrication, quality & electricals inhouse
5	Lessons learned sessions/ meetings
6	Setting responsibilities for KI processes
7	Develop systems for inter-project learning, eg. webinars accessible to all
8	Increase awareness of CKI need & benefits to senior management/ teams
9	Enable remote participation for lessons learned sessions by E&E
10	Quality management software
11	Proactive to gather inputs from experts
12	Training engineers to develop foresight for practical & commercial implications
13	Information/ knowledge/ scope to be shared with all project participants
14	Mix junior & senior staff in sub-teams to maximize intra-project learning
15	Use 4D BIM & modernize engineering processes
16	Identify weak spots/ areas/ competencies and develop KPI's for KI
17	Outsource design activities
18	Momentary leanings should be added to preserve knowledge
19	Lessons should be stated in broad manner to make people think
20	Not only major, but smaller lessons also need to be recorded in standard format
21	Keep removing lessons after fixed period
22	Lean knowledge – considering only top lessons, risks
23	Improve integration of past project data for tendering, estimation, project controls
24	Sending out document sheets to all participants together
25	Data management in contracts
26	ROC drills & Physical mock-ups
27	Method statements (feedback system)
28	JIP's (Joint Industry Practices), seminars, industry wide participation/ sharing
29	Intranet to be detailed further
30	Detailed organograms with precise expertise listed
31	Share virtual model developed inhouse with fabricator to save latter's effort

Figure 18 – Comparison between issues in current CKI regime & suggestions to improve

Concluding key issues

The above steps presented inter and intra linkages of issues and suggestions with the aim of streamlining the list of issues to those that have the biggest impact on the construction knowledge integration of the sample regime and take them forward for devising recommendations. As the beginning of this sub-section pointed out that the hierarchy of the findings may vary depending on inter and intra-linkages between the findings, this step mainly focusses on deriving the altered hierarchy of issues hindering construction knowledge integration. Based on the previous steps, the commonality of interrelated issues and suggestions and the intra-related issues can be combined. **The altered commonality of findings has been presented in *Table 12*, below. To keep the depiction simple, only the top 10 entries have been reassessed as the remaining had fairly less commonality to make a difference in the final findings.**

Step 2 showed the overarching or most important issues to be the lack of standard protocol for KI/CKI and lack of a single structured knowledge database, based on high intra-linkages. Similarly the most dominant suggestions were those of formalizing the KI/CKI processes and moving towards a single knowledge database. Step 3 showed the inter-linkage between the most dominant issues and suggestions respectively. Hence, these have been repeated in the table as A and B because these take into account the intra-linkage within the issues as well, while the rest add up only the inter-linkages.

Table 12 – Discerning key focus by combining inter & intra-linkages of issues & suggestions (hierarchically arranged)

No.	**Issues hindering CKI**	**Suggestions for CKI improvement**	**DBU BoP**				**DBU MBF**				**BOR**			
			1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
A	No standard work protocol for KI/ CKI – **(COMBINED WITH SIMILAR)**	Formalise KI/ communication processes	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
B	No integrated database for all available knowledge – **(COMBINED WITH SIMILAR)**	Single structured & convenient database of all knowledge available	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1	Shortcomings with 'Lessons learned' register	--			✓	✓	✓	✓	✓	✓	✓		✓	✓
2	No standard work protocol for KI/ CKI	Formalize KI/ communication processes	✓	✓	✓	✓	✓				✓		✓	
3	Competencies of fabrication, quality mgmt.., electrical etc. missing	Fill the missing competencies		✓	✓	✓		✓	✓	✓				✓
4	Late involvement of fabrication/ installation specialists	Involve all relevant participants at early stages		✓	✓		✓			✓	✓			✓
5	No integrated database for all available knowledge	Single structured & convenient database of all knowledge available	✓			✓		✓					✓	✓
6	No steps for inter-project learning of teams	Develop systems for inter-project learning				✓			✓		✓		✓	
7	High time constraints – no time for CKI	--		✓				✓	✓		✓			

No.	Issues hindering CKI	Suggestions for CKI improvement	DBU BoP				DBU MBF				BOR			
			1	2	3	4	1	2	3	4	1	2	3	4
8	Designers lack practical & commercial foresight/ impact of decisions	--				✓				✓			✓	
9	No software for interface/ quality mgmt.	Quality management software	✓		✓							✓		
10	Diverse geo. locations of project parties	--								✓		✓		

The main alterations from the above analysis have been listed below:

- The issues which had a corresponding suggestions, as received from the interviewees, moved up in order, implying higher commonality. For instance, the 3rd and 5th most stated issues moved to 7th and 8th spots respectively.
- The issue of lack of standard protocol for CKI considerably increased in commonality. The analysis shows it to be the second most common issue from the interviewee's perspective. Notably, the concern for missing competencies also has equal commonality.
- The alterations from inter-linkages gave important insights, but accounting for the intra-linkages within the issues provided the highest deviations.
- As mentioned in the introduction of this step, the issues accounted for intra-linkages have been numbered as A and B. In the commonality analysis in ***Table 12***, A & B can be seen as the most common/ dominant outcomes with both being backed by 11 out of 12 responses.

The aim of the analysis presented in this sub-section was to streamline the findings and define the focus for recommendations which will have the maximum impact. The above analysis clearly indicates the two main issues, lack of standard protocol for KI/CKI (A) and lack of a combined standard knowledge database (B), and their corresponding suggestions have the highest commonality. Since the issue and their suggestion itself links to many other issues and suggestions in the findings, addressing them would have the biggest impact on construction knowledge integration in OW projects.

4.3 Conclusion

One of the main purposes of pursuing case studies was to assess the regime of construction knowledge integration in practice and find the key issues hindering construction knowledge integration. This is also the 2nd sub-objective of the research. The regime (existing system or set of procedures) for construction knowledge integration in OW projects was derived using combined results from case study analysis. The existing CKI regime was devised using tools/ practices in use and key positives in the system stated by interviewees. The regime is represented in context to the existing mandatory project processes, shown in ***Figure 15***. It is conclusive from the existing regime that most processes and tools in use for CKI are not formalised, meaning they are not defined objectively for knowledge integration within the company and/or are not conducted in pre-planned intervals. The only formal mention is of lessons learned register to be completed and integrated in database after project completion. No formal mention of using lessons learned database/system in earlier stages officially permits project team members to skip it. In terms of KI stages fulfilled by the regime, it was concluded that the regime mainly makes use of lessons learned data and sessions and hence, theoretically fulfils the KI stages. However, since the regime relies on one type of tool for KI, the integration is bound to be limited. This is also substantiated by the list of issues about the lessons learned sessions and register itself. Analysing the issues and suggestions further revealed that there is limited integration of crucial sources of construction knowledge. For e.g. fabrication and installation knowledge, inter-project learning and learning from past projects. This concludes the current regime of CKI in OW projects. This analysis is significant as it introduces the situation of CKI to the collaborating company as well and implies areas which can be improved.

Case study analysis was also targeted to decipher the key issues hindering construction knowledge integration, hence fulfilling the 3rd sub-objective of this research. Initial analysis revealed intra and inter linkages within and between issues and suggestions respectively. The intra linkages were mainly causal or correlational in nature. Further, it is logical that a suggestion implies an underlying shortcoming/issue. This is what prompted this analysis and revealed interesting linkages, summed up in section 4.2.4. The analysis concluded that the key issues in the regime are lack of standard protocol for CKI and lack of a single integrated knowledge database. Since these issues link to many other issues, resolving them will be the most impactful for CKI improvements. This finding is crucial for the research as the next chapter would devise recommendations to counter these issues.

"An investment in knowledge pays the best interest"

– Benjamin Franklin

5. Findings

The previous chapters concluded with findings from literature study and case study. The case study analysis yielded key issues with the biggest impact on the assessed project regime. Those key issues will be addressed through recommendations in this chapter which is also among the final deliverables of this research. This chapter on 'Findings' is divided in 3 sections: ***The Process*** where the steps taken to devise the recommendations and first concrete set of recommendations are presented. The second section is vital as it covers the validation of recommendations. The third and final section of this chapter incorporates the feedback from the validation process to devise the final set of recommendations.

5.1 The Process

This section elaborates on the process followed to devise the recommendations and also presents the first concrete set of recommendations to be validated. The analysis till now has been based on isolated data either from literature or case studies. The learnings from the literature and case study has been merged in this chapter to achieve the research objectives. To devise the recommendations, a 3 step process has been followed (own method) which is listed below:

1. In the first step, the key issues in focus, that is A and B, are detailed with the other issues that are intra-linked to A and B. This provides more specific problems to the otherwise broadly stated issues of A and B. Then each of these individual issues are linked to argumentatively justifiable solutions **gathered from tools/ processes in literature study and list of suggestions/ improvements from the case study.** This yields a comprehensive list of issues with corresponding solutions.

2. Each issue hindering KI/CKI affects it in a different manner. Referring to 5 stages of knowledge integration[4] by *Ruikar et. al, 2007*, these issues can affect KI/CKI by reducing accessibility, shareability, new knowledge creation etc. Hence, it is essential to not only review the KI steps affected by issues but also the KI steps positively influenced by the proposed solutions. This analysis has been merged with the list from step 1 and is presented in ***Table 13*** below. This analysis ensures that all aspects of knowledge integration are taken care of.

3. Steps 1 and 2 mainly derive recommendations for broader applicability, for instance for the entire OW sector. This step mainly focusses on proposing recommendations for partner company of the research, Van Oord OW. While the recommendations for issue 'B' (lack of consolidated knowledge database) are sufficiently covered in ***Table 13***, recommendations for issue A need more elaboration considering the process timeline within the company. These are integrated with the company processes, and hence present a more relatable protocol for the company to be implemented and valid sample for the readers of this research.

[4] Locating & Accessing, Capturing, Representing, Sharing and Creating New Knowledge. Out of these, the 3rd stage is not in the scope of this research as mentioned in Section 2.1.

The table below combines steps 1 and 2 and presents the recommendations corresponding to key issues hindering construction knowledge integration in the regime. Noticeably the assessment of KI steps affected/ influenced by issues/ solutions confirm that all aspects affected by the issues have been considered while devising the recommendations. Issue 'B' has been covered sufficiently while 'A' will be detailed further as it can be put in context to the existing processes in the company. For higher readability of the table below, the following things have to be kept in mind:

- The serial numbers have been changed. Issues which correspond to the lack of standard work protocol have been numbered from A 1-7 and solutions are numbered similarly, as multiple recommendations are given per issue. A similar numbering system is followed for issue B.

- The black dots (●) show the KI steps affected by issues and the orange dots (●) show the KI steps positively influenced by proposed recommendations.

Table 13 – Recommendations (key issues & corresponding solutions) & KI step influenced

Sn.	Issues hindering CKI	Solutions based on literature and case study	KI Step Influenced			
			L&A	CAP	SH	NEW
A	No standard work protocol for Knowledge Integration (KI)/ Construction Knowledge Integration (CKI)	A0.1 – **Formalize KI/CKI** and communication processes in the project/company;	● ●(orange)	● ●(orange)	● ●(orange)	●
A	No standard work protocol for Knowledge Integration (KI)/ Construction Knowledge Integration (CKI)	A0.2 – Analyze KI performance through KI indicators, **like NCRs**. Absorb & learn from problems revealed in this analysis;				●(orange)
A1	High time constraints – no time for 'Construction Knowledge Integration' (CKI)	A1.1 – Setting up **Responsibility Matrix** for KI/CKI activities, like knowledge session facilitator, lessons learned feeder etc.;	●(orange)	● ●(orange)	● ●(orange)	●
A1	High time constraints – no time for 'Construction Knowledge Integration' (CKI)	A1.2 – **Setting up a Constructability Team** – A cross-functional team setup in early phases to review & impart construction knowledge throughout the project;	●(orange)		●(orange)	●(orange)
A1	High time constraints – no time for 'Construction Knowledge Integration' (CKI)	A1.3 – **Enable remote participation** to knowledge sharing sessions, like lessons learned sessions;			●(orange)	
A2	Late involvement of fabrication/ installation specialists	A2 – Early involvement (latest by start of preliminary design) of staff **responsible** for all relevant phases/ stakeholders. Mere representation of future phases can cause conflicting opinions later, e.g.: future OCM vs other representation from installation phase;	● ●(orange)		● ●(orange)	● ●(orange)
A3	No steps for inter-project learning of entire team	A3.1 – Inter-project meetings/ information sessions within PM & project engineers of various projects for cross-project learning;			● ●(orange)	● ●(orange)
A3	No steps for inter-project learning of entire team	A3.2 – Enable remote participation of such sessions also;			●(orange)	●(orange)
A4	Troublesome when inhouse expertise busy/ missing	A4.1 – Setting up **Responsibility Matrix** for KI/CKI activities, like knowledge session facilitator etc.;	● ●(orange)	●(orange)	● ●(orange)	●

Sn.	Issues hindering CKI	Solutions based on literature and case study	KI Step Influenced			
			L&A	CAP	SH	NEW
		A4.2 – **Setting up a Constructability Team** – A cross-functional team to review & impart construction knowledge throughout the project;	●(orange)		●(orange)	●(orange)
A5	End of package/ project reports not openly shared (due to confidentiality)	A5.1 – Mandatory req. to check if learnings from end of project reports are fed in to the database;	●	●(orange)	●	
		A5.2 – A skimmed/ non-confidential version of the report shared openly internally;	●(orange)		●(orange)	
A6	No incentive to list lessons as no info received in return	A6 – All KI activities as mandatory part of standard work protocol;	●(orange)	● ●(orange)	● ●(orange)	●(orange)
A7	Knowledge behind major engineering decisions not shared	A7 – Rationale behind major engineering decisions, like choice of foundation type, shared in updates & knowledge sessions with junior team members;		● ●(orange)	● ●(orange)	● ●(orange)
B	No integrated database for all available knowledge (lessons, best practices, templates, standards, req., protocol)	B0.1 – All available knowledge like lessons learned, best practices, templates, protocol etc. in single knowledge database;	● ●(orange)	● ●(orange)	● ●(orange)	● ●(orange)
		B0.2 – Make use of advanced data & text mining algorithms to retrieve knowledge from database, e.g.: better lessons learned searches;	●(orange)		●(orange)	
		B0.3 – Easy feedback feature for knowledge entries to improve/refine it;		●(orange)		●(orange)
		B0.4 – Using analytical outputs from software, like knowledge search frequencies, to **refine** and rearrange recorded knowledge;	●(orange)		●(orange)	
		B0.5 – Monthly knowledge review meetings by project office/knowledge management team refine & remove repetitive entries;		●(orange)	●(orange)	
B1	Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format	B1.1 – Should be merged with a single knowledge database;	● ●(orange)	● ●(orange)	● ●(orange)	● ●(orange)
		B1.2 – Digital means of registering momentary/ daily learnings;		●(orange)		●(orange)
B2	Lessons are project/ situation specific	B2 – **Standard tags** should be added to the current regime of storing knowledge for better retrieval;	●(orange)		● ●(orange)	
B3	Difficult to describe complex information in knowledge database	B3.1 – Entries can be linked to technical documents/ project reports for reference;	● ●(orange)	● ●(orange)	● ●(orange)	
		B3.2 – **Compulsory contact of knowledge entrant** ensures a communicable channel;	●(orange)			●(orange)
B4	Difficult to transfer tacit knowledge through databases	B4 – Ensure participation in knowledge sessions to make staff aware of recorded knowledge. This can increase database usage;		●	● ●(orange)	

● – KI Step influenced by issues
●(orange) – KI Step influenced by solutions

NOTE : The influence on KI steps by 'solutions' is based on literature study while for 'issues' is inferred based on understanding of the issue and KI steps by the author. Recommendations are not based on influence and remedy of KI steps. Instead it is used as a supportive analysis to see how the solutions (which are derived from case & literature study) remedy multiple facets of the knowledge integration cycle.

Having covered the broader recommendations (based on applicability), step 3 was to devise more company specific recommendations and present a valid, relatable, applicable and standardizable protocol for construction knowledge integration in the context of project processes at Van Oord.***Figure 19*** presents the standard protocol integrated with a simplified representation of the project processes at Van Oord. The sequence on the lower side of the figure shows the standard stage gate process at the company in which the engineering phase (which is the primary scope of this research) lies between stage gate 3 and 4. It was observed during document analysis that the standard work module for engineering phase of offshore wind foundations is still under development. Further, the only mention of a relatable KI/CKI activity in the entire standardized PMP (Project management plan) was only after stage gate 6 – to register the lessons from respective project and share it to the lessons learned database. A work in progress engineering process model was gathered and simplified for this representation. The protocol mainly consists of smaller interventions/ recommendations integrated at a specific point in the project lifecycle (which is shown by arrows in the figure). The list of interventions is given below:

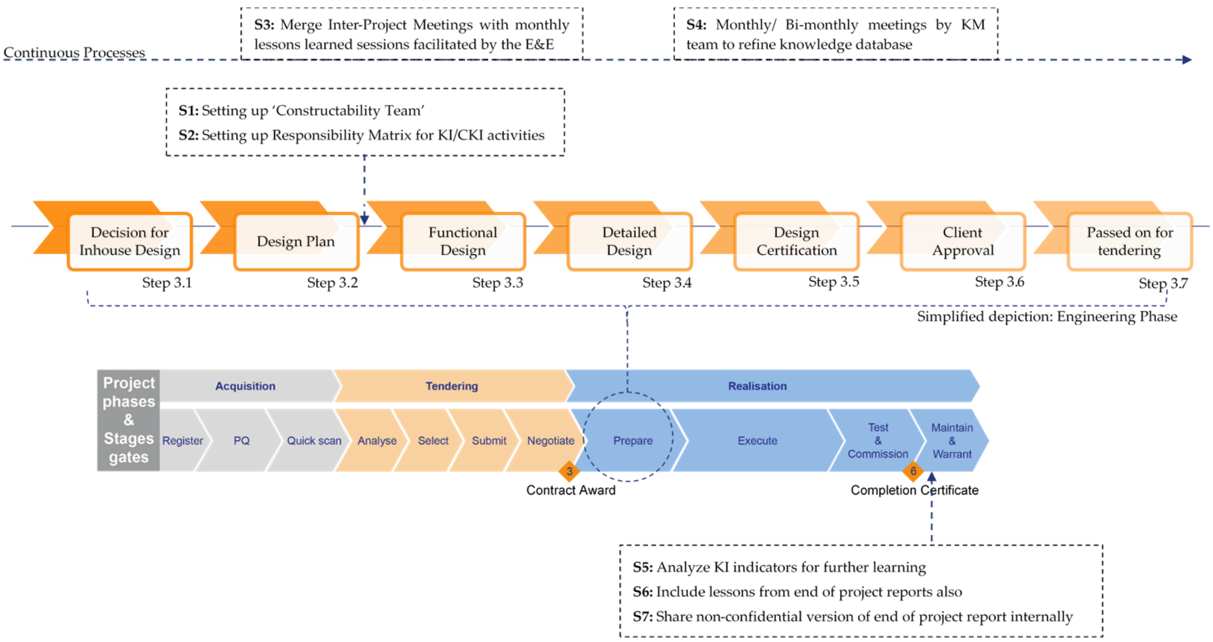


Figure 19 – Standard protocol recommendations for KI/CKI during project phases

S1 – Setting up 'Constructability Team'
S2 – Setting up Responsibility Matrix for KI/CKI activities
S3 – Merge Inter-Project Meetings with monthly lessons learned sessions facilitated by the E&E
S4 – Monthly/ Bi-monthly meetings by KM team to refine knowledge database
S5 – Analyze KI indicators for further learning
S6 – Include lessons from end of project reports also
S7 – Share non-confidential version of end of project report internally

The three steps shared above conclude the process followed to devise the recommendations for this research. It took a few iterations to be written and presented the way it is shown in this sub-section. However, this does not provide the final set of recommendations as they would be screened and validated further in the sections to follow.

5.2 Validation

The previous section presented the recommendations to optimize construction knowledge integration in offshore wind projects. These were based on literature study and case studies which mainly included inputs from 12 interviewees. Since this is a practice oriented research, the results of the research will also be evaluated from the perspective of applicability. To render higher reliability to the recommendations, these have to be validated. The process and feedback has been covered below.

Validation Process

Since construction knowledge integration is a niche area and feedback on usability and applicability highly depends on the experience and expertise of the respondent, the process chosen for validation is through an **'expert panel'**. In this, relevant experts are gathered to share their feedback on the recommendations. The experts chosen for validation were from the collaborating company, Van Oord since the recommendations itself were strongly based on case study of OW projects by the company. The aim was to arrange a multi-specialty panel with the highest available experience. A panel of 9 experts attended the validation session. The expertise and years in the field are listed in the table alongside. Notably, this is mainly an overview of their current roles. The experts were invited for a 1 hour session. The session began with presenting the research context and recommendations. After this, individual feedback was gathered in writing on individual handouts.

Table 14 – Details of experts in validation panel

Expertise	Experience (years)
Steel Fabrication, Project mgmt.	30
Construction mgmt.	28
Project mgmt., Offshore Eng.	20+
Engineering mgmt.	15
Planning & Risk mgmt.	11
Knowledge mgmt., Project mgmt..	10
Process mgmt.., Systems Eng., Value Eng.	10
Engineering mgmt..	10
Quality mgmt..	5

If the proposed solution is beneficial against respective issues

If the proposed solution is practically applicable in OW projects

Sn.	Issues hindering CKI	Solutions based on literature and case study	Under-standable (Y/N)	Beneficial (Y/N)	Applicable (Y/N)	Remarks
1	XXXX	YYYY	Y	Y	Y	Optional
2	XXXX	YYYY	Y	N	N/A	Remarks on beneficiality
3	XXXX	YYYY	Y	Y	N	Remarks on Applicability

Remarks, obligatory for 'No' responses in previous Y/N columns

Figure 20 – Sample structure for recording validation feedback

The figure above shows a sample of the table that listed the recommendations and had various rows for gathering various feedback. If some expert entered 'No', filling the latter columns for the same solution was not applicable. The remarks were requested, especially for every 'No' answer to gather insights and consider for improvements if the remarks were perceived as crucial by the author. The original feedback has been attached in **Appendix B**.

Validation Data

This sub-section presents and analyses the feedback received from experts in the validation session. As mentioned earlier, the compiled data and original entries can be seen in Appendix B. The three Yes/No columns for solutions being understandable, beneficial and applicable have been analyzed as percentage values. The percentages stated are for 'Yes' responses. **A high permissible percentage of 67% (2/3rd) has been chosen for recommendations being understandable, beneficial or applicable.** If the value is less than it, it has been highlighted in the table below and addressed in remarks and further sections. It was obligatory for experts to state remarks for every 'No' response, while it was optional for their positive responses. In general, the experts were very expressive even if they agreed with the solution, which has been beneficial for this research as it provides experience rich data. Since there were many remarks for the solutions, they have been screened and only ones which the author felt critical have been listed in the table below.

Table 15 – Validation Data Summary

Sn.	Understand-able (Y/N)	Beneficial (Y/N)	Applicable (Y/N)	Analysis
A0.1	89%	78%	67%	Two out of 3 disagreements were because the solution did not provide executable details. The third stated KI is mainly through experience & not going through knowledge database.
A0.2	89%	89%	89%	The main feedback was to consider it with other KPIs or to detail the instruction & link it with the lessons learned / root causes
A1.1	89%	56%	56%	**Experts were critical of this solution creating more processes than exist and it increases paperwork/ work burden of staff. One expert said it does not guarantee people's availability.**
A1.2	89%	78%	78%	Most experts positive about it. It needs to be added that this practice is to be on project by project basis. Some experts stated it should be at an organisational level, not operational level.
A1.3	78%	78%	78%	Some experts said it is in place. Maybe it needs to be elaborated with an example where the shortcoming is.
A2	89%	89%	44%	**The terminology 'Early involvement' raised the biggest alarm as it also covers sub-contractors which are not available and arranging their availability is out of scope of this research. This tool was merged with A1.2 in the process model. Clarifying actors can be helpful.**
A3.1	100%	89%	78%	Cautionary advice to keep it structured, received from experts. Well received.
A3.2	78%	67%	67%	One experts likely pointing towards logistical issues in arranging it.

Sn.	**Understand-able (Y/N)**	**Beneficial (Y/N)**	**Applicable (Y/N)**	**Analysis**
A4.1	89%	44%	44%	**Dissenting experts stated this solution still does not guarantee their availability, too much paper-work & needs to be collaborated with E&E.**
A4.2	89%	56%	56%	**No severe remarks stated. One positive remark was that 'being busy' cannot be tolerated.**
A5.1	89%	89%	89%	No critical remarks
A5.2	100%	78%	56%	**Main remark was extra work required for creating a different version. If the previous solution is implemented, the need for a different version would reduce. Confidentiality should be assessed.**
A6	78%	44%	44%	**Sounds similar to formalizing KI. The solution still does not incentivize staff but instead force people for tasks which may not work.**
A7	100%	78%	78%	While this tools is useful & applicable, it should be detailed further w.r.t. target staff (project teams or organization wide). Some experts also stated that it is already part of Stage gate process.
B0.1	89%	67%	56%	**Main critical questions were on how can a single database be achieved. Some doubted its effectiveness but did not justify why.**
B0.2	100%	78%	56%	**Main critical point was that it would only work if there is a single structured database.**
B0.3	89%	67%	67%	No explicit remarks which could be incorporated
B0.4	67%	56%	56%	**Low percentage mainly because of less understandability. Otherwise 1 negative remark of non-achievability without further justification.**
B0.5	89%	67%	56%	**No adequate justification for dissent. Some experts raised question on achievability but did not say why. The frequency can be flexible. Expert from KM team agreed to solution.**
B1.1	100%	89%	78%	Same issues raised as with the achievability of a single knowledge database.
B1.2	100%	56%	56%	**Dissenting experts concerned of quality of these learnings if added to the database. Author's solution should be elaborated further.**
B2	100%	89%	89%	One key constructive feedback that these standard tags should be understandable even without project/ database experience.
B3.1	100%	78%	78%	One interesting feedback was to create a reverse link as well where entered lessons get updated with change in standards/ other knowledge.
B3.2	78%	78%	78%	Some experts said this is already being done at the company, is very useful. The contact person is tagged as owner of knowledge at the company
B4	78%	78%	67%	The experts found the solution description unclear. One expert said awareness is essential but there can be more ways to achieve it.

Table 16 – Summary of validation data on standard protocol

Sn.	Solutions mentioned in process model	Applicable (Y/N)	Remarks
S1	Setting up 'Constructability Team'	62.5%	While 'No' responses were received, remarks have not kept pace. Major process improvement is to implement before preparation of design plan.
S2	Setting up Responsibility Matrix for KI/CKI activities	62.5%	The only process improvement remark was to implement before preparation of design plan.
S3	Merge Inter-Project Meetings with monthly lessons learned sessions facilitated by the E&E	50%	Many experts stated it to be already in place. One expert also raised how it is different from the lessons learnt session itself, which calls for better elaboration of inter-project learning.
S4	Monthly/ Bi-monthly meetings by KM team to refine knowledge database	62.5%	Main remark on process implementation is that time gap between meetings should eb flexible but this needs to be held continuously.
S5	Analyze KI indicators for further learning	100%	Many experts advised it to a continual process and not one-off at the end, which would also ensure learning for the ongoing project as it is mergeable with the standard set of KPI's.
S6	Include lessons from end of project reports also	100%	High agreement in applicability. One expert suggested that it should already be in place, implying implementing it an earlier stage.
S7	Share non-confidential version of end of project report internally	87.5	The main criteria is if such a report is needed. No clear remarks on timing of this solution.

The two tables above present an overview of data collected from the validation suggestion and also an analytical summary of the feedback. The experts put effort in sharing their views. While some remarks did not justify their dissent, there have been enough responses to guide an overall improvement of the recommendations which will be taken up in the next section.

5.3 Adapted Recommendations

This section discusses the remarks of experts on the recommendations and integrates concrete changes wherever applicable. The sub-section concludes with providing the adapted list of recommendations. The key remarks and changes thereof for list of recommendations have been discussed below. Minor changes such as detailing the language or adding an example is not discussed below and implemented directly. The recommendations with major change have been shown in bold:

- **A0.1** was perceived as a non-descriptive solution. **The reason for its inclusion in the list was to put forward the need for formalization of the KI/CKI processes in the regime.** This research presents the list of recommendations and a process model as steps to formalize, but the formalization potential is not limited to these recommendations only.

- **A0.2** does not directly relate to an issue or root cause on the list of issues. The recommendation can still include or state that there can be other indicators of CKI in the project that need to be reviewed. Merging it or not doing so will be inconsequential to the utility.

- **A1.1** was not agreed by all experts as it does not guarantee people's availability. Author's perception is that a start needs to be made in making people accountable for KI/CKI activities and people in a professional environment are expected to fulfill their responsibilities. There was one comment from an expert that 'being busy' is not an excuse for not executing responsibilities. This statement is in favor of defining responsibilities early on.

- **A2 was not well received with the experts as early involvement of all relevant parties also includes fabricators which has been a continual struggle. The root cause lies in the project delivery mechanism which is out of the scope of this research. The issue at hand can still be diluted with setting up a constructability team which if set up in early phases (which it can be), it would ensure construction knowledge integration in the project.**

- **Agreeably, A4.1 does not stand true for the issue A4 and hence will be removed from the list. This is because setting a responsibility matrix for KI activities does not provide technical expertise. It was also pointed out in the expert feedback.**

- **A6 does not provide an adequate solution for the respective problem. This is being replaced with an interpretation of a step under development by the project office. The aim is to highlight best or most useful knowledge entries (through feedback received) which would incentivize people to share more and share higher quality content.**

- Experts were critical on the recommendation to achieve or devise a single structured knowledge database (**B0.1**), mainly on account of achievability/ feasibility. The importance and need of such a tool has been reinstated in literature study and case study interviews. Hence, even with a slightly less validation percentage, this recommendation will be maintained as is.

- Main critical remark for **B0.2** was that it would only work if the previous recommendation of a single database is fulfilled. Since recommendations are made in a certain context & research states that it is an essential feature of a database, this recommendation will be kept as is.

- **B0.4** has not been elaborated well enough to explain the core concept which can be the reason for its lower validation percentage. This would be elaborated further in the recommendations.

- Same as the previous point, **B0.5** also needs to be elaborated further to reveal the core concept.

- **B1.2** seems to be misunderstood as a source of unfiltered knowledge in the system by the experts. The core concept imagined by the author is different from this and will be elaborated further. Basically momentary learnings are stored for personal reference so that these are not lost between the long gaps of lessons learned sessions. These informal registers, technically made possible by this intervention, can be used during lessons learned session to formalize and detail while ensuring quality input.

- B2 received a suggestion to simplify the standard tags with each knowledge entry which can be understood to even the person less experienced with the database. This will be added to the recommendation to improve it further.

Table 17 – Adapted recommendations after validation

Sn.	Issues hindering CKI	Recommendation to corresponding issues
A	No standard work protocol for Knowledge Integration (KI)/ Construction Knowledge Integration (CKI)	A0.1 – **Formalize KI/CKI** and communication processes in the project/company. This can be achieved through (but not limited to) the recommendations made in this research;
		A0.2 – Analyze KI performance through KI indicators, **like NCRs, TQs, contract variations etc**. Analyze, register & share learnings from this analysis;
A1	High time constraints – no time for 'Construction Knowledge Integration' (CKI)	A1.1 – Setting up **Responsibility Matrix** for KI/CKI activities, like knowledge session facilitator, lessons learned feeder etc.;
		A1.2 – **Setting up a Constructability Team** – A cross-functional team setup in early phases to review & impart construction knowledge throughout the project; team is setup from project to project basis;
		A1.3 – **Enable remote participation** to knowledge sharing sessions, like attending lessons learned sessions in NL while posted in DE;
A2	Late involvement of fabrication/ installation specialists	A2 – **Setting up a Constructability Team** – Definition same as in A1.2; key consideration is to decide responsibilities early on and not involve mere representatives e.g.: future OCM vs other representation from installation phase;
A3	No steps for inter-project learning of entire team	A3.1 – Inter-project meetings/ information sessions within PM & project engineers of various projects for cross-project learning; Inter-project learnings are not only to absorb lessons learned from other projects but to absorb ongoing progress, challenges and solution under development so that effort is not repeated unknowingly within the same organization;
		A3.2 – Enable remote participation of such sessions also;
A4	Troublesome when inhouse expertise busy/ missing	A4.1 – **Setting up a Constructability Team** – Definition same as A1.2;
A5	End of package/ project reports not openly shared (due to confidentiality)	A5.1 – Mandatory req. to check if learnings from end of project reports are fed in to the database; This should be registered & shared by the respective project team and like other knowledge, reviewed by KM team;
		A5.2 – A skimmed/ non-confidential version of the report be shared openly internally; Confidentiality restrictions might vary project to project
A6	No incentive to list lessons as no info received in return	A6 – Most useful or best knowledge entries (judged from feedback received) will be highlighted along with knowledge entrant motivating staff to contribute sincerely to database with more & quality inputs;
A7	Knowledge behind major engineering decisions not shared	A7 – Rationale behind major engineering decisions, like choice of foundation type, shared in updates & knowledge sessions with junior team members;
B	No integrated database for all available knowledge (lessons, best practices, templates, standards, req., protocol)	B0.1 – All available knowledge like lessons learned, best practices, templates, protocol etc. in single knowledge database;
		B0.2 – Make use of advanced data & text mining algorithms to retrieve knowledge from database, e.g.: better lessons learned searches;
		B0.3 – Easy feedback feature for knowledge entries to improve/refine it;
		B0.4 – Using analytical outputs from software, like top knowledge searches, unassessed material on database, to **refine** and rearrange recorded knowledge; Such systems are present in readymade databases from various companies & can even be used for searches on intranet;

Sn.	Issues hindering CKI	Recommendation to corresponding issues
		B0.5 – Timely knowledge review meetings by project office/knowledge management team refine & remove repetitive entries;
B1	Lessons learned register is inconvenient, unstructured, poor in knowledge retrieval & filling momentary learnings, non-standard lessons format	B1.1 – Should be merged with a single knowledge database;
		B1.2 – Digital facility to register momentary/ daily learnings; These do not go straight into the system but act as reference for respective staff during lessons learned discussions where it is detailed, registered & shared; Noting momentary learnings digitally would prevent it getting lost;
B2	Lessons are project/ situation specific	B2 – **Standard tags** should be added to the current regime of storing knowledge for better retrieval; These tags should be simplified so that they are understood to even staff with less experience of the database;
B3	Difficult to describe complex information in knowledge database	B3.1 – Entries can be linked to technical documents/ project reports for reference;
		B3.2 – **Compulsory contact of knowledge entrant** ensures a communicable channel;
B4	Difficult to transfer tacit knowledge through databases	B4 – Ensure participation in knowledge sessions to make staff aware of recorded knowledge. Once staff know what knowledge is available in the database, they are more probable to use the database;

The next step is to include the changes in the standard process model shown in ***Figure 19***. The changes being made to the process model are discussed below:

- S1 & S2 are shifted prior to preparation of design plan within engineering processes. The intent earlier was to indicate their inclusion latest before the start of functional design. But as research says, the earlier the better and further if more room is allowed for actions to be performed, all the buffer time will be used up, something similar to the *student's syndrome*.

- Certain new processes have been added as continuous processes like registering momentary knowledge (S3). Further the analysis of KI indicators has been changed to being continually evaluated rather than previous suggestion of evaluating only after stage gate 6.

- Another new suggestion has been added to make it mandatory to analyze and incorporate learnings from database during the tendering phase.

The above were the main changes in the process model. The updated process model as shown in **Figure 21** incorporates a series of recommendations applicable to a broader context as well as company specific findings.

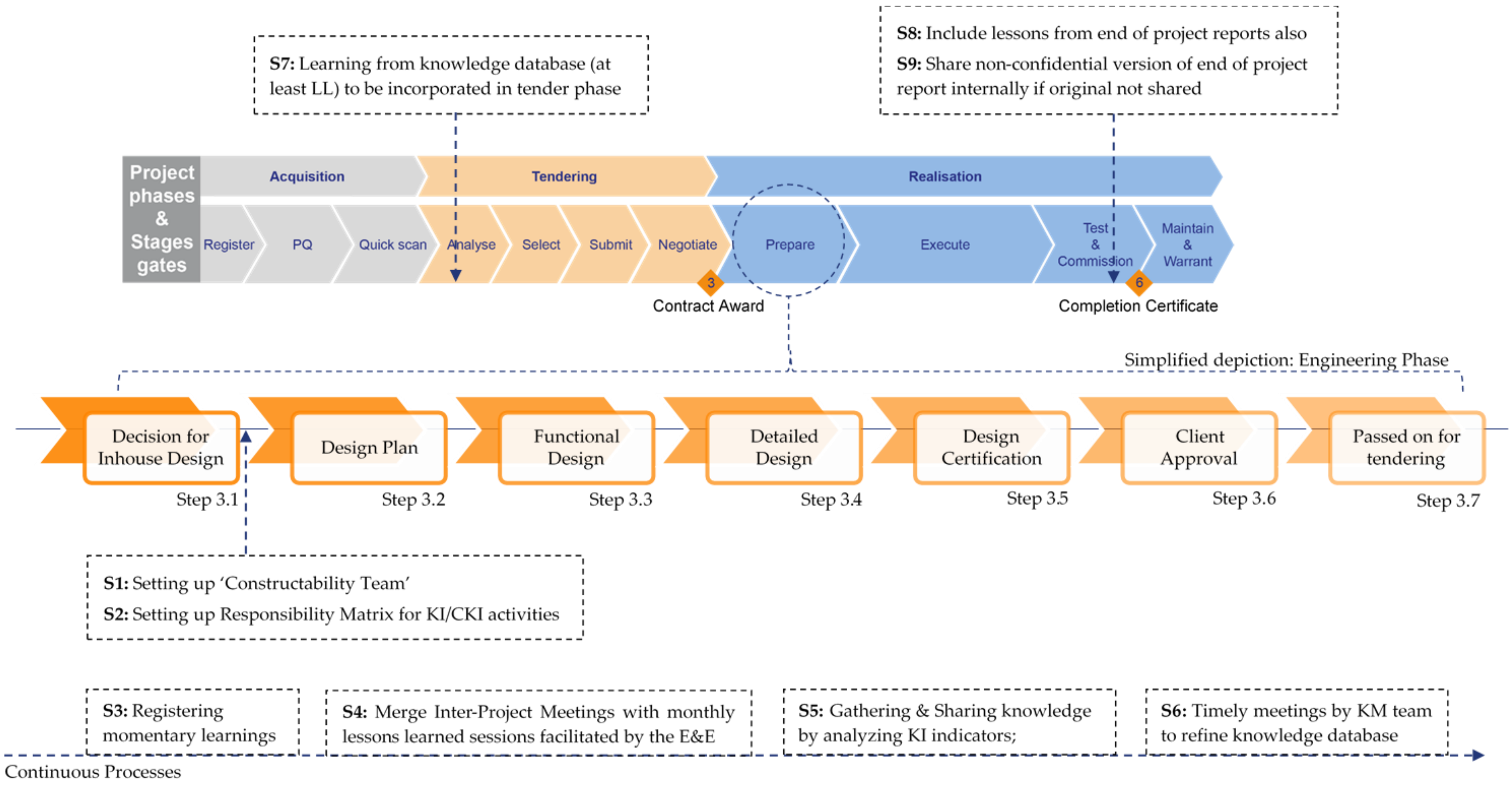


Figure 21 – Adapted model for standard KI processes in OW projects

Knowledge Sources Addressed

This chapter presented the recommendations to optimize construction knowledge integration in the assessed regime. Analyzing the existing regime also revealed the sources of knowledge not addressed/ used, which were all except market knowledge through market participation and research (Refer section 4.2.3). This section presents the sources of knowledge, the use of which was remedied by the recommendations of this chapter. To integrate essential knowledge from various packages during execution like procurement, fabrication and installation was addressed through recommendations like setting up constructability team (A2) and to some extent by setting up responsibility matrix (A1.1). Similarly learning from ongoing projects is expected to be boosted by setting up inter-project meetings/ sessions and enabling remote participation in such sessions (Refer A3.1 and A3.2 for further detail). For optimizing transfer of stored knowledge within the company, setting up of an integrated knowledge database has been advised with specific recommendations from B0.1 to B4 to address more intricate challenges of a knowledge database. Finally, a list of recommendations aligned with specific source of knowledge that it addresses is given below to make it more relatable for the reader.

- Fabrication/ Procurement/ Installation Knowledge – A0.1, A2, A1.1
- Lessons from ongoing projects – A3.1, A3.2, A0.2, A7
- Past lessons/ database – Entire B series of recommendations, A5.1, A7

This implies that the recommendations of this research address all sources of knowledge which are partially integrated in the current regime. This has been depicted in the figure below (The grey arrow implies the source that has not been addressed through the recommendations).

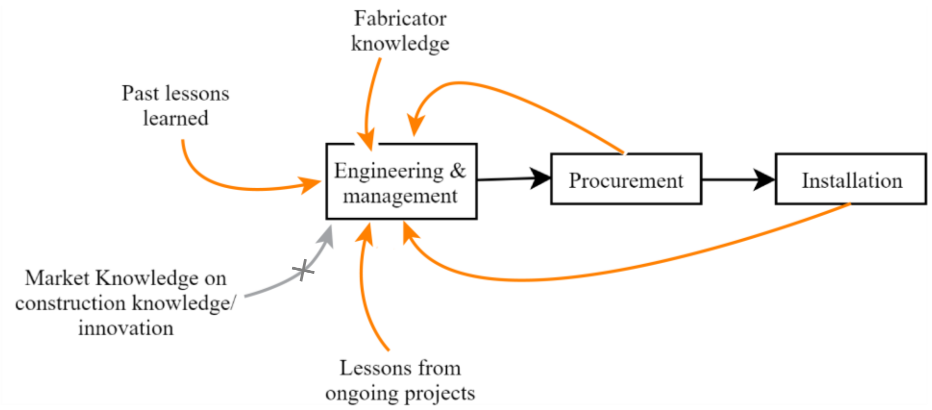


Figure 22 – Knowledge sources remedied by recommendations

6. Discussion & Conclusion

This chapter analyses and presents the main findings of this research, answers to the research question(s) and what it adds to the offshore wind sector and the scientific community. The chapter begins with discussing the findings throughout the research process followed by limitations of this research

6.1 Discussion

This main research objective has been to optimize construction knowledge integration (CKI) in offshore wind (OW) projects and create higher value. This was motivated by the preliminary finding that there is limited integration of construction knowledge in the realization of offshore wind projects. The finding was derived through exploratory interviews at the collaborating company, Van Oord, and a preliminary literature study of the subject. This section discusses the significance of findings throughout the research process.

To optimize CKI, it is imperative to explore and communicate the subject effectively, which was achieved through a detailed literature study. The literature in the project management aspect of the offshore wind industry has been scarce, if not rare, and for knowledge integration and management perspective on the sector, almost non-existent. This provided a challenge in gathering insights specific to the sector. Many researches in diverse sectors like transport infrastructure, building construction and fabrication were included in the study which helped argue that the theoretical findings may be applicable to the entire construction sector, including offshore wind. The literature study provided reliable and useful concepts like knowledge integration steps, ideal time to begin CKI efforts in a project, desired sources to be captured, benefits of CKI and tools and practices to integrate construction knowledge. Concept of KI steps helps understand the functions which are imperative for any practice to aid in KI/CKI. Time of intervention in the project and sources to be addressed are crucial for the success of CKI efforts as only desired construction knowledge sources, used at the right time in a project lifecycle can provide usable inputs. Communicating the benefits of CKI can motivate staff and management of an organization to invest in CKI practices. Lastly, the comprehensive list of tools and practices fulfils the purpose of making te reader aware of the methods available for construction knowledge integration. Hence, the literature study not only provided a theoretical base for the next stages of this research but also makes the reader familiar with the dynamics of construction knowledge integration which has broader application in the civil engineering industry.

While the literature study presented a set of general, owner, designer and contractor barriers, the source was not based on research in the offshore wind sector. Hence, to explore the dynamics of construction knowledge integration in offshore wind projects, case studies were pursued. With the help of 12 semi-structured interviews and documents, key project management challenges, perception of respondents on CKI, practices in use, issues, suggested improvements, CKI indicators and value implications were gathered. It is interesting to note that combined results show alignment to literature. For instance, perceived effects of CKI on value are same as what the literature study suggests. Same is the case for issues and PM challenges. The tools and practices in use, respondent's perception and document analysis helped conclude on the existing construction knowledge integration regime (existing procedures to achieve CKI) in OW projects. Analyzing issues and suggestions combined with the current regime also revealed the KI steps and knowledge sources addressed by the current system. The issues concluded from interview data were further streamlined to derive key issues which have the biggest impact on construction knowledge integration in offshore wind projects. Finding key issues paved the way for devising recommendations for the same and conclusively optimizing CKI in OW projects. One of the key issues is about lack of formalization in KI/CKI practices which is same as the first owner barrier found through literature study (Ref. section 2.4). This implies the validity of case study results. Conclusively, the combined findings from interview data, the current regime and the key issues add to the field of research as it is a scarcely explored context and also the organizations working in the sector.

The last and the final step of the research was to address the key issues derived through case study analysis. The recommendations were devised using processes stated in the relevant literature and case study data. The main set of recommendations has not been stated in a company specific language to make it more relatable for the entire sector and other organizations as well. To give a more relatable set of recommendations for the sponsoring company, Van Oord, a process model was also proposed. Both the recommendation sets were validated through a panel of 9 experts from different domains. The feedback was critically analyzed before integrating in the final set of recommendations. Overall the validation feedback was positive and since further improvements have been made after it, which makes the findings more beneficial, applicable and convincing. In addition to these, the research also presents recommendations for further research and recommendations for practice which are applicable to the offshore wind sector.

In conclusion, this research presents a positive proposal to achieve more constructible offshore wind components/projects. Where it strongly adds to the literature is by exploring the concept of construction knowledge integration in the realm of offshore wind projects, which had not been amply researched.

6.2 Conclusion

This section answers the main research question of the thesis. Since answer to the main research question is based on the sub-research questions, these would be elaborated first.

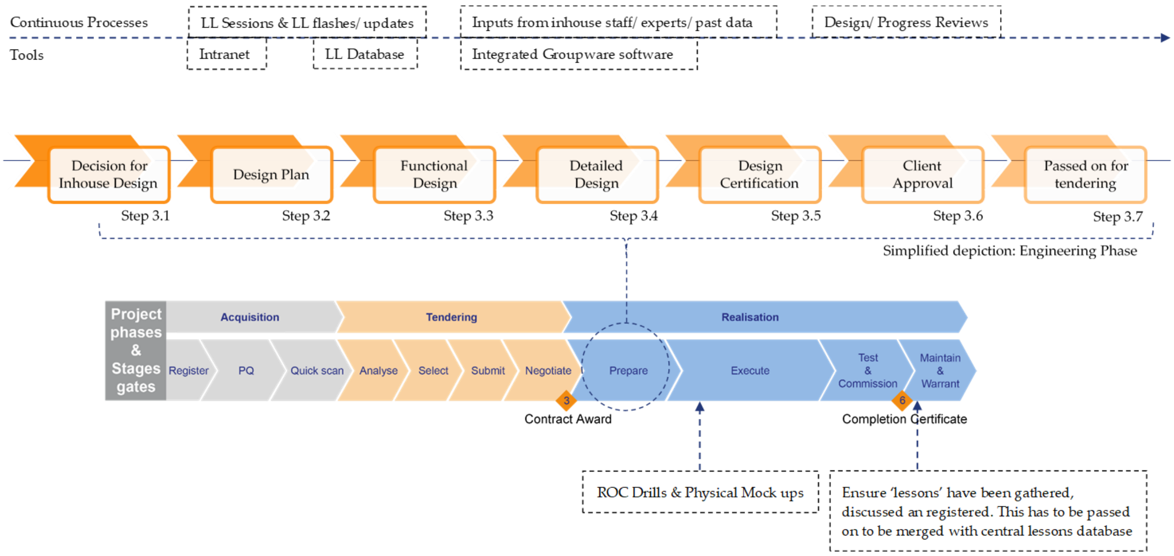
1. *What is construction knowledge, its integration, benefits, sources and ways to achieve it?*

   Construction knowledge is the requisite knowledge needed for construction work to effectively and efficiently take place. It is the knowledge and experience of construction/ fabrication/ installation processes and dynamics, which might stretch over multiple phases in the project. For example, it can be added insights on the labor, materials, equipment, space, logistics and techniques required to build or the opportunities and challenges of executing various design details. When these insights are amalgamated (included) in the project processes, it is integration of construction knowledge. It is the process of combining knowledge across business entities, e.g. across teams, business entities and departments. It was also found that knowledge integration is a cyclical process with 5 stages (Ruikar et al., 2007) namely locating and accessing, capturing/storing, representing, sharing and creating new knowledge. Only if a tool or practice fulfil one or more of these functions, it can contribute to knowledge integration.

Construction knowledge integration can have many benefits (as found in the literature study), the main ones being reduction in contract variations, project quality enhancement, reductions in cost and duration, improvement in design and communication etc. Research also suggests that construction knowledge should be integrated in the early/ pre-design phase of the project for maximum benefits. Construction knowledge is specialized knowledge which is why its integration and usability largely depends on its source. Gathering inputs from all relevant project participants, especially contractor/ fabricator, at an early stage is a big challenge. The necessary knowledge sources can vary based on project type, context, resources available, project delivery method etc.. The desired situation in the end is to find a right mix between these knowledge sources based on project dynamics.

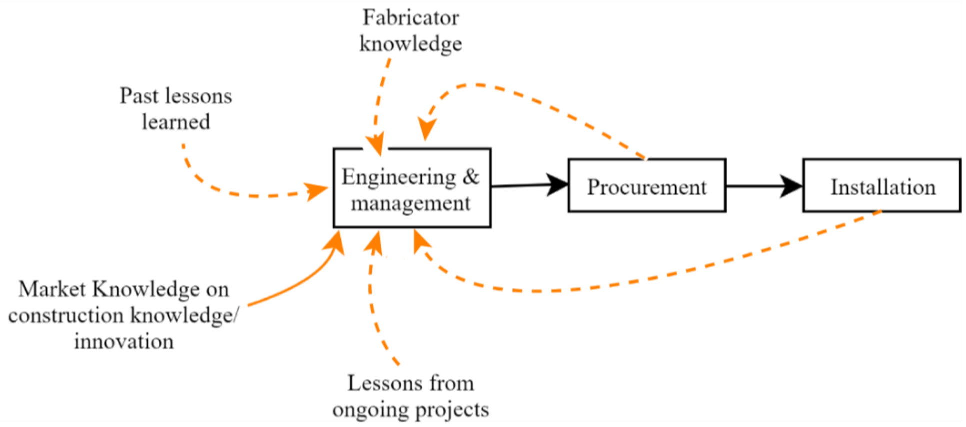
A comprehensive list of tools and practices, 32 to be precise, was derived through the literature study where the most commonly stated practices were constructability/design reviews, knowledge database and hypermedia/multimedia. However the desired situation here also, is to balance the system with use of various tools and practices and not rely upon a single choice.

2. *What is the current construction knowledge integration regime in engineering processes for OW projects?*



A 'regime' in simple terms, is a system or ordered way of doing things. Hence, here the procedures followed to integrate construction knowledge in OW projects is what we refer to as the current CKI regime. The regime was assessed using combined list of tools and practices and documents derived from case studies. It was concluded from the analysis that formal presence of knowledge integration tools and processes is scarce. The only formal process is for staff is to gather lessons learned after project completion (stage gate 6), register in a pre-set local file and share it with the management. Since use of lessons learned register in early project stages is not formalised as the standard work practice (which can be one way to formalise it), the company staff is officially not supposed to do it. Further, the continuous processes are not formalised in the current regime, meaning they are not defined objectively for knowledge integration within the company and are not conducted in pre-planned intervals. The ROC drills and mock ups are not recognized as activities which aid in communication. The current regime is presented in the context of formal project processes within the company in the figure above (same as ***Figure 15*** in the main text).

The regime was also assessed in terms of knowledge integration stages it fulfils and knowledge sources it addresses. Since most of CKI efforts in the regime are based on lessons learned data, it theoretically covers all 4 stages of knowledge integration namely locating and accessing, capturing, sharing and creating new knowledge. But since the tools/ practices in current regime are fairly limited and strong issues are stated with the lessons learned database/ system itself, knowledge integration has large scope of improvement. With reference to knowledge sources, it was observed that there was limited integration of fabrication, procurement and installation knowledge, inter-project learning and from knowledge stored within the company, like lessons learned. This is shown in the figure below where the dotted arrows represent limited integration (same as ***Figure 16*** in the main text).



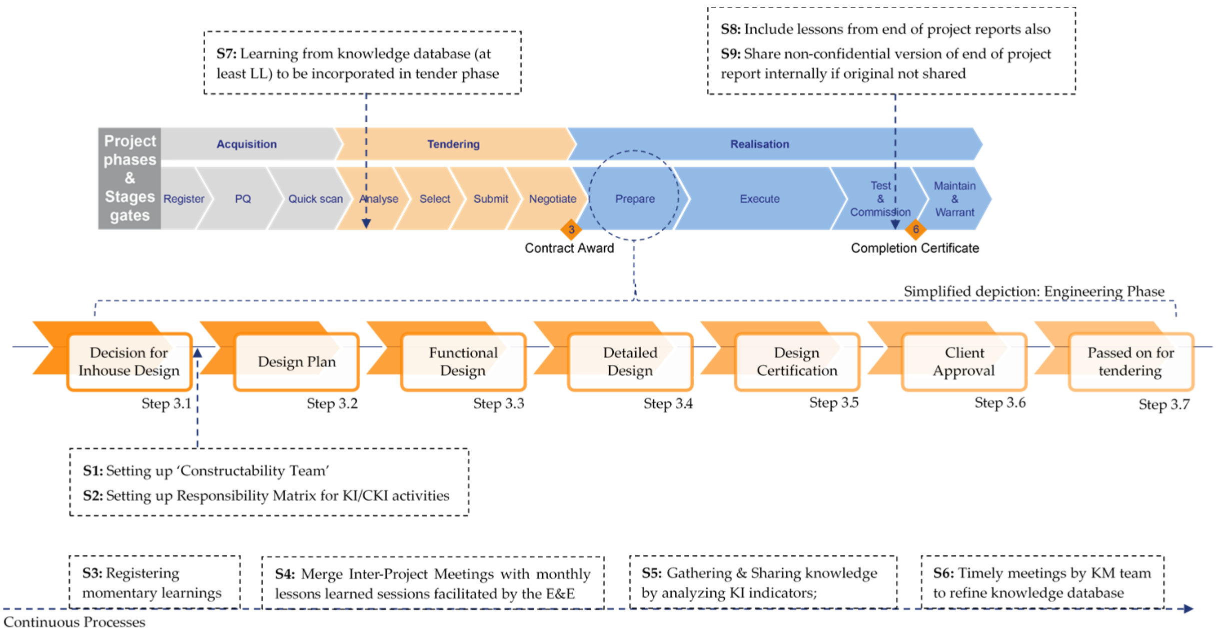
3. *What are the key issues hindering construction knowledge integration in OW projects?*

The case data analysis provided a list of 24 different issues hindering construction knowledge integration in offshore wind projects. The most commonly stated issues were lessons learned register being inconvenient, unstructured and poor in knowledge registering and retrieval; No standard lessons format; Less/ no inhouse experts for fabrication, quality management and electrical installations; High time constraints reducing time available for CKI efforts and no standard work protocol for KI/ CKI. Since the key focus was to find the issues which are causing the most hindrance in construction knowledge integration in the cases studied, the issues had to be screened further. After analyzing the correlational and causal relationships between issues and suggestions, two key issues were found in the regime which are listed below:

A. No standard work protocol for KI/ CKI
B. No integrated database for all available knowledge

4. *What are the applicable process interventions to address the key issues hindering CKI in OW projects?*

The straightforward solution to key issues derived earlier is to formalize the KI/CKI processes within the organization and develop a standard efficient and effective knowledge database (including lessons learned, best practices, templates etc.). Since issues A and B had causal and correlational relationships respectively with other issues in the regime, standardizable recommendations are proposed for each of these issues. The compiled list can be seen in ***Table 17***, section 5.3, which lists recommendations for the sector and not only the organization.

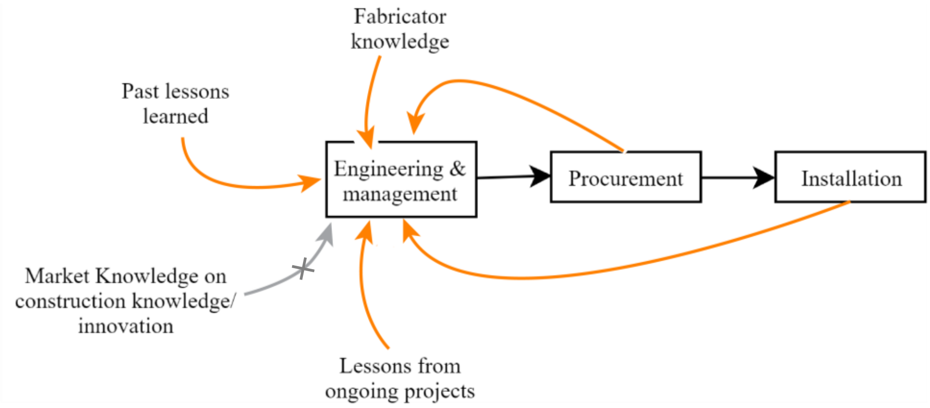


The standardizable processes also form a regime. This proposed regime is also presented in the context of formal project processes within the company in the figure above (same as **Figure 21** in the main text). The process model above is company specific because of the contextual processes but the underlying message is to formalize the processes as it increases the possibility of being followed. Most recommendations for the second issue (B) are not present in the figure above as those are essentially additions to create a knowledge infrastructure for better KI. While the detailed recommendations are in ***Table 17***, the main points have been listed below:

- Create a single effective and efficient knowledge database consolidating best practices, lessons learned, standard protocol, technical data, templates etc.
- Advance data & text mining algorithms to improve knowledge retrieval
- Filter knowledge using usage analytics or feedbacks (through feedback feature)
- Knowledge review meetings by KM team to refine database periodically
- Feature to enter momentary learnings, to be detailed later
- Entries linked to technical data to communicate complex information
- Standard tags and contact of knowledge entrant
- Enable participation in knowledge sessions to increase awareness on extent and types of knowledge available in database

"How can construction knowledge integration be optimized in the engineering processes of Offshore Wind projects?"

Construction knowledge integration in Offshore Wind projects can be optimized by formalizing the knowledge integration practices within and between the organizations involved and ensuring that the registered forms of knowledge are effectively and efficiently reachable. Construction knowledge integration is an ongoing process but a regime, set up to continually allow knowledge integration steps (locating & accessing, capturing, sharing and creating new knowledge) will ensure its recurrence. It is also important to ensure that essential knowledge sources are used in the engineering processes, ideally right from the early stages. The offshore wind projects studied, showed limited integration of certain knowledge sources, as detailed in sub-question 2 above. The recommendations presented by this research presented a scheme to integrate essential sources of knowledge for the offshore wind sector. The knowledge sources addressed are shown in the figure below (same as **Figure 22** from main text).



In the end, the idea here is to resolve what's hindering the integration of construction knowledge. With the theoretical data and obstacles and corresponding solutions to relate, this research provides a package which can optimize construction knowledge integration in offshore wind projects..

6.3 Limitations

Like all research projects, specially one with time and resource restrictions, there are certain limitations in the research as well as findings. They key limitations are discussed below:

- Being a practice oriented research, it was strongly based on case studies of recently completed/ ongoing offshore wind projects. However the data was collected from the perspective of contractor's staff. Project participants like the client, sub-contractors, suppliers and consultants also impact the construction knowledge integration in the project. But not addressing their perspective is a limitation of this research.

- The findings of this research are based on CKI regime examined from cases executed by the sponsoring company. The issues and practices in use can also vary from organization to organization. This research has not examined the sector wide regime which remains a limitation of this research.

- While the main objective of this research has been to pave way for higher value addition to projects, examining it has not been the main focus as it was more directed towards optimizing construction knowledge integration itself. While impact on value was concluded through feedback from interviewees and literature study (also the former's perception matched with literature study findings), it still needs a detailed quantitative analysis to present it as a scientific finding of this research. This has been a mild limitation of this research.

- Since the research talks around the concept of construction knowledge and its integration, it realizes that the success of its recommendations largely depends on people's actions. The research has not evaluated the issues from the behavioural point of view. This can be seen as a limitation of this research.

- Since quantitative measurement of KI is not part of this research, the extent of KI steps fulfilled in practice cannot be fully confirmed and are indicative. This is a limitation of this research.

6.4 Recommendations for Practice

The key recommendations that this research provides for the offshore wind sector are:

1. (Construction) Knowledge Integration needs a symbiotic mix of tools and practices. Reliance on single tool like lessons learned is not sufficient.

2. Identify and integrate relevant knowledge sources in early project phases. Integration of fabrication knowledge is crucial yet severely limited in the offshore wind sector and needs to be addressed.

3. There is a need to increase awareness of knowledge integration benefits and formalize knowledge integration efforts in the projects.

6.5 Recommendations for Further Research

This researched adequately addressed the limited integration of construction knowledge in offshore wind projects, considering the stipulated time and resources for this research. As mentioned in the sub-sections above, there are certain limitations in the findings which create ground for further research. These have been listed below:

- Researching what is the perspective of other actors in the OW project chain on construction knowledge integration and how this impacts the optimizations for the same.

- Researching how the findings change if study is based on cases from a different organization

- A quantitative research on the precise impact of construction knowledge integration on project value (cost, duration, quality and safety).

- Researching impact of implementing the recommendations of this research.

- Researching how the recommendations change when behavioural aspects of project participants are integrated in depth in the research.

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Glossary

Abbreviations

KI – Knowledge Integration
OWF – Offshore Wind Farm
OWT – Offshore Wind Turbine
WTG – Wind Turbine Generator
ETO – Engineered To Order
DBB – Design Bid Build
EPC – Engineering Procurement & Construction
BoP – Balance of Plant
COKE – Construction Knowledge Expert (Tool by Fisher, 1991)
CPPMM – Conceptual product/process matrix model (Tool by Pulaski & Horman, 2005)

Definitions

Knowledge – Knowledge is the 'acquired' information, skill or perspective about something through various sources.

Construction Knowledge – Construction knowledge, simply put, is the knowledge and experience of construction/ fabrication/ installation processes and dynamics, which might stretch over multiple phases in the project. It is the requisite knowledge needed for construction work to effectively and efficiently take place. For example, it can be added insights on the labor, materials, equipment, space, logistics and techniques required to build or the opportunities and challenges of executing various design details.

Construction Knowledge Integration – When construction is amalgamated in planning, executing and reviewing various activities in the project lifecycle, it is integration of construction knowledge and experience into project processes.

Constructability – It is the optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve project objectives.

Value - Among the several definitions of the term 'Value', lies the underlying literal meaning of usefulness or importance. In common terminology, value also relates to monetary worth of an object or service. While all tangible goods, services and their outcomes can be associated with a monetary worth, it is important to look at the underlying phenomenon which impacts the monetary worth, for instance, schedule delays. In alignment with this, Macomber and Howell (2004) stated that properly understanding waste is the basic prerequisite to understanding value (Musa, Pasquire, & Hurst, 2016). Lindfors (2000) stated that value is the product or service that decreases cost and time, increases profit and improves quality for the company, generating profit for the customer (as cited by Musa et. al. 2016). It is a common observation in practice that the attribute of safety is intrinsic to quality, cost, time and the eventual success of a project (Lester, 2016). In extension to this, safety is impacted by engineering decisions and integration of project participants can help improve safety (Weinstein, Gambatese, & Hecker, 2005). **This brings us to the conclusive reference of the term 'value' for this research as a combination of cost and time reductions with improvements in quality and safety.**

Constructability Team – Fisher (2007) used this policy/ practice based tool to describe the practice to set up a cross-functional team setup with the task to review the construction knowledge of a project at various phases. It should be setup in the early phases for the entire project with slight changes in members etc.

Constructability Engineers – This policy based tool, advocated by Fisher (2007), implies using the senior and expert staff within the organization to impart construction knowledge to projects. Fisher imagined that mostly the senior staff is involved in management, which does not yield their expertise in projects.

Formal Implementation Processes – It is practice/policy based tool where Fisher (2007) implies defining the steps and procedures of using a modeling or technology based tool. Fisher argues that most companies have some informal ways of integrating knowledge. Formalizing new or existing tools would ensure their implementation in a systematic manner, tackling issues in construction knowledge.

Community of Practice (CoP) activities – CoP's comprises of an informal network of individuals that, through a long history of collaboration together, develop a cohesive community through shared understanding, For e.g. they share common problems, common resources, share good practices, explore common solutions etc. (Khalfan et al., 2010).

Project constructability agreement – A drafted agreement for the constructability team to state their commitment to the knowledge integration process. The agreement can also address other issues like objectives/ responsibilities for individuals in the team, communication issues and problem solving strategies.

Value Engineering – Simply put, value engineering (VE) is a process to analyze a project by function. The value of each function is compared to the total cost to implement. This process reveals problems in construction knowledge integration using certain tools and alternate tools are introduced.

Critical Path Method – This is a famous planning/ scheduling tool under use in most modern construction projects. However, Fisher (2007) sees as an important step in formalizing any tool for construction knowledge integration as it presents a sequential interconnection of all activities in the network. The formal implementation practice mentioned above also dealt with including the steps and procedures of a tool in the hard schedule of a project for which the critical path needs to be reviewed.

Constructability resources – It refers to an outside source or an organization that is included in a project to fulfil a project quality that was missing in the project, e.g. fabrication knowledge. **This approach is very helpful when the project delivery method prevents the involvement of the contractor/ sub-contractor at early stages of the project.**

Special Interest Groups for tasks – A SIG is a community within a larger organization with a shared interest/ responsibility of advancing a specific area of knowledge, learning or technology where members cooperate to affect or to produce solutions within their particular field (Sig conference community).

COKE – Or Construction Knowledge Expert is a tool developed by Fischer (1991) to integrated construction knowledge in CAD through an online construction expert. This implies, it is a software prototype that uses an online database of gathered construction knowledge and integrates it to CAD. (Fischer, 1991).

CPPMM – is the 'Conceptual Product/ Process Matrix Model' developed by Pulaski & Horman (2005) as a model for organizing construction knowledge so that it can be extracted at the adequate detail and at the proper phase of design (Pulaski & Horman, 2005). Hence, it is way of organizing knowledge databases.

Appendix A
Case Study Data & Analysis

Interview Guide

The questions below show the primary steps and questions common in each case interview, while extra discussions or questions are based on the participant's response to the primary questions or discussion. The highlighted questions were added in the second round of interviews.

Table 18 – Interview Protocol

Subject	Discussion	Rationale/ Motive
General	- Explain research focus, context and process 1. What are the main project management challenges in Offshore wind projects? - Explain construction knowledge integration / constructability	- For better understanding & response of participant - To understand OWF projects further - Same as 1st
Need for construction knowledge integration	1. What does the interviewee understand from 'construction knowledge integration' in OWF projects? 2. Does the interviewee think construction knowledge integration is an issue for OWF projects? Why? 3. How do you rank the importance of knowledge integration in project management?	1. To gather perspective of practicing engineers 2. Further validation of problem 3. Problem as a part of project management practices
Current integration regime in BoP components of OWF projects	1. Current steps followed for construction knowledge integration in the respective project? 2. Current issues in construction knowledge integration? 3. What good do you see in the current regime 4. How can it be improved? 5. How do these issues stand for monopile foundations? 6. How can the extent of integration be measured?	1. To decipher current regime 2. Understand & address issues 3. Understand & preserve good practices 4. Same as 2. 5. Understanding current regime & issues for monopiles specially 6. To measure integration
Construction knowledge integration and value	1. Does construction knowledge integration affect the value performance of the project? Explain what the interviewer means by value. 2. Ask on documented proof of value performance	1. Validating value link 2. Link validation & further analyze documented practices
Tools/ Practices for construction CKI	1. What specific tools/ practices does the interviewee suggest for ideal construction knowledge integration?	1. To understand practitioner's opinion on ideal knowledge integration tools

Case Analysis – Comparing Responses

In compliance with step 2 of the case analysis methodology, explained in Section 3.4, this section presents the comparison of interviewee responses on various subjects posed during the interview. Since the comparison is an intermediate step in the analysis process, it has been extracted out of the main text to avoid repetitiveness in the analysis description.

Key PM challenges being the first subject in the interview protocol, is compared below. In the table below, the key project management challenges are compared. Since finding the key PM challenges is not the key focus of this research, these would not be analyzed any further. As a reliable outcome from the researched sample set, merging the top 3 rows gives us the main project management challenges (since these are common across all cases).

Table 19 – Comparing Key PM Challenges from case studies

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Time constraints in execution	Time constraints in execution	Time constraints in execution
Communication between the project participants and the client	Extensive no. of project participants	Extensive no. of project participants, interfaces & their requirements to be managed
Extensive documentation/ tests for client approval	Excessive information to be managed	--
--	Managing various technical & commercial risks	Increasing technical complexity of components/ sector
--	Controlling the project within budget;	--
--	Lower cost margins;	--
--	--	Lack of experienced staff in sector
--	--	Project may face extra legislations/ scrutiny due to govt. subsidies

Staring with the tools/ practices used in the projects for construction knowledge integration, the following table below the case results beside each other and assesses the commonality. Noticeably the top 3 rows show similar tools/ practices suggested by respondents across the cases while the next 5 rows show similarity in 2 out of 3 cases.

Table 20 – Comparing tools/ practices used in cases

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Lessons learned sessions/ register	'Lessons Learned' sessions/ database/ flashes	Lessons learned sessions/ register, maybe monthly
Inputs from inhouse/ external experts	Inputs from inhouse/ external experts/ team members(face to face meetings preferred)	Inputs from inhouse & external experts

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Referring to past projects	Face to face interactions with team members of past relevant work packages Using past data to assess or detail tender invitations	Referring to similar projects in past
Feedback through end-of-works reports	End of project/ package discussions/ feedback (document sheets)	--
Progress meetings/ Design reviews	--	Design reviews/ Weekly engineering meetings/ Bi-weekly project team meetings (all including fabricator)
List of requirements through systems engineering docs.	--	Systems engineering documents impart client requirements
--	Formal notices/ queries like TQ's	Formal queries
--	Discussions with sub-contractors/ fabricators during tendering process	Pre-tendering & design coordination with fabricators/ OCM's
Integrated groupware solutions	--	--
Design certification	--	--
--	Action-trackers were created & followed	--
--	Webinars with interactive discussions – open to project/ package managers	--
--	Intranet	--
--	--	ROC drills (drills of installation processes) & physical mock ups
--	--	Operational meetings within package managers for inter-project learning

NOTE: The table entries which are either similar or can be merged are stated in the same row. The rest of the tables that follow as a comparison for results of other questions are devised in the same manner. The similar or dissimilar entries are not in any hierarchical order.

Next is the major question of finding the main issues/ challenges in construction knowledge integration in these projects. Effort was made to drive the interviewee into thinking as many issues possible. Hence, the list of issues is quite extensive and even more so when an attempt to compare the issues is being made. The reason why issue listings have not been trimmed (shortened) in words is to present a transparent comparison and which issues are precisely going to be merged. In the table below, it can also be seen that the first four rows show issues common across the three cases followed by issues common across 2 out of 3 cases. While this does highlight on the prominence of these issues, the target of this research is to confirm the important further.

Table 21 – Issues hindering construction knowledge integration

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Lessons learned database unstructured, unfiltered, not merged well, feels like an obligation, difficult to retrieve knowledge	Difficult to extract information from listed knowledge due to different type of input – lessons are broad or deep; Hassle to record momentary learnings	Lessons learned database is inconvenient & unstructured, difficult to retrieve knowledge, fill momentary lessons
The competencies of quality mgmt., fabrication knowledge, noise mitigation & electrical are weak for foundations	Fabrication/ Electrical/ SCADA (signal system) knowledge missing	Fabrication experts, quality inspectors & electrical experts are limited of missing in-house
Missing realization of long-term effects and risks of decisions & context like soil conditions, component design in engineers	Current designers lack foresight of influence in fabrication	Designers lack practical & commercial knowledge
Inputs hard to get due to time crunch	Knowledge registering hindered due to time constraints Time constraints hindering personal interactions	Time crunch
No integrated knowledge database	--	Every knowledge type has a different database/ type like systems engineering, lessons learned, templates etc.
No software for interface/ quality management	--	No single platform for interface management
Poor inter-project learning	--	No steps for inter-project learning
Actions associated with project processes are informal in nature	--	Lack of standard system/ protocol for knowledge integration (the who, how, what, when)
Inputs hard to adopt when received at a later stage	--	Late fabricator selection/ installation team formation delays integration
--	Troublesome when inhouse expertise unavailable	Troublesome when inhouse expertise unavailable
--	Diverse geographical locations of the team members hinders knowledge sharing (case specific)	Diverse geographical locations of project participants/ suppliers
Lessons registered are very project/ circumstance specific	--	--
Difficult to describe complex information in database	--	--
Certain standard templates missing like for quality inspections	--	--
Opportunity lost to moderate designs when engineering is sub-contracted	--	--
Lack of awareness of resources required for design certification **(case specific)**	--	--
--	Sub-contractors have different drivers & lack staff for coordination (also verified by lessons learned register)	--

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
--	End of project/ package reports not openly shared maybe due to confidentiality	--
--	Hassle to arrange documents for reference by younger staff	--
--	Difficult to communicate tacit knowledge/ experience through writing	--
--	The company did not raise alarm on constructability of mono-buckets due to inexperience & late involvement; Incomplete design was passed on to company due to financial close **(case specific)**	--
--	Risks have been underestimated for mono-bucket due to inexperience **(case specific)**	--
		No incentive to list lessons as no info received in return
--	--	Lack of experienced staff as industry is relatively new
--	--	Team members not aware of rationale behind major decisions/ changes
--	--	Lack of awareness of KI benefits, existing knowledge & sourcing methods

The next question is on the interesting subject of positives in the knowledge integration regime. While the entire list shows positive practices or tools used in the system, there exist some commonalities. This list puts light on what the users think of the systems in place. While problems with lessons learned are plenty (as shown in the table above), it is interesting to see that users appreciate the efforts being made in this regard and for knowledge integration as a whole. Some more prominent efforts which more users felt are standard templates (while they need to increase according to list of issues), the organic nature of communication at the company and certain physical mock-ups and drills.

Table 22 – Comparing 'Positive' tools/practices used in assessed cases

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Lessons learned sessions at end of package/ project are useful	Lessons learned sessions	Increasing focus on lessons learned sessions/ register
Fixed templates for correspondence with client, sub-contractor	Standard forms/ templates like risk registers, trade-off matrices, DPR's etc.	--
ROC drills	--	ROC drills & mock-ups
Organic interaction	--	Company staff is helpful
Continued involvement of design manager in the fabrication phase	--	--

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
Design was fully complete before fabrication (DBU BoP)	--	--
Structured weekly meetings	--	--
Current size of company/ dept., proximity to other project teams	--	--
Efforts to formalize KI	--	--
Feedback to corporate dept.	--	--
--	--	Intranet (news flashes) give company updates
--	--	Periodic review meetings among project directors
--	--	Required expertise is sanctioned

Among the last of the project specific questions was on gathering suggestions for improvements or tools and practices to be used in the system for ideal construction knowledge integration. Again, this list is also quite extensive, with efforts made to relate the suggestions, assessing the core meaning or conceptual direction of the suggestion. Here also we see 4 suggestions being similar across the three cases and other 5 being common across two out of three cases.

Table 23 – Comparing suggested tools/practices/ improvements

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
A single efficient knowledge database for core concepts, standards, best practices, lessons, templates for monitoring & reporting etc.	Register knowledge/ lessons in a smart standardized structure	Standardized & convenient, integrated knowledge database of knowledge, lessons learned, list experts etc. instead of excel database
Formalizing pre-requisite information & steps for engineering processes, preparation works, knowledge integration etc.	Formalize process to involve experts at pre-decided/ relevant intervals, can be mandatory, increase no. of sessions;	Formalize knowledge integration processes
Strengthen fabrication knowledge	Fill missing competencies inhouse like fabrication, electrical, quality	Quality inspectors should be hired by the company
Early involvement of corporate experts, experienced staff, all relevant disciplines;	Regular sessions for design/ process improvement with all project participants including design certifier, fabricator, planners, installation experts etc. starting at **early** stages	Integrating expert knowledge early in the process, like installation input
Training engineers to develop foresight of decision impacts on project objectives;	--	Training programs like technical traineeships for inhouse engineers for rapid knowledge gain
Increase awareness to benefits of CKI to company/ senior management	--	Trade-off (cost-time-quality-safety benefits) matrices to motivate teams/ management for KI
--	Responsibilities should be set for knowledge integration activities;	Imparting responsibilities for 'lessons learned' efforts

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
--	Webinars or inter-project sessions should be extended to maximum team members;	Develop system for inter-project learning
--	Weekly/ Bi-weekly lessons learned sessions instead of monthly [5]	Monthly lessons learned sessions
Information/ knowledge/ scope to be shared with all participants	--	--
Mix junior & senior staff in sub-teams to maximize intra team learning;	--	--
Use 4D BIM & modernize engineering processes	--	--
Quality management software like 'Relatics'	--	--
Convenient register for spontaneous lesson additions	--	--
Identify weak spots/ areas/ competencies and develop KPI's for knowledge integration	--	--
Proactive to gather inputs from experts	--	--
Outsource design activities	--	--
--	Lessons should be stated in broad manner to make people think	--
--	Not only major lessons, but smaller lessons should also be recorded in standardized format	--
--	Keep removing lessons after stipulated period	--
--	Lean knowledge – considering only top lessons, risks	--
--	Enable remote participation for lessons learned sessions by E&E	--
--	Improve integration of past project data for tendering, estimation, project controls;	--
--	Sending out document sheets to all participants together;	--
--	Data management in contracts	--
--	--	ROC drills & Physical mock-ups
--	--	Method statements (feedback system)
--	--	JIP's (Joint Industry Practices), industry wide participation/ sharing
--	--	Intranet to be detailed further
--	--	Detailed organograms with precise expertise listed

[5] The highlighted cells show contradictory suggestions made by respondents. To overcome the more logistics of more frequent lessons learned sessions, the former suggested having this sessions digitally.

Deutsche Bucht BoP	Deutsche Bucht MBF	Borssele 3&4
--	--	Share virtual model developed inhouse with fabricator to save latter's effort

There was another question posed to all interviewees to assess the applicability of the knowledge integration regime to other BoP components, the project as a whole. **Noticeably, all responses (11 of 11) to this question stated that most (if not all) concepts shared about the regime are applicable to the other components and even other projects.** As a word of caution, 2 respondents stated that certain foundation specific technical knowledge or specific issues or missing competencies/ experience might not be applicable, but in general most concepts stated, are. This implies that the results assessed in this section so far are also applicable within the cases (except case specific issues) and can be combined to extract the top issues, tools/ practices, positives etc. in the regime. This would be taken up in the next section, which focuses on combining the results of case studies.

Appendix B – Validation Data

Table 24 – Compiled validation data

Sn.	Understand-able (Y/N)	Beneficial (Y/N)	Applicable (Y/N)	Remarks
A0.1	8/1	7/2	6/3	**CL:** Constructability can only be brought into design by experience, not by reading lessons learnt. **MH:** ISO 9001 standard to formalize process **RT:** Please make sure to align with existing processes that are already in place in the Project Office. This applies for all solution proposals. **FDG:** Strongly depends on practicality of procedure and coherence. **DGO:** Too broad, make it specific
A0.2	8/1	8/1	8/1	**JM:** Requires a more elaborate instruction + link to lessons learnt process based on NCR, root causes. **MH:** To learn from NCR is a standard. VO-OW is currently working on a NCR database. **WS:** Which should be part of larger KPI indicator review and not separate for KI. **DGO:** Too broad definition
A1.1	8/1	5/4	5/4	**JM:** Seems like standard component of formalizing the process. **RU:** Too much paperwork **MH:** ISO 9001 standard whether this need to be a matrix can be discussed. **RT:** Should be company-wide standard. **FDG:** Matrix is not a solution. Making people available is. **DGO:** We should not create even more processes etc, keep it simple.
A1.2	8/1	7/2	7/2	**CL:** I believe this is the best way **MH:** This item needs further elaboration to be validated. **RT:** This should be organisational level not operational level. **WS:** Should be part of standard workflow and to be selected on project level. **FDG:** People don't always want early involvement. **DGO:** Project team + Support Ops
A1.3	7/2	7/2	7/2	**MH:** Remote participation is a standard work practice. **WS:** Is in place.
A2	8/1	8/1	4/5	**JM:** Dependent on staff you are aiming for : Van Oord or sub-contractor. Van Oord staff might be challenging due to pressure on organization. Sub-contractor staff might have commercial constraints. **RU:** Hard to achieve **MH:** Early involvement can be improved. However, further elaboration is needed to be validated. **NC:** Not for fabrication as the current supplier selection process does not allow for early involvement. **WS:** See A : This would be Imo not add anything more. **FDG:** Are these people available and do they want to be in the office?
A3.1	9/0	8/1	7/2	**CL:** The issue with constructability is that without construction experience it is hard to recognize issues **RU:** Time Constraint **MH:** Much appreciated **RT:** But should be structured and give added value
A3.2	7/2	6/3	6/3	**RU:** Hardly achievable **MH:** See 9001 Standard. **WS:** Is in place
A4.1	8/1	4/5	4/5	**JM:** Does not seem to be a solution for particular problem. **RU:** Too much paperwork **RT:** Needs to be in collaboration with E+E. **FDG:** See A1

Sn.	Understand-able (Y/N)	Beneficial (Y/N)	Applicable (Y/N)	Remarks
A4.2	8/1	5/4	5/4	**MH:** This item needs further elaboration to be validated. **RT:** See Above (A1) **WS:** 'Busy' should not be accepted. Escalate when there is resource issues. **DGO:** Project team to be diverse, be supported and use available info. Is this true or correct?
A5.1	8/1	8/1	8/1	**JM:** Not clear how this exactly to be called out. In principle a beneficial option. **MH:** Must have **RT:** Already in place at Project Office.
A5.2	9/0	7/2	5/4	**JM:** Prefer translation to lessons learned. Difficult to assess confidentiality factor. **RU:** Already Suitable **MH:** Beneficial **RT:** Difficult if it creates a lot of additional work. Needs to be in collaboration with PQ desk. **DGO:** All to be shared. Project team/management should take the role of constructability team, Diverse, looking for knowledge and applying with support of examples foundation unit, cable unit, E&E.
A6	7/2	4/5	4/5	**JM:** What is the difference with formalizing the process **RU:** First discipline **MH:** Be very careful with mandatory works. Process first need to prove itself. **NC:** Yes, but each project should be able to have a customized approach. **RT:** This improvement is already taken up by the Work group on Lessons learned. **WS:** I would suggest to communicate on actions following LL.
A7	9/0	7/2	7/2	**JM:** Only team members or organization wide? Would prefer the latter. **MH:** Isn't this done in LL session. How can this be achieved in practice? **RT:** Already in place as a part of the Stage Gate process. **DGO:** Review sessions taking place.
B0.1	8/1	6/3	5/4	**CL:** Doubt if this will help **RU:** Not achievable **MH:** LL and NCR can be in one database. How the rest is included is unclear. **RT:** General Remarks for B1-B4 : These topics are taken up as part of the Work Group Lessons Learned. Important for mutual validation. B3 specifically is covered by the Standard Work Modules of the Project Office. **WS:** Yes single database I like buy these should include guidelines/ working practices that LL are implemented in. **FDG:** A database is not a solution. Standardized procedures are. **DGO:** in process project office
B0.2	9/0	7/2	5/4	**JM:** Next step after formalizing the process. **RU:** Not achievable **MH:** Must **NC:** Not yet, as there is no simple database and one language yet. **WS:** and more active methods. **DGO:** First step is validation. Lessons learnt database.
B0.3	8/1	6/3	6/3	**JM:** Future Step **RU:** Not achievable **MH:** Feedback is important for all entries. Is that the question?
B0.4	6/3	5/4	5/4	**RU:** Not achievable **MH:** Must **NC:** Next step for UO Item above. **FDG:** A dependency check with NCR's would be nice.

Sn.	Understand-able (Y/N)	Beneficial (Y/N)	Applicable (Y/N)	Remarks
B0.5	8/1	6/3	5/4	**RU:** Not achievable **MH:** Important to keep lean. Exact way to achieve that might be different. **FDG:** Key item. Outdated entries should be removed. **DGO:** See above initiator to validate ongoing.
B1.1	9/0	8/1	7/2	**RU:** Not achievable **MH:** Must **DGO:** First discipline to register, second validation, third making people use – behavioral change.
B1.2	9/0	5/4	5/4	**RU:** Not achievable **MH:** Who can administrate that. Daily learnings. **FDG:** High chance of polluted database.
B2	9/0	8/1	8/1	**JM:** Also cross check on entry data + understandable without project knowledge? **RU:** Not achievable **MH:** Must **DGO:** See notes above.
B3.1	9/0	7/2	7/2	**JM:** Prefer linking lessons learned into update of standards. **MH:** Who and how will this look like in practice.
B3.2	7/2	7/2	7/2	**WS:** There should be an owner for each knowledge section and he should be the gatekeeper.
B4	7/2	7/2	6/3	**JM:** Don't get the link to the issue. MH : Awareness to be promoted. Way to achieve this might be different. **WS:** Make your knowledge explicit and traceable and make your work processes explicit and traceable. Then lessons learnt can often be incorporated in the standard work method and the lesson becomes obsolete.

Table 25 – Validation data of standard protocol

Sn.	Solutions based on literature and case study	Applicable (Y/N)	Alternate Route (Y/N)	Remarks
S1	Setting up 'Constructability Team'	62.5%	--	**WS:** Project specific design board session **DGO:** Project team **RT:** Should be on organizational level ; point should be for project team to speak to organizational level team **MH:** To be considered whether a team is required **JM:** Roll-out as described in design plan : Bring in lessons learnt from the previous projects during tender stage.
S2	Setting up Responsibility Matrix for KI/CKI activities	62.5%	--	**RT:** Should be standard **MH:** Does that need to be project specific **JM:** Should be input in design plan
S3	Merge Inter-Project Meetings with monthly lessons learned sessions facilitated by the E&E	50%	--	**WS:** I think this is done **RT:** Already in place **JM:** What is the difference with regular lessons learnt sessions, might save time for alternatives.
S4	Monthly/ Bi-monthly meetings by KM team to refine knowledge database	62.5%	--	**DGO:** Should be continuously **RT:** Already in place

Sn.	Solutions based on literature and case study	Applicable (Y/N)	Alternate Route (Y/N)	Remarks
S5	Analyse KI indicators for further learning	100%	--	**WS:** Part of overall KPI review **RT:** Should be continual throughout the project **MH:** Must **JM:** intermediate analysis in earlier steps can be beneficial for the project itself. Periodic evaluation of NCR's and root cause can reveal improvement potential during the running project. Acting on this will speed up the CKI and improvement process of both the project and organization.
S6	Include lessons from end of project reports also	100%	--	**WS:** But make sure these are fed back into standard work methods **DGO:** Should be in database **FDG:** Needs to be done continuously **RT:** Ongoing, already in place for dredging and offshore
S7	Share non-confidential version of end of project report internally	87.5	--	**DGO:** Should already be available **FDG:** Needs to be done continuously **RT:** Nice but timing needs to be considered, who will do it?