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Investigating the role of process mapping in facilitating data transfer between structural analysis and structural design software

Anna Kontaxopoulou
Student No: 6050530

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Author: Anna Kontaxopoulou
University: Delft University of Technology (TU Delft)
Faculty: Civil Engineering and Geosciences (CEG)
Master: Construction Management and Engineering (CME)
Student Number: 6050530
Date: 03-12-2025

Thesis committee

Dr. Ir. G.A. (Sander) van Nederveen Civil Engineering and Geosciences	TU Delft, Chairperson
Ir. S. (Sander) Pasterkamp Civil Engineering and Geosciences	TU Delft, First Supervisor
Dr. Ir. E. (Eleni) Papadonikolaki Civil Engineering and Geosciences	TU Delft, Second Supervisor
Ir. T. (Teodora) Cristutiu Head of Structural department at Iv-Consult	Iv-Groep, External Supervisor

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LIST OF SYMBOLS AND ACRONYMS

(AEC): Architecture, Engineering and Construction

(BCF): BIM Collaboration Format

(BIM): Building Information Modeling

(BPM): Business Process Modeling

(BPMN): Business Process Model and Notation

(bsDD): buildingSMART Data Dictionary

(bSI): buildingSMART International

(HRD): Human Research Development

(GoM): Guidelines of Modeling

(IFC): Industry Foundation Classes

(IDEF): Integration Definition for Function Modeling

(IDS): Information Delivery Specification

(IEEE): Institute of Electrical and Electronics Engineers

(7PMG): Seven Process Modeling Guidelines

(UML): Unified Modeling Language

(WBS): Work Breakdown Structure

ABSTRACT

Across the AEC industry, project data must move repeatedly between structural analysis and structural design environments. As the market shifts toward digitization and cloud-based delivery, teams are expected to make data operate across platforms throughout the project lifecycle. Although technical capability of BIM interoperability and other tool interfaces has improved significantly over the past decade, end-user's knowledge and ability to leverage that capability needs to improve as well. Many breakdowns are the result of informal procedures. Specifically, how data exchanges are specified and executed, how best-practice handovers are organized, along with still-maturing open standards and uneven exchange requirements. When information exchange is problematic, then quality drops, rework increases and schedules are delayed. These problems are amplified by tight budgets, limited manpower and project complexity.

Process maps are often proposed to solve this complexity, yet a persistent research and practice gap remains. Organizations design process maps, but very rarely implement them in day-to-day work. This thesis addresses that gap by examining both the technical and organizational reasons why data exchange between structural analysis and design software fails. It also develops a process map designed specifically to promote its adoption rather than simple design.

A mixed-methods design was used. Firstly, semi-structured interviews with engineers, designers and managers investigated recurring challenges in handovers. These insights informed a BPMN process map that standardizes handoff protocols and includes semi-automated checks using buildingSMART standards. Secondly, a survey gathered user feedback to validate the map's usefulness and fit. The responses were interpreted using Kotter's model about change management to identify the organizational conditions that enable adoption.

The thesis contributes literature-derived specifications for building robust and effective process maps around open standards. It also proposes an empirically grounded explanation of why maps fail at the implementation stage and links successful adoption to cultural readiness and organizational enablers rather than intent alone. In doing so, it reframes process mapping from a static design artifact into an practically applicable workflow diagram for reliable data transfer between analysis and design software.

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PART I: LITERATURE & FRAMEWORK

This thesis is organized into four parts to make its mixed-methods logic explicit and easy to navigate. *PART I: Literature & Framework* establishes the problem, synthesizes prior work on interoperability and process mapping and explains the specifications that define what effective process mapping should mean. *PART II: Qualitative methodology & Design* explores practice by analyzing challenges and needs in the company context, so that the developed process-map is grounded in real workflows. *PART III: Quantitative methodology & Findings* then tests and validates those specifications and the change-management assumptions at scale. *PART IV: Discussion & Conclusion* synthesizes the findings to answer each sub-question and the main research question and presents the study's contributions, limitations and directions for future research. This structure reduces complexity and separates design from implementation evidence and supports integration in the general discussion, where qualitative insights and quantitative results are brought together to answer the research question.

PART I: Literature & Framework establishes the conceptual foundation for this thesis by placing the problem of interoperability and data transfer between structural analysis and structural design software within the broader digital transformation of the AEC industry. The literature consistently mentions a gap not in designing process models but in implementing them effectively in organizational settings. Therefore, PART I: Literature & Framework combines research on interoperability approaches, typical reasons for failure and process mapping as an intervention to clarify responsibilities. It integrates three complementary guidelines into a set of specifications for effective and implementable process maps.

1. INTRODUCTION

The growing interest in modern construction methods and technological advancements has encouraged construction firms across the world to rethink their operational strategies. Many organizations are now exploring innovative solutions to improve productivity and project efficiency (Chen et al., 2021). Instead of making small improvements to traditional workflows, digital technologies are driving fundamental transformations in the way projects are planned and delivered (Royal Institute of British Architects, 2020). Because innovation continues to increase, project practices often need to be adapted and improved. As a result, design and construction teams must constantly "adjust their ways of working to maintain their competitiveness and the quality of their design output" (Chen et al., 2021).

For decades, the construction industry has struggled with challenges such as inefficiency, low productivity and poor safety management. The involvement of multiple parties in most projects further complicates the sharing of information between them. This makes accurate and timely communication a critical factors for project success. According to Poirier et al. (2014), a major issue that prevents smooth data and information exchange within the Architecture, Engineering and Construction (AEC) sector is the "lack of technological interoperability". This is further confirmed by Chen et al. (2017) who argue that one of the main reasons for inefficiency is the weak interface between design and construction, where design errors and on-site design changes usually cause time delays and budget overruns. To address these issues, organizations have to develop new working processes and adopt innovative technologies (Lenberg et al., 2017). In this complex and changing environment, the ability to manage and adapt to change has become a key factor for organizational success.

1.1 Problem statement

Process models have been widely adopted in many industries to simplify complex procedures and detect inefficiencies in the flow of information. They are used to visualize the sequence of activities within a system. However and despite their proven advantages, according to White et al. (2024), their use within the construction industry is still minimal. Although relationships among project participants tend to be dynamic, the fundamental processes that guide project delivery are mostly similar across projects. Therefore, a valuable method for improving consistency and coordination is the mapping of these processes. Without a shared process map, each team member may develop their own version of the “correct” way to perform tasks, which will result in confusion and inefficiency throughout the project (Royal Institute of British Architects, 2020).

In theory, to facilitate clear and consistent data exchange between different software systems the use of standardized protocols is encouraged. These protocols also minimize the misunderstandings that happen between those who sent data and those who receive it (Nguyen et al., 2013). However, the sharing of information across digital platforms remains difficult because currently “no single standard integration method” exists to promote full interoperability (Baars, 2024). But more and more organizations are interested in the adoption of integrated software environments that support project management activities. Nevertheless, much of the current literature focuses more on the design of process models rather than their implementation in practice, leaving a noticeable gap in research. Tzortzopoulos et al. (2005) argue that process management studies usually provide only “superficial advice on implementation”. Instead they focus on the visual and structural elements of process models. This has resulted in overly complex models that, while theoretically correct, cannot be implemented effectively in real projects.

Because every construction project is unique, drawing direct comparisons between their outcomes is challenging. This makes it equally difficult to evaluate the specific influence that process models have on project performance. As a result, measuring the real benefits of using these models remains a significant research challenge. Chen et al. (2021) highlight the need for more research to explore the factors that promote or prevent the adoption of new technologies. This is a gap in current literature, which offers limited insight into the conditions necessary for the successful implementation of process maps. Moreover, Tzortzopoulos et al. (2005) emphasize that strategies for adopting process models must be aligned with both the organizational setting of a company and the human aspects of teamwork (motivation, collaboration and consensus building). This connection has also not been researched enough

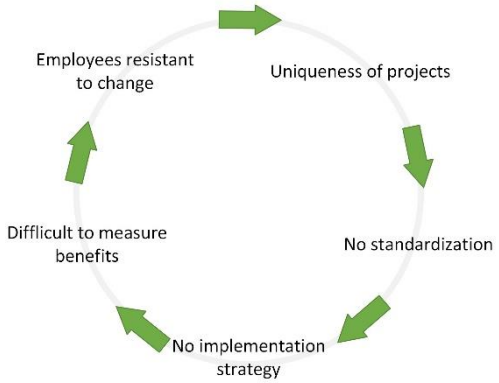


Figure 1: Challenges to implementing process maps in construction industry

yet. Likewise, the usefulness of model content at both organizational and project levels has not been properly evaluated. It is therefore evident that implementation should be conceptualized as a practical, context-driven process rather than a simple theoretical one. To provide organizations with much-needed guidance for successfully applying these models in practice, a comprehensive and integrated framework on process modeling implementation should be developed (Tzortzopoulos et al., 2005).

1.2 Company context and case study

The case study will take place at Iv, an Dutch engineering company at the department Iv-Consult under the supervision of Teodora Cristutiu, head of the Structural division. Iv specializes in providing innovative engineering solutions and utilizes a range of advanced software tools to ensure the highest standard of design and execution.

In Figure 2, a simplified flowchart of the design phase of a construction project is shown, starting from the client's requirements which inform the first conceptual design. Using that, the first analysis is done in structural analysis software like Ansys and SCIA Engineer and that results in an optimized geometry. The designers then sketch that geometry in structural design software like Tekla and Inventor and then the workshop drawings. Of course, the process is never that simple and usually there are many iterations required to finalize the drawings.

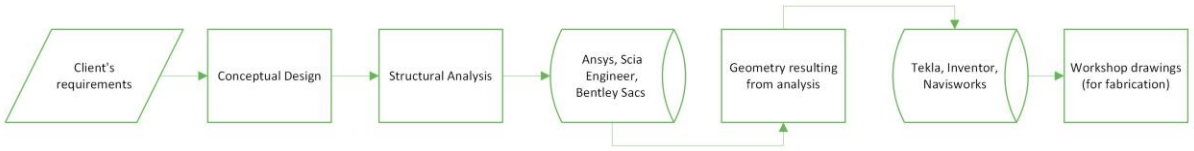


Figure 2: Flowchart of design phase

One of the projects they are currently working on an offshore platform in the North Sea. This platform is the first in a series of platforms that Iv will design for a public client. This project requires the integration of multiple analysis and design software to ensure accurate and efficient data transfer. The design software used is the Tekla package. As for the structural analysis software, there are 3 different ones used for different parts of the structure. The primary software is Ansys and specifically SpaceClaim which is used for 3D modelling of most of the structure. SCIA Engineer is used to model the antenna mast, while Bentley Sacs is used to model the helideck substructure. From a brief meeting with the lead engineer of the project, it was noted that it would be beneficial if there was a more direct link between Ansys and Tekla, because right now all data is being transferred manually and that lead to delays and sometimes errors. Therefore, it is evident that a process map detailing the steps to facilitate this transfer is necessary.

In the Dutch project context, the roles of structural engineer and structural designer/modeler are deliberately separated during the design phase. The structural engineer leads the technical verification of the load-bearing system. They gather site data and specifications, set design parameters and load scenarios, interpret relevant codes and standards and develop the analytical model (Yeager, 2016). Using commercial software such as Ansys and SCIA Engineer as well as targeted hand calculations to calibrate the model, the engineer determines global and member-level behavior. This includes parameters such as bending moments, shear forces, axial forces, stresses and deflections. These are then translated into element designs, that specify materials, cross-sections, reinforcement requirements, connection concepts and

ultimate limit state checks. The engineer typically writes the calculation report, design notes and is responsible for demonstrating code compliance and structural safety.

In contrast, the structural designer/modeler focuses on representing the engineer's intent faithfully in the project's graphical and data environment (Yeager, 2016). Working primarily in BIM and CAD platforms (like Inventor and Tekla), the designer develops and updates the 3D model, plans, sections and details. The designer also prepares schedules and sheets and manages coordination with architecture, MEP, geotechnics as well as fabrication. In this Dutch setup the designer does not perform analytical or sizing calculations. Instead, they translate the engineer's design outputs into buildable, clash-free information, including fabrication details where applicable.

The workflow is iterative and collaborative. The engineer proposes or revises the structural scheme and member capacities, while the designer models these decisions, flags coordination issues and feeds back constructability constraints so that the engineer can refine the analysis model accordingly. This division helps maintain clear responsibility while accelerating iterations. The general process (gathering inputs, applying design codes, analyzing the structure digitally with hand-calc checks, then fixing element sizes and details) is not project specific. However, it is probable that in smaller and less complicated projects than the design of an offshore topside platform, the two roles could be done by a single person. In the scope of this thesis, there are considered separate functions with a clear distinction.

1.2.1 Description of current processes

This section focuses on the exchange of data between Tekla (design/modelling) and Ansys (structural analysis), because in the case study of this thesis, it is both the most frequently used interface and the most error-prone. While Tekla operates well with IFC, most analysis tools (including Ansys, but not SCIA Engineer) struggle with it. So the workflow relies heavily on STEP files and annotated check prints. That mix creates recurring issues around element identity, material specification and geometry interpretation (e.g., plates as surfaces vs. profiles as lines). By examining how the team maps materials, uses color agendas, manages IDs and histories and performs checks via STEP/PDF exchange, the point where information is lost or distorted can be found.

The structural designers translate the engineer's analytical intent into coordinated, fabrication-ready geometry. Although each designer has personal conventions for defining element properties, the team standardizes a minimum set of attributes on every element so that data hand-offs are effective: material type (e.g., steel), material grade/quality (e.g., S235) and material weight (as total mass or mass per unit with explicit units). This requirement is carried as object properties and checked during model exchange to keep connection detailing, load bearing and logistics aligned with the engineer's calculations.

As had been already mentioned, Tekla works best with IFC for open exchange, yet many analysis tools struggle with it. Consequently designers usually receive STEP files exported from Ansys for change proposals. Because the Ansys and Tekla models share a common origin, incoming STEP references can be read directly without rotations or shifts. Designers place the STEP as a reference and "draw over" it in Tekla to update plates, stiffeners and profiles. Where changes are small and localized (for example, a plate thickness increasing from 10 mm to 12 mm), engineers often issue check prints (PDFs) with mark-ups in red. These are quicker for designers to interpret than a full STEP compare, which in practice may show

only wires/surfaces. For larger or more complex revisions, engineers may replace STEP or check prints with Power Point slides that combine annotated screenshots and selected Ansys results to explain the changes made clearly.

Within Tekla, each profile receives a unique ID and a rich set of attributes accessible through the object inquiry. Designers can see section type (e.g., T-section), total length, weight and area, material thicknesses and other metadata. Crucially, the inquiry also exposes a complete timeline of any modification, whether a 1 mm move or a material edit. It stores the editor's name and update time. While the exact change is not mentioned, this audit trail supports targeted follow-up with the modeler responsible, which improves accountability. To aid selection, filtering and drawing production, designers use "faces". They define faces per deck and apply attribute-based filters so that model views, drawing sets and exports can be sliced by deck, face or discipline. Engineers do not work with faces inside Ansys, because the analysis model itself shows the geometry as a single volume. But when needed the design team exports with face data so stakeholders can review these regions in Trimble Connect.

A shared color agenda supports fast visual communication. Plates are color-coded by thickness (e.g., yellow for thin, blue for thicker) so anyone opening the master copy or a screenshot can instantly read the rough specification. To keep model text clear and easy for the contractor to read, the team names materials as neutral "Type" labels (Type 1, Type 2, etc.) rather than spelling out grades in every object. The general notes then explain what each type represents as well as the particular quality of the material. Filters such as "Type 1-S235" help isolate similar elements for quick checks.

Because Ansys and Tekla are not linked live, the workflow has a slight delay. Engineers run analyses and identify hotspots (e.g., overstressed corners or deck regions). Then they propose solutions and transmit either STEP geometry files or annotated PDFs. Designers import, review and implement those changes in Tekla. In parallel, a Navisworks model connects all disciplines (mechanical, electrical, piping and structure) on a daily basis. Both analysis and design models are exported at the end of day and the next morning before the start of the working day the Navisworks model is updated. So teams start the morning with a one-day-delay snapshot. This reflects the reality that even small edits require human review, yet it ensures a predictable rhythm for clash detection and multidisciplinary alignment.

1.2.2 Looking forward for solutions

Currently, the delay between design proposals and the corresponding engineering analyses is one of the major obstacles faced by lead designers. When structural analysis software becomes capable of providing feedback in real time during the design process, modeling will be faster and also more accurate. Moreover, this will deliver more reliable data for the decision-making process (Royal Institute of British Architects, 2020). To achieve this, continuous research and development are essential for sustaining innovation. Those willing to adapt and invest in learning will benefit from these changes, while organizations that resist change and rely on outdated practices will find it difficult to remain competitive (Royal Institute of British Architects, 2020). Iv recognizes this and is interested in researching the topic of improving data transfer between structural analysis and structural design software in depth..

The most important questions about the changes happening in the construction industry are whether any new methods have being introduced, whether such innovations have been proven valuable yet and whether the industry as a whole is ready to implement them effectively

(Chen et al., 2021). Lenberg et al. (2017) highlight that the success of organizational change strongly depends on employee attitudes. They identified three important factors that determine the attitudes of software engineers toward change. These are “their knowledge about the intended change outcome, their understanding of the need for change and their feelings of participation in the change process”. Furthermore, they argue that “organizational change cannot be considered successful without a change in the employees’ behavior”. Researchers in the field of social psychology agree with that as they believe that attitude plays a critical role in influencing behavior.

As digital tools are used more and more in project workflows, careful planning of project information systems and ensuring software compatibility across teams are now critical success factors (Royal Institute of British Architects, 2020). For organizations that are interested in transforming their digital workflows, the most important challenge is selecting the most suitable technologies and tools that match their working methods. Developing a “current state” process map is a valuable starting point for evaluating existing practices. It will also help in the creation of an improved “future state” map and in measuring the benefits of its implementation (Klotz et al., 2008). A well-defined process map also establishes clear requirements and allocates responsibilities for information exchange across all project stages (Borrmann et al., 2018).

Although technologies such as BIM interoperability are reshaping the AEC industry, they do not automatically enhance project outcomes. Their effectiveness depends a lot on the organizational and human factors that support technological use. Often the speed of technological progress exceeds an organization’s ability to adapt. Unfortunately this can lead to underperformance. So this proves the need for strong leadership and a workplace culture that supports constant improvement. Otherwise, the potential benefits of digital transformation are not realized in practice.

To be more specific, it is important to note that simply producing process maps does not necessarily lead to organizational improvement or workflow optimization (White et al., 2016). Lawson et al. (2003) think this can be explained by the lack of user’s motivation. They note that despite the time and expertise invested in creating them, process models are usually left unused. Sadly, employees’ resistance to change can prevent firms from achieving the advantages of emerging technologies (Maali et al., 2020). Therefore companies in the AEC industry must strengthen their capabilities in managing organizational change if they want to maintain their competitiveness. To successfully implement change management strategies an understanding of the key factors that support adoption and minimize the risk of failure is required (Sittrop et al., 2021).

1.3 Research question

Based in the above, the following research question will be addressed:

What management strategies and organizational practices can support the successful adoption of process mapping specifications for data transfer between structural analysis and structural design software?

This thesis report aims to also answer the following sub-questions:

1. What are the most important specifications and standards needed for developing an effective process map for data transfer?

2. What are the current challenges to seamless data transfer between structural analysis and structural design software?

3. What are the perceived benefits of implementing process mapping specifications for data transfer in real-world construction projects?

4. What are the main factors influencing the successful adoption of process mapping for facilitating data transfer between structural analysis and structural design software?

1.4 Research approach

To develop answers to the main research question, the study followed a mixed-methods design that moves from exploration to validation. Figure 3 schematically shows the sequence. Qualitative evidence (literature review and interviews) was used to build the process map and quantitative evidence (surveys) was used to verify its utility and to evaluate adoption factors through an organizational-change lens.

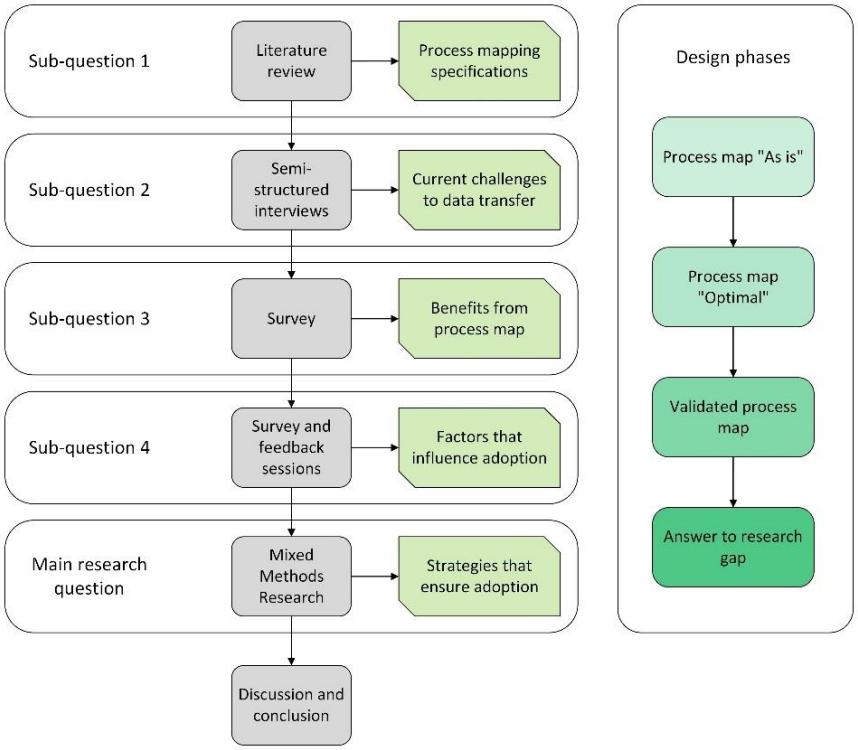


Figure 3: Research methodology

Sub-question 1: A structured literature review will identify and evaluate existing process maps and modeling guidelines. From this, the study will narrow down the characteristics that make a map both cognitively effective and easy to implement. These specifications will form the initial design criteria for the map.

Sub-question 2: Semi-structured interviews will be conducted with Iv staff across relevant roles. The goal is to examine current workflows, bottlenecks in analysis and design software data exchanges and recurring failures. To extract recurrent challenges and requirements for the map, thematic coding of the interviews will be done. Insights from these interviews will directly inform the first draft of the process map by identifying key activities, decision points and information transfers over time. The first draft will represent the situation as it currently is and the final map will be created to show the optimal procedure for transferring data.

Sub-question 3 & 4: A quantitative survey will be used to verify and validate the developed map. A quantitative research methodology is preferable, when the researcher wants to identify factors that determine the outcome of a process and the utility of an intervention like a process map. To evaluate the results of the surveys, descriptive statistics and Kotter's model about management of organizational change will be used.

A mixed-methods methodology was chosen because qualitative inquiry is best suited to explore processes and define requirements (SQ 1–2), while quantitative measures help verify perceived utility and evaluate adoption conditions at scale (SQ 3-4). Using Kotter's model provides a theory-grounded structure to interpret what must be true organizationally for a process map to move from design to day-to-day use.

1.5 Expected outcomes and scope

This thesis aims to generate new understanding of how process mapping specifications can facilitate data transfer between structural analysis and structural design software. In doing so, it will improve how companies operate and facilitate cooperation between employees in different stages of a construction project. To achieve this, a clear set of process mapping specifications will be developed. This framework will help minimize design errors and reduce delays and cost overruns in construction projects. Additionally, it will be practical and easy to implement across various AEC projects, because it will also be carefully evaluated during this research. Furthermore, a set of best practices and strategies for the successful implementation of the process map will be proposed as well as insights into overcoming organizational barriers to ensure collaboration across project stakeholders. Finally, this study will provide a deeper understanding of how Kotter's change management theory can be applied in the context of the construction industry. This will contribute to the broader body of knowledge on organizational change in construction. Through these outcomes, this thesis aims to contribute to the ongoing digital transformation in the construction industry, supporting a more efficient integration of structural analysis and design processes.

As far as the scope of the thesis is concerned, it will focus on the design phase of offshore projects in the environment of a medium-size company. This phase is critical for setting the foundation of a successful construction project and significantly influences downstream activities such as construction and maintenance. By concentrating on medium-sized companies, the study will address challenges that are relevant to organizations with limited resources and infrastructure compared to large multinational firms. Generally, these companies face constraints in technology adoption, interoperability and process

standardization, which makes them an ideal case for investigating the practical implementation of process mapping specifications.

1.6 Thesis outline

The structure of this thesis report consists of nine main chapters that address the research problem and findings concerning the factors that influence the effectiveness and organizational adoption of process mapping specifications for data transfer between structural analysis and design software. In order to investigate this, both qualitative and quantitative research methods were employed, complemented by the development of a process map. The structure of the thesis is organized in four parts which include the following chapters:

- Chapter 1 introduces the research problem, focusing on interoperability challenges in data transfer between structural analysis and structural design software. It also outlines the research objectives, goals, scope and overall structure of the study.
- Chapter 2 reviews relevant literature, presenting the state of research on interoperability, file exchange approaches, implementation difficulties and process maps. Furthermore, it introduces process mapping specifications and standards, including Moody's principles, the 7PMG guidelines and Becker's Guidelines of Modeling, in order to establish a theoretical foundation for the proposed framework.
- Chapter 3 explains the qualitative research methodology, outlining the interview design, sampling approach and data collection process. It also discusses the analysis techniques used to extract insights from the expert interviews.
- Chapter 4 presents the results and findings from the interviews, highlighting the practical challenges, organizational perspectives and key factors influencing interoperability and process mapping adoption in the industry.
- Chapter 5 focuses on the development of the process map, integrating findings from the literature and interviews into a structured BPMN-based specification framework. This chapter details the design decisions, standards applied and justification of the proposed process mapping model for data transfer.
- Chapter 6 describes the quantitative research methodology, presenting the survey design, distribution process and data collection strategy. It also introduces the reasoning behind the chosen 4-point Likert scale.
- Chapter 7 analyzes the survey results, linking the quantitative findings to Kotter's change management theory in order to explain the organizational dynamics influencing the adoption of process mapping specifications. This chapter synthesizes both qualitative and quantitative findings to provide a comprehensive understanding of the research problem.
- Chapter 8 discusses the answers to the main research question and the sub-questions. It reflects on the theoretical and practical implications of the study, outlines its limitations and provides recommendations for future research.
- Chapter 9 concludes the thesis by summarizing the most important insights.

2. Literature review

Before diving into the literature review and more specifically how the existing literature could apply and connect to the current problem statement in order to fill the existing gap it is essential to present the following:

The effective transfer of data between software tools is a recurring challenge in the AEC industry. An additional effort is usually needed, when analysis that requires the transfer of data from one tool to another is performed. This is due to the incompatibilities in file exchange (De Gaetani et al., 2020). Even when common file standards are used, different file format versions can create inconsistencies, as updates may introduce new problems. To solve these problems it is necessary to describe the term “interoperability”. The Institute of Electrical and Electronics Engineers (IEEE) defines it as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged” (Flynn, 2022).

Another essential concept for this thesis is process mapping. According to Borrmann et al. (2018), process maps define “a clear structure for the requirements and the assignment of responsibilities for information exchange scenarios throughout all the steps of a process”. Moreover, process mapping which is also known as workflow mapping, is “a technique used to visualize and document processes in an organization” (Voráček, 2024). It visualizes complex workflows, it explains the dependencies between data and highlights inefficiencies in information exchange.

2.1 Data transfer

The AEC industry relies heavily on the management and exchange of information and this makes it one of the most data-driven fields (Amoah, 2019). In the past, the sector did not require the integration of multiple design and analysis software tools. However, because of the evolution of digital practices and project delivery methods, there is a growing demand for efficient data management across the project lifecycle (Amoah, 2019). Over time, professionals have increasingly sought interoperability and seamless communication between their own software and third-party tools (Racz et al., 2009). Despite some advances, the exchange of information usually still occurs through printed reports or electronic documents that must be manually interpreted. Then relevant data is re-entered into specialized tools, which is a time-consuming process prone to human error. Furthermore, this process limits the possibility of using more advanced computational solutions (Amoah, 2019).

Still, file exchange remains a necessity at multiple stages of project workflows in the AEC industry (De Gaetani et al., 2020). Therefore, it is informative for stakeholders involved in data transfer to assess the capabilities as well as the limitations of software in terms of interoperability. Although some file types (such as IFC) are designed to ensured perfect interoperability, practical experience shows that flawless data transfer rarely occurs (De Gaetani et al., 2020). It still remains a significant technical challenge to design and implement a fully automated solution that can adapt to all projects types (Racz et al., 2009).

In reality, the structural design process is not linear but iterative and it involves multiple revisions, feedback loops and constant modifications. This cyclical workflow requires frequent data exchanges among different analytical and modeling tools. To manage these exchanges people should focus on identifying changes and differences in the transferred information and this can be challenging. Since the source platform has access to the complete design history, it should explain which elements are new, altered or deleted. Unfortunately, most software

tools provide very limited support for such detailed tracking. When the origin system indicates that an object has changed without specifying how, the receiving system must perform additional analysis to determine the change. When change tracking is insufficient, this often involves comparing object attributes one by one. After the differences are identified, updates must be manually applied to the destination model.

This then creates the following problems. Firstly, it is important to convert the updated incoming model into the format used by the destination software. Secondly, the elements in the receiving software should be updated. For example, if the geometry of a floor slab is changed, the loads in the analytical model may fall outside its new boundary, while others may become active in the new extend of the shape. Such corrections must be carried out manually, when there is no automatic management of changes. Because this management is usually very complex, quality control in software is still manual (Racz et al., 2009). The lack of standardized change management protocols across software makes it difficult for developers to create reliable automated synchronization tools.

Another important issue during data transfer is the inconsistency in how different software define and represent the same objects, even when their functions are equivalent (De Gaetani et al., 2020). This challenge was also raised during several interviews, with a common example being the difference in how beams are represented in structural analysis compared to structural design tools. Consequently, components created in one application often cannot be exchanged with another and retain full functionality or metadata. This lack of interoperability when project members use different software tools, leads to inefficiencies and higher costs (Amoah, 2019). And as Amoah (2019) points out, fragmented workflows make managing user activities, tracking model versions and comparing data across platforms nearly impossible.

2.2 Interoperability

To maintain a consistent and efficient workflow, interoperability is very important. It enables seamless information exchange, reduces the need for data recreation and supports collaborative workflows that rely on data sharing (Santos, 2009). However, interoperability issues continue to be one of the main causes of wasted time, money and inefficiency in design, planning and construction activities (De Gaetani et al., 2020). The most common solution for these issues is manually re-entering data, which is extensive work and often decreases productivity (De Gaetani et al., 2020).

AEC projects involve collaboration between various disciplines and because of that they require the use of multiple software and file formats, such as IFC, DXF, DWG, XML and STEP to facilitate communication and modeling (Alreshidi et al., 2018). No single software platform can handle all aspects of project execution yet. Therefore, the industry has moved toward the creation of standardized frameworks to improve compatibility between tools (De Gaetani et al., 2020). So to achieve software interoperability, models generated in different programs must be capable of being exported into a shared format that preserves all the information of the elements during data transfer (Grilo et al., 2010).

Another important factor to consider is that the interoperability situation is rarely static. Software tools are constantly being updated or modified. When a developer changes the modeling approach of one tool or releases a new version the related applications must also adapt to remain compatible (Racz et al., 2009). To maintain stable and reliable data exchange, constant monitoring of changes as well as training for development teams is required.

The Industry Foundation Classes (IFC) format (ISO/PAS 16739:2005) has become the most recognized standard for data exchange in the AEC industry (Sacks et al., 2018). It offers an open and neutral data format that allows information to be shared across different platforms (Grilo et al., 2010). Its main principle is data independence. It emphasizes information rather than the tools themselves to ensure that project participants using different software can still collaborate effectively (Amoah, 2019). The IFC framework is also designed to enable communication across all phases and disciplines of a project (Jönsson, 2015).

Despite these advantages, IFC does not guarantee perfect compatibility. Its effectiveness relies on software developers implementing IFC support within their systems (Jönsson, 2015). Fortunately, most software companies have already made their tools compatible with IFC. It should be noted, however, that case studies in IFC-based exchanges have revealed that data loss still occurs and manual adjustments are needed (Pazlar et al., 2008). This study's context shows a clear contrast: Tekla and SCIA Engineer handle IFC reliably, with a mature, well-tested link that preserves geometry and key attributes with minimal problems. By comparison, exchanges involving Ansys are problematic because Ansys does not natively support IFC. So attempting to transfer data to and from Ansys via IFC leads to missing metadata and mismatched element types. These findings indicate that no current interoperability solution is entirely reliable and that challenges still remain in seamless data transfer. Although IFC includes features designed to support repeated data exchanges, such as the "owner history" concept, standardization efforts have not focused enough on enforcing these elements yet (Racz et al., 2009). Without synchronized updates and collaborative improvement across software platforms, recurring exchanges will continue to be inconsistent.

Research (Racz et al., 2009; De Gaetani et al., 2020) highlights several requirements for effective interoperability:

- Reuse of available information: The primary objective of interoperability is to share already defined data between software with limited loss and without the need to redefine it.
- Process acceleration: By reducing the repetition of similar tasks, working time can be improved.
- Quality improvement: Shared digital information minimizes human errors that are a consequence of repetitive manual work.
- Change management: Software should be able to track, manage and update modifications in interconnected design processes.
- Simplified data translation: The conversion of similar concepts between connected systems should be intuitive and straightforward.
- Automation tools: Specialized software tools should be available to automate large-scale interoperability operations to improve efficiency and quality.
- Navigation and filtering capabilities: Tools that enable users to group, view and filter transferred data, such as by building element type help to manage complex interoperability situations.

2.3 File exchange approaches

When multiple software platforms are used in the same workflow, organizing how they operate with each other becomes just as critical as the accuracy of the exchanged data. In these cases, coordinating deliveries and managing information flow between tools directly affects

project efficiency. Many interoperability methods are used, including file-based exchange, add-on, direct software links and database integration (Racz et al., 2009). Because of its simplicity, file-based exchange is still the most common approach. However, current trends indicate a slow transition toward more collaborative systems that connect applications within an integrated data environment.

In the file-based exchange, information is exported as a file either in a native format or an intermediate format. This approach is relatively easy to implement and can be adapted to different project setups, but it is not effective for iterative design processes where a lot of updates are required. Intermediate file formats improve independence between software systems but involve two separate conversions (source → intermediary → destination). This means that there are two occasions where data loss or inconsistencies can happen. On the other hand, using native file formats makes the conversion process simpler but creates a dependency between platforms. This makes long-term maintenance and version control more challenging.

Add-on solutions enhance the capabilities of a software by embedding the features of another tool within it. This makes the conversion process smoother. However, for more advanced analyses, many add-ons still rely on traditional file exports to fully process data.

A direct link helps two different software to share information instantly and no file transfers are required. This type of exchange happens in the background and allows real-time synchronization between tools. This approach improves speed and reduces user intervention, but it also has limitations. Both applications must be accessible at the same time and costs can increase, depending on the license. Users also need to be familiar with both programs to manage the workflow locally. If the direct connections are remote, less software expertise is needed and more coordination among project participants. Within the scope of this thesis, tools such as Ansys and Inventor have a direct connection, as do Tekla and SCIA Engineer.

The final approach involves database integration, where different tools access and update data stored in a common local or remote database. This removes the need for manual file transfers and avoids some of the synchronization requirements associated with direct linking. At the same time, a shared and consistent data environment is created.

Once data has been exchanged, it must be converted so that one software can interpret and use the information produced by another. According to Racz et al. (2009), interoperability solutions can function in manual, semi-automatic or fully automatic ways, depending on the complexity and nature of the data being transferred. In a manual conversion, the receiving software imports unprocessed data and the user has to interpret them and rebuild the model. A common example is DWG-based file exchange, where users manually draw again the analytical elements within their native environments. On the other hand, automatic conversion relies on agreed-upon rules that translate incoming data straight into the destination's format. Although this approach increases efficiency, it works only for simple geometries such as regular-shaped buildings or standard model types. Finally, semi-automatic conversion combines automated translation rules with human input. The imported model remains mostly the same, while users selectively apply automated rules to each component. Racz et al. (2009) note that this hybrid approach "balances efficiency with flexibility, allowing more control over the exchange outcome".

2.4 Interoperability difficulties in practice

Although interoperability solutions have greatly improved, many obstacles remain when they are applied in practice. One of the most significant challenges is the fact that design and analysis software represent the same structural components in different ways (Racz et al., 2009). These variations happen not only in the representation of geometry but also in the levels of detail and how parameters such as materials, cross-sections and loads are defined.

A common mistake by users is that they think that advanced computer systems are capable of recognizing the characteristics of an imported model and generating the correct analytical model without human input (Racz et al., 2009). This happen because software developers who are motivated by market competition, often hide the limitations of their tools. For instance, Tekla Structures (Tekla, 2009) and Revit Structure (Autodesk, 2009) both advertise their ability to define analytical information. However, for actual structural analysis, the models still need to be exported to other more specialized software (Racz et al., 2009). Therefore, two tools are required to complete the workflow and any changes to the analytical model must be reflected in both systems. This increases the effort needed and complicates the exchange of data between programs.

Another recurring problem is the conversion of geometry. The way a physical model is represented by an analytical model changes according to the design phase (Racz et al., 2009). Specifically, early conceptual models require less simplification, while later design stages demand greater detail. For example, when the geometry of a slab changes in an architectural model, the associated analytical loads may no longer align with the new boundaries. This requires manual corrections so that the loads are correctly applied. This is also confirmed by Rönneblad (2002), who mentions that inconsistencies often occur between design and analytical boundaries and they result in unreliable conversions. These incompatibilities disrupt automated data transfer and so the risks of mistakes increase. Figure 4 illustrates this problem by showing how the boundaries of architectural and analytical models can be different when not properly synchronized.

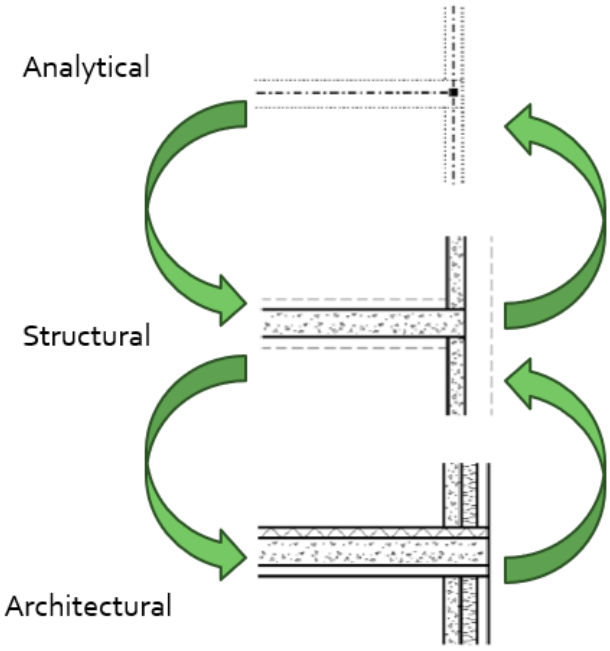


Figure 4: Boundaries in analytical, structural and architectural models do not match (Rönneblad, 2002)

Translation of compatible information is another source of difficulty. Even between sub-disciplines such as structural modeling and structural analysis, identical concepts may be handled differently. Concrete grades, steel profiles or reinforcement parameters defined in one program sometimes don't exist in the receiving software's database or may be interpreted differently. For instance, the representation of material properties or grades ("C20/25" vs. "C 20/25", there is a space in the second material name). This minor mismatch forces engineers to manually reassign materials, which increases the likelihood of errors and inefficiencies.

Another example of different approaches is the definition of material parameters. They can be defined by referencing data from tables directly from the building code or by specifying key variables and calculating dependent properties based on the code's regulations. Although both approaches should have equivalent results, differences in rounding or calculation precision can still produce mismatched outputs. This also leads to data loss during transfer (Racz et al., 2009).

The diversity of data formats adds another layer of complexity, because identical information can be encoded in multiple forms. For instance, a slab contour might be expressed as a sequence of points, a series of two-dimensional primitives, arcs defined by endpoints and midpoints or even as circular references with angles (Racz et al., 2009). Each new representation is a potential for incompatibilities and makes the job of developers more difficult because they have to maintain consistency. A common example is how beams are represented differently across tools. As it is shown in Figure 5, in Ansys beams are modeled as centerline elements without full 3D geometry. Their dimensions are added later as properties.

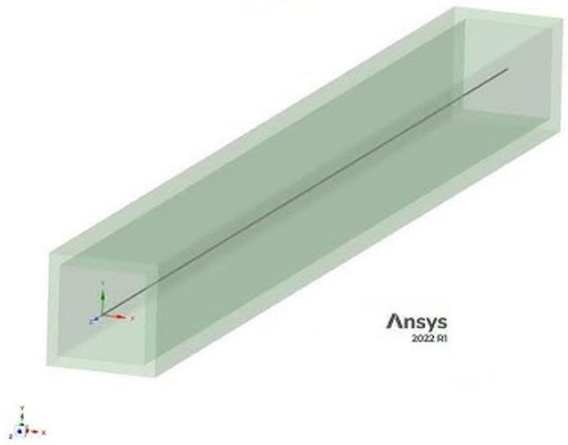


Figure 5: Beam modeled in Ansys

On the other hand, in Tekla (Figure 6), beams are represented as solid 3D objects with explicit geometric parameters. These different representations complicate the data exchange process and often result in lost or incomplete information that must be manually corrected.

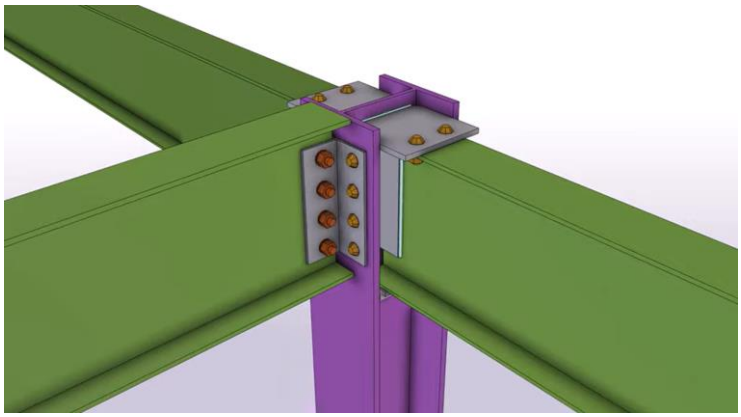


Figure 6: Beam modeled in Tekla

Finally, the differences in software capabilities also create interoperability problems. Each program offers unique modeling and analysis features. To be more specific, some modeling tools include advanced features such as curved surfaces, intersecting geometries, compound objects or irregular openings that analysis software may not support (Racz et al., 2009). Therefore, transferring data between these tools often leads to incomplete translations or the loss of complex object definitions.

Overall, these challenges demonstrate that achieving interoperability involves far more than developing common file formats or protocols. The primary issue lies in the fundamental differences of how software applications conceptualize and manage data. That's why, the development of more adaptable and flexible interoperability solutions is essential. According to Racz et al. (2009), future interoperability standards should also be customizable and easy to implement to ensure that they can evolve alongside new tools and project needs.

2.5 Open standards for data neutral formats

Traditional project workflows in the AEC industry depend on the use of multiple software platforms, which as was previously discussed creates issues in data exchange between disciplines and project stages. To address these challenges, buildingSMART International (bSI) was established as a leading global organization to advance open standards. Their goal is to enable effective collaboration and data sharing throughout the entire lifecycle of assets (buildingSMART, n.d.). To achieve this, buildingSMART have developed a set of standards that together form the foundation for digital interoperability. These include the Industry Foundation Classes (IFC), the buildingSMART Data Dictionary (bsDD), the Information Delivery Specification (IDS) and the BIM Collaboration Format (BCF). To be more specific, IFC is a standard for information exchange, bsDD provides a shared language for understanding what the information represents, IDS specifies which information is required, when it must be provided and in what form and BCF facilitates communication by allowing users to attach comments directly to model elements (Mogollon, 2014).

The bsDD is an open, object-oriented database that defines the terminology and semantics used to describe BIM objects (Bell et al., 2008). It should act as a shared vocabulary and ensure that elements are defined consistently across software as well as national contexts (Palos, 2012). By providing standardized definitions, bsDD allows information to be universally understood and transferred without data loss (Jönsson, 2015).

IDS defines information requirements in a computer-readable format. This allows for automatic validation of IFC-based models which improves the reliability of data (buildingSMART, n.d.). Moreover, IDS supports efficient quality control because it establishes clear expectations for what information needs to be delivered, by whom and at what stage. Through IDS, users can define the expected properties of objects, materials, classifications and property values within an IFC model. This format can also complement other international frameworks, such as Exchange Information Requirements (ISO 19650), Levels of Information Needs (EN 17412) and Product Data Templates (ISO 23387).

BCF serves as a communication protocol for model-based collaboration. Unlike traditional text-based issue tracking, it allows users to associate comments, screenshots and viewpoints directly with elements in a 3D model. This makes communication more transparent and context-specific (buildingSMART, n.d.). Because the communication history is stored and accessible, project workflows are predictable and traceable. When all the previous standards are combined, they form what is referred to as openBIM. OpenBIM is a methodology that emphasizes openness, interoperability and software neutrality. Rather than referring to a single tool, it represents a framework of standards and best practices that enable diverse digital tools to work together seamlessly.

These open standards give project teams the flexibility to select specialized tools for different tasks. This way they can take advantage of each software's strengths while maintaining a common data environment (Racz et al., 2009). For instance, one program may be better for the analysis of steel frame structures, while another is better for analyzing reinforced concrete slabs. When all building data is stored in open formats, the most suitable software can be used for each design task without the risk of losing access to essential information or becoming dependent on a specific software. OpenBIM also enhances team flexibility and broadens opportunities for collaboration between different organizations and professionals (Racz et al., 2009). Therefore, adopting open solutions is preferable for successful interoperability than relying on proprietary technologies.

The successful implementation of buildingSMART standards was clearly demonstrated in the Pontsteiger Project, a landmark residential development in Amsterdam, Netherlands. The 90-meter-tall building of 366 apartments, retail spaces and a marina, is considered one of Europe's most advanced examples of openBIM implementation (buildingSMART International, 2019). The project team applied an openBIM workflow based on IFC and BCF to ensure transparent collaboration and data exchange among architects, engineers, subcontractors and software tools. The team guaranteed that all information remained accessible and consistent across all project phases, by enforcing IFC compliance from the very beginning. Notably, the project utilized Tekla Structures and SCIA Engineer which are the same software tools examined in the case study of this thesis.

Figure 7: BIM model of Pontsteiger project

This project proved that large-scale, multidisciplinary projects can be executed successfully using open standards alone, without depending on proprietary file formats. By integrating IFC and BCF, collaboration and communication improved. Additionally, the creation of a highly coordinated 3D model (Figure 7) that was approximately 90% clash-free prior to construction was made possible. The project was completed within schedule and budget and established a new benchmark for digital construction in the Netherlands (buildingSMART International, 2019).

2.6 Process maps in organizations

Among the many methodologies used to drive organizational improvement, process mapping is widely recognized as one of the most essential tools (White et al., 2016). Its main goal is to create a clear representation of how organizational processes work and how activities are connected (Malinova Mandelburger et al., 2013). In addition, process mapping reveals how various stages are linked with each other and how information and data moves through the process (Voráček, 2024). Maps also help organizations understand their workflows better and identify bottlenecks in them, because they visualize how processes are structured. They serve as effective guides through complex systems without requiring detailed process knowledge (Kesari et al m., 2003). Process maps facilitate the understanding of organizational dynamics by highlighting core functions and promoting process standardization. They make communication channels explicit, enhance engagement and increase the chances of successful process implementation (Kock et al., 2008). Therefore, the accuracy and quality of process maps are critical for the success of process management efforts.

2.7 Cognitive effectiveness of process maps and Moody's Nine Principles

Malinova Mandelburger et al. (2013) observe that although some process maps incorporate a range of visual elements to align with specific project goals, many models still do not pay enough attention to design quality. A recurring issue in process documentation is that most casual modelers have a generally low level of modeling proficiency (Mendling et al., 2010). Since most large-scale process documentation initiatives often depend on these casual participants, Mendling et al. (2010) also stress that providing clear guidance is important. To achieve cognitively effective visual representations, such as process maps, Moody (2009) introduced nine principles that serve as a framework for effective map design. These principles aim to imporve comprehension, minimize visual complexity and ensure that the structure of the map reflects its intended purpose. Studies confirm that following these guidelines makes the process easier for users to understand, particularly with complex notations such as BPMN (Figl et al., 2012).

According to Moody (2009), the most relevant principles for designing effective process maps include:

- Semiotic clarity: Each symbol should represent only one specific concept. In the context of data transfer and to avoid confusion, this means using distinct and consistent symbols for different categories, such as data preparation, exchange and analysis.
- Perceptual discriminability: Symbols should be visually distinct from one another. For example, color or size variations can be used to highlight major processes, such as data exchanges, while making secondary actions like quality control less dominant.
- Semantic transparency: The appearance of symbols should intuitively convey their meaning. Arrow-like shapes, for instance, naturally represent direction in data flow.
- Complexity management: Information must be organized in a way that doesn't overload the user. Users can more easily follow data flows when processes are grouped into logical categories (input, analysis, verification and output). It also helps to give each category a distinct shape or color.
- Cognitive integration: The way symbols interact within the map should express how different processes depend on one another. This is particularly important for data exchange maps, where upstream modifications can affect downstream models.
- Visual effectiveness: Using at least three distinct visual variables (color, shape, brightness, etc.) can improve understanding. They help convey hierarchy, process order and interdependencies to visually optimize the map.
- Dual coding: Combining text labels with graphics improves understanding more effectively than using either alone. For example, labeling symbols with terms like "Export IFC" or "Validation Step" ensures better comprehension of the activity.
- Graphic economy: There should be a limited number of visual elements and those used should be logically structured. Too many shapes or colors can make interpretation difficult.
- Cognitive fit: The design of the process map should match its intended audience and objectives. A high-level overview for managers, for instance, should emphasize clarity between relationships, whereas a technical version might include more detail, such as error-tracking routines.

Malinova Mandelburger et al. (2013) argue that process maps which follow these principles closely tend to be cognitively effective for both expert and novice users. In contrast, simpler or less visual maps only help experienced staff who are already familiar with the workflow. Collectively, Moody's nine principles provide a robust framework for designing process maps that are not only aesthetically appealing but also functional in communicating complex organizational processes.

2.8 Seven Process Modeling Guidelines (7PMG)

The Seven Process Modeling Guidelines (7PMG) introduced by Mendling et al. (2010), build upon Moody's design principles and present a set recommendations for developing effective process models that have been empirically validated. These rules specifically target the usual

difficulties of modeling and guide modelers on how to apply these guidelines. The fact that 7PMG was empirically validated makes it different from similar guidelines found in literature. It was created based on research findings that examined the influence of different modeling techniques on users' understanding and their ability to avoid errors (Mendling et al., 2010; Sharp et al., 2001; Malone et al., 2003). Moreover, the guidelines are applicable across many popular modeling standards such as Event-Driven Process Chains (EPC), Business Process Model and Notation (BPMN) and Unified Modeling Language (UML) activity diagrams (Mendling et al., 2010). Because 7PMG addresses creating new models as well as the refining existing ones, it is as a valuable guide for modelers looking to improve the effectiveness of their models.

Below the seven rules of the 7PMG framework are presented:

- Use as few elements as possible. Keeping models small makes them easier to interpret and reduces the likelihood of errors (Mendling et al., 2007; Mendling et al., 2008).
- Minimize the routing paths of each element. Mendling et al. (2007) found a strong relationship between modeling errors and the number of connections in a diagram. The greater the number of connections entering or leaving an element, the harder it becomes to follow the model's logic.
- Use one start and end event. Defining one clear entry and exit point improves the clarity of models, because multiple start or end events create confusion within the workflow (Aalst et al., 2003).
- Model as structured as possible. Structure in a process model means that every split gateway connects to a matching join of the same type. Mismatched models are harder to understand and lead to logical or syntactic errors (Mendling et al., 2007).
- Avoid OR routing elements. Logical connectors such as AND and XOR are easier to interpret. In contrast, OR connectors often cause contradictions within the flow (Mendling et al., 2007).
- Use verb-object activity labels. Activities should be named using a clear verb–object label ("Validate results") rather than an action-noun form ("Results validation"). Studies such as Malone et al. (2003) show that this phrasing is more user-friendly and less confusing.
- Decompose large models. It is difficult to read and manage models that have more than 50 elements. To improve clarity, they should be divided into smaller and logically related sub-models.

2.9 Guidelines of Modeling

Another influential contribution is the Guidelines of Modeling (GoM) framework proposed by Becker et al. (2000), which defines seven essential criteria for model quality outlined below. They are considered an important reference to verify and construct process models that are accurate and practically applicable.

- Syntactical correctness concerns the consistent use of the modeling language and notation rules. A simple manual review of the model can ensure it has the correct

syntax. When the modeling method used is simple, it's easy to maintain syntactic integrity.

- Semantic correctness relates to the accuracy of a model in representing the real-world domain it describes. Because semantics depend on the specific context of a model, it is difficult to offer guidance. This makes it difficult to use in practice.
- Relevance of content applies the principle of minimalism to process modeling. A well-designed model should include only the information necessary to fulfill its intended purpose. Determining which elements are relevant is simple, when a model's objectives are clearly defined.
- Economical design promotes efficiency in model creation. Using standardized modeling templates reduces the effort and time required to build models from scratch.
- Clarity of representation is considered an optional criterion within the GoM framework. Becker et al. (2000) argue that maintaining visual clarity is more manageable, if the rule of syntactical correctness is properly established.
- Comparability of related content refers to the ability to be compared with related models, even when different modeling methods have been used.
- Systematic design dictates that process models should have a coherent and logical structure. This enhances understanding and supports model consistency.

2.10 Specifications for effective process maps

The nine principles of Moody (2009), the Seven Process Modeling Guidelines (7PMG) and the Guidelines of Modeling (GoM) proposed by Becker et al. (2000) all aim to improve the quality of process models. However, they approach the problem from different perspectives. GoM defines what a processing model should achieve (e.g., correctness, relevance, clarity), while Moody and 7PMG define how these qualities can be achieved in practice (e.g., verb-object labels, avoidance of OR connectors, minimum three visual variables). Moody and 7PMG emphasize cognitive effectiveness, which can be achieved by reducing complexity and managing user perception. GoM does not address perception but assumes that syntactical correctness and clarity lead to understanding.

To create a set of integrated specifications for designing effective process maps for facilitating data transfer, Moody's nine principles were combined with the 7PMG framework as well as the GoM. The results are presented in Table 1:

Table 1: Process map specifications

Process map specifications	Moody's principles	7PMG	GoM
Clear and consistent symbols	Semiotic clarity, perceptual discriminability	Use verb-object activity labels	Clarity of representation
Intuitive design	Semantic transparency	Model as structured as possible	Systematic design

Manageable complexity	Complexity management, graphic economy	Use as few elements as possible, decompose large models	Syntactical correctness
Explicit relationships of activities	Cognitive integration		Semantic correctness
Visual optimization	Visual effectiveness, graphic economy		Relevance of content
Support graphics with text	Dual coding	Use verb-object activity labels	
User orientation	Cognitive fit		Comparability of related content
Error prevention		Minimize the routing paths per element, avoid OR routing elements	Economical design

2.11 Overview of modeling approaches in civil engineering

In the AEC industry, several modeling approaches are employed to represent processes, including the Unified Modeling Language (UML), Business Process Model and Notation (BPMN) and the Integration Definition for Function Modeling (IDEF) (Borrmann et al., 2018). The level of detail required and the specific purpose of the modeling task determine which is the preferred method. UML is used in software engineering because it is helpful for developers who want to visualize and manage complex codes in a hierarchical manner (Voráček, 2024). Its standardized format is accepted by professionals, but interpreting it effectively requires technical expertise. On the other hand, BPMN is made to model business processes for technical as well as non-technical users. It is ideal for detailed process mapping and automation projects, because it focuses on workflows, activity sequences and decision points. By visualizing workflows, BPMN also helps identify inefficiencies and bottlenecks in business procedures. Finally, IDEF is best used for “high-level functional analysis and system design” (zur Muehlen et al., 2010). It is valuable when the goal is to understand how different functions relate to one another. To sum up, UML is code-centric, BPMN is process-centric and IDEF is function-centric. Therefore, the three methodologies can complement one another, but the modeling objectives determine which is the best to use.

For the objectives of this research, BPMN offers a combination of features that make it the best choice. Specifically, BPMN is used for detailed mapping of processes and facilitates workflow automation. Both are essential for analyzing and improving data exchange mechanisms between structural analysis and design applications. Unlike IDEF, BPMN enables the clear definition of data exchange points and dependencies across activities through its a process-oriented perspective (Borrmann et al., 2018). Furthermore, BPMN is already more adopted within the Business Process Management (BPM) community than UML. Another important characteristic is that it can be used to close the gap between business stakeholders and technical experts in interdisciplinary engineering projects (von Rosing et al., 2015).

Additionally, BPMN's standardized graphical notation improves readability and supports the consistent long-term use of models (zur Muehlen et al., 2010). Its proven effectiveness in BIM related workflows further confirms its applicability for civil engineering projects (Borrmann et al., 2018). Finally, BPMN is also the preferred method for workflow mapping in Iv.

2.12 Characteristics of BPMN

The Business Process Model and Notation (BPMN) is an internationally recognized graphical standard used to represent, document and analyze organizational processes (Voráček, 2024; von Rosing et al., 2015). It offers a structured method for visualizing how business activities are organized and this makes it one of the most used tools in Business Process Management (BPM). Its standardized notation is BPMN's main advantage, because it promotes consistency in the interpretation of process models across organizations. This minimizes miscommunication that arises when various modeling approaches are used to represent similar processes (zur Muehlen et al., 2010). Furthermore, research indicates that a model's simplicity is an important factor that influences long-term adoption (Davies et al., 2006).

Unlike traditional flowcharts, BPMN is capable of representing complex processes and maintain its readability. Its formalized notation makes it useful for process automation, an increasingly vital aspect of digital transformation in modern industries. However, one important disadvantage is that advanced BPMN software tools often have high licensing costs, which can be a limiting factor for some organizations.

Its growing adoption has also extended into the BIM domain, where BPMN diagrams have been successfully used to define data exchange points and clearly model structures (Borrmann et al., 2018). Because of these advantages, BPMN has become one of the most preferred modeling languages among business analysts and information systems specialists (zur Muehlen et al., 2010).

In the construction industry, the adoption of centralized BIM servers and advanced planning tools has contributed to the increasing reliance on workflow management systems (Borrmann et al., 2018). The BPMN method matches well with the objectives of these systems by supporting the three key aspects of effective workflow management:

- process transparency, which is achieved by clearly documenting decision-making procedures
- process reliability which is ensured through standardized workflows and
- improved information management which is made possible by reducing the interruptions between tools and enabling users to control data access.

2.13 Summary

PART I: Literature & Framework establishes why interoperability between structural analysis and structural design software remains a persistent bottleneck in AEC practice. Despite the constant development of new standards and exchange formats (e.g., IFC), daily workflows still rely on manual data re-entry, file format conversions and change tracking. Iterative design cycles exacerbate issues such as geometry and metadata loss, analytical–physical model mismatches and inconsistent semantics across tools. The literature review also shows that industry discourse has focused heavily on the design of process models while largely overlooking their implementation within real organizations. Therefore previous research

doesn’t take into account roles, responsibilities, coordination and adoption behaviors which ultimately determine success.

To address this, PART I: Literature & Framework synthesizes three complementary guideline frameworks, Moody’s principles, the Seven Process Modeling Guidelines (7PMG) and the Guidelines of Modeling (GoM), into a cohesive specification baseline for process maps. The resulting criteria emphasize clear and consistent symbols, logically structured flows, complexity management, explicit representation of dependencies and handovers, dual coding (graphics and precise labels), user-appropriate terminology and error-preventing structures and gateways. Beyond notation, the analysis highlights the need for organizational standards, such as naming conventions, versioning and change logs, legends and a lightweight modeling checklist to ensure consistent practice across projects. Together, these specifications operationalize effectiveness and implementation quality. They serve as the design criteria for the process map developed later and PART II: Qualitative methodology & Design uses them to theoretically evaluate the map. BPMN is proposed and adopted as the preferred notation because it balances expressiveness for complex, iterative exchanges with accessibility for technical and non-technical stakeholders. Furthermore, it aligns with emerging workflow management practices.

Complementing these modeling specifications, PART I: Literature & Framework also proposes open standards as a solution to interoperability problems. BuildingSMART’s standards: IFC (share information), bsDD (agree on meanings), IDS (declare information requirements in a computer-checkable way) and BCF (coordinate model-based issues), form a framework often referred to as openBIM. Used together, they reduce reliance on multiple software, support discipline-specific tooling and improve quality via explicit requirements and model-based communication. Their practical value is proven by projects such as Pontsteiger in Amsterdam which used tools that overlap with the Iv context.

PART II: QUALITATIVE METHODOLOGY & DESIGN

PART II: Qualitative methodology & Design investigates how data actually moves between structural analysis and structural design tools at Iv and why it often breaks down in practice. It uses qualitative research to ground the specifications from PART I: Literature & Framework in real workflows. Nine semi-structured interviews were conducted across roles (engineers, designers, project/quality managers, information managers, commercial lead) using purposive recruitment. They were audio-recorded, transcribed and then analyzed inductively using a thematic approach. Saturation guided sample sufficiency and the credibility of results was supported through triangulation across roles and projects. Seven bottlenecks in the process emerged from the analysis. These findings explain why interoperability is problematic and they specify which interventions can be useful. They directly inform the BPMN-based process map developed here and use the specifications from PART I: Literature & Framework to evaluate it.

3. QUALITATIVE RESEARCH METHODOLOGY

The use of surveys and interviews is strongly recommended by White et al. (2024) in operational and process-oriented research. The mixed-methods research (MMR) approach integrates both quantitative and qualitative forms of data collection and analysis. So it provides a more holistic approach of examining complex research questions (Dawadi et al., 2021). By combining them, the mixed-methods approach leverages the strengths of both while mitigating their respective weaknesses (Dawadi et al., 2021). This integration leads to deeper and more credible findings. Although merging different methodologies can be challenging, MMR remains the most effective strategy for addressing complex research problems that require both breadth and depth of understanding. Therefore, it is adopted in this study as the most suitable framework for achieving a well-rounded analysis.

To understand the current challenges in the data transfer process between structural analysis and structural design software at Iv, a series of semi-structured interviews were conducted with employees in Iv across multiple departments and roles. The goal of the interviews is for participants to reveal their experiences and perspectives related to current data exchange problems and process transformation. This qualitative element enables the interviewer to capture detailed narratives that help explain not only what challenges exist, but also why they do. Iv provides an ideal environment for this type of research due to its diverse departments, such as Iv-Consult and Iv-Offshore. They also make simultaneous use of various software tools across engineering, design and project management roles. These conditions provide a good background for identifying how technical workflows and organizational practices interact and how inefficiencies in data exchange come up in practice. Chapter 3 outlines the methodology used to design, execute and analyze these interviews. To do that, it draws upon the framework established by Hennink et al. (2011) in their book Qualitative Research Methods. Their framework for thematic analysis provided a structured and academically grounded methodology to interpret and validate patterns from the interviews. The authors emphasize the importance of developing a coding framework after the analysis of the data, followed by categorizing these codes into broader themes.

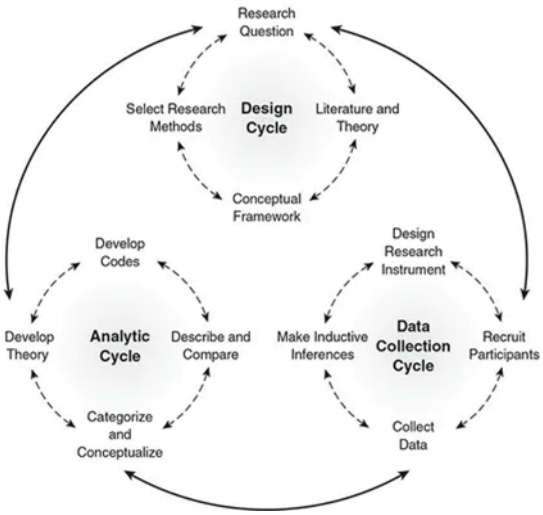


Figure 8: Hutter-Hennink qualitative research cycle

Figure 8 presents the qualitative research cycle devised by Hutter and Hennink which acknowledges the cyclical nature of the qualitative research process. The cycle consists of 3 interlinked cycles, which are the design cycle, the data collection cycle and the analytic cycle.

The goal of this qualitative data collection was to answer the second sub-question: *What are the current challenges to seamless data transfer between structural analysis and structural design software?*. To be more specific, the purpose was to understand why and how data transfer issues occur and how they are experienced by different actors in the workflow. The process involved designing and conducting interviews with employees from different roles, transcribing the data and coding interview transcripts using a thematic approach. The final steps were the synthesis of recurring themes, their validation across participants and the extraction of practical bottlenecks supported by participant quotations. These steps are outlined below to explain how the raw interview data was analyzed and written into the structured findings presented in Chapter 4.

3.1 Participant recruitment

In general, the process of participant recruiter involves two stages: the first is to define an appropriate study population and the second is to identify strategies for recruiting participants from this study population (Hennink et al., 2011). Random selection of participants is not acceptable in qualitative research and it will not enhance the robustness of the study findings. The purpose is to gain a detailed understanding of a certain phenomenon. This requires a small number of participants so that issues can be explored in depth. Furthermore, it also involves the recruitment of participants with specific characteristics than can best inform the research topic. Qualitative research therefore uses purposive recruitment, which is both deliberate and flexible (Hennink et al., 2011). It is advised to select people who are information rich on the study topic and can provide detailed understanding of the issues. Moreover, a diverse range of participants is needed so that they can provide a variety of experiences. Finally, purposive recruitment is flexible as researchers can refine the types of participants selected during data collection.

The study population is defined during the design cycle of the study, because the research questions define the most appropriate target population for the study. In this case, because the research question is to examine people’s experiences of using a particular software, the

study population will be limited to users of these tools. However, after the initial data collection, the topic becomes clearer and it is possible that the interview participants may identify other types of participants to also include in the study.

3.1.1 Criteria for recruitment of participants

Therefore, to ensure a comprehensive perspective, participants were selected from different departments and software domains. The criteria for their recruitment were:

- Active involvement in structural design or analysis projects
- Familiarity with software tools such as Ansys, Tekla, Inventor, SCIA Engineer, Bentley SACS
- Experience with interdepartmental collaboration and file exchange processes.

In total, eight interviews (one with multiple participants) were conducted and representation from both Iv-Consult and Iv-Offshore and Energy teams was secured. The participants were chosen based on the diversity of their roles, expertise and team association. Interview participants ranged from structural engineers and designers to project managers and quality coordinators within Iv. This provided multiple perspectives of how data moves (and often stalls) between analysis tools such as Ansys, SCIA Engineer and Bentley SACS and design/modeling software such as Tekla, Inventor and Revit. Each one has a distinct perspective on how data is produced, shared and validated. This diversity was essential to understand not only the technical aspects of the workflow, but also the organizational and communication-related dimensions. The selection criteria for each role are outlined in the Table 2.

Table 2: Criteria for participant selection

Perspective	Why it is needed
Technical (structural engineering)	To understand how data is generated in structural analysis tools, including what data is exported, what formats are used and what limitations exist in accuracy or completeness. Engineers are the primary users of analysis software such as Ansys and SCIA Engineer. Their perspective is important in understanding the nature of analytical data, file exports as well as limitations related to model simplification and accuracy. They also face first-hand the consequences of transferring data downstream to design teams.
Technical (structural design)	To capture how analysis outputs are used in design environments (e.g., Tekla, Inventor) and to identify challenges in file compatibility, manual conversion of elements and modeling assumptions. The input of designers helped assess how well data which is transferred from analysis software integrates into their design workflows. They also helped clarify how frequently rework is needed due to compatibility issues or missing information.
Process & quality assurance	To talk about the presence and effectiveness of quality control mechanisms during data exchange. For example file validation, visual checks, error logging and version tracking. This role was crucial in order to evaluate current mechanisms and their effectiveness in detecting or preventing data loss or misinterpretation during handovers.

Workflow & collaboration	To understand how collaboration between departments happens in practice. Specifically, how and when engineers, designers and managers communicate and where coordination breaks down.
Organizational / managerial	The sales manager offers insight into how workflows affect commercial deliverables, timelines and client expectations.
Information systems	To investigate technical constraints, limitations in the integration of data and opportunities for automation in data exchange. This also includes system interoperability. The information manager plays a key role in overseeing software integration, data management systems and digital workflows. Their view helped close the gap between the technical and organizational layers of the research problem by clarifying system parameters and strategic limitations.
Business & client interface	To understand how inefficiencies in the data transfer process may affect client deliverables, deadlines or project scope. This point of view is also helpful to connect technical challenges with commercial outcomes.

In the Table 3, the exact characteristics of each interviewee are outlined. Three structural engineers with various degrees of specialty were interviewed. The two structural designers were interviewed together, which was very beneficial as they complimented or corrected each other when needed. One project manager who also serves as a team leader for projects and a quality coordinator was contacted to assess the current quality control mechanisms. Two information managers were needed to describe the way information and data is handled and what could be improved in the process. Finally, one commercial manager was interviewed to provide an overview of the way the company operates and handles projects from the tendering phase to the handover or decommission phase. All participants are given code names to ensure their personal information and opinions remain confidential. From this point on, these codes will be used to express the data gathered from the interviews.

Table 3: List of participants

Role of employee	Code name	Position level
Structural engineer	SE1	Lead structural engineer
Structural engineer	SE2	Senior specialist
Structural engineer	SE3	Structural engineer
Structural designer	SD1	Lead designer
Structural designer	SD2	Designer
Project manager	PM1	Senior project manager, Team leader Projects
Information manager	IM1	Discipline leads
Information manager	IM2	Information manager
Commercial manager	CM1	Commercial manager CSA (Civil, Structural, Architecture)

3.1.2 Saturation

The number of participants to recruit for qualitative studies is guided by a theoretical principle called saturation (Glaser and Strauss, 1967). This is simply the point at which the collected information begins to repeat itself. After reaching information saturation, further data collection becomes redundant because the purpose of the recruitment is to seek variation and context of participant experiences rather than a large number of participants with those experiences (Hennink et al., 2011). It becomes clear that identifying the point of saturation can only begin after data collection is under way. It requires an iterative process which involves collecting some data, assessing the variation in the issues raised and then continuing to collect and assess data to determine whether saturation has been reached. So to achieve this, data analysis continued until no new information emerged. For example, the bottleneck regarding file format exchange (STEP vs. IFC vs. PDF) appeared in nearly every interview, indicating thematic saturation.

3.2 Data collection and interview design

To ensure the collection of consistent and meaningful data across participants, a single set of semi-structured interview questions was used for all interviewees, regardless of their role or department. This approach allowed for thematic comparability across disciplines while still enabling participants to elaborate based on their unique experiences and expertise. The standard set of questions also helped identify whether similar challenges and perspectives were shared across departments or varied depending on technical roles and responsibilities. This format aligns with recommendations in qualitative research literature for designing purposeful and targeted questions that promote open, reflective responses while maintaining alignment with the study's analytical framework (Palinkas et al., 2015).

The interview questions were structured to explore four key domains relevant to the research sub-question on challenges in data transfer between structural analysis and structural design software: general context and tool usage, current data transfer processes and pain points, past experiences with process improvements and ideas for future solutions. The questions of the first domain were designed to get familiar with the participant's context, daily responsibilities and the specific software tools they use. This helped link later comments to their practical environment. The second section focused on the actual process of data exchange between analysis and design software tools. It explored both operational procedures and common technical issues. The final two groups of questions examined whether any process improvement attempts had been made and asked for suggestions from the participants for future improvements.

Each interview followed a semi-structured format, which allowed the flexibility to adapt questions based on the interviewee's expertise. The interviews were guided by a list of prepared, open-ended questions. The questions were designed on purpose to allow the participants to elaborate freely, in line with the interpretive paradigm outlined by Hennink et al. (2011). The goal was not only to capture surface-level descriptions but also to understand the underlying meaning participants assign to challenges and practices in their daily workflows. The open-ended nature of the questions encouraged participants to reflect on exceptions, bottlenecks and potential improvements. Rather than strictly controlling the direction of the conversation, interviewees were able to speak freely and follow their own train of thought. Although this sometimes meant they did not directly answer a question right away, in the end most arrived at relevant insights that addressed the core topics, often in more depth than if

the interview had been rigidly structured. This approach proved valuable, as it gave participants time to reflect and express detailed views. This flexibility was essential to uncovering rich, contextual narratives. In addition, this semi-structured format enabled a conversational flow that encouraged participants to share specific incidents, examples and suggestions without being restricted by yes or no questions.

3.3 Transcription and Familiarization

All interviews were audio-recorded using a smartphone and initially transcribed using Microsoft Word's built-in transcription tool. Following the first stage of qualitative analysis, each interview was transcribed verbatim and thoroughly reviewed. However, the first drafts were not sufficiently clear or accurate enough due to mispronunciations, filler words and non-linear conversation patterns. Pauses or hesitations might in other contexts indicate discomfort. However, in this case they reflected the interviewees taking time to formulate thoughtful responses or recall specific project examples. As a result, many sentences contained interruptions or repeated words (e.g., "um," "you know," or partially formed phrases), which is common in natural speech but obscures meaning in written form. To ensure data quality and readability, each audio recording was reviewed in full and the transcripts were manually corrected. This included fixing misrecognized words, restructuring interrupted phrasing and removing irrelevant filler expressions. In doing so, the transcripts remained true to the original content while being clear and suitable for analysis.

3.4 Data analysis

The analysis stage involved several read-throughs to identify repetition, exceptions and notable quotes that might signal deeper problems or opportunities. This step was essential to "immerse in the data" and to begin identifying preliminary ideas, repeating terms and explicit or implicit concerns raised by participants. Important information that was discussed in the interviews includes:

- Role and responsibilities in the project
- Experience with software such as Ansys, Tekla, Inventor, Bentley SACS and SCIA Engineer
- Data exchange methods (file types, workflows, tool combinations)
- Coordination and quality control mechanisms
- Recurring themes and terminology (e.g., "STEP files," "check print," "face IDs")
- Specific bottlenecks encountered (e.g., delayed updates, data loss, role confusion)
- Common tools and workflows used in practice

3.5 Thematic Coding

In line with the framework laid out in Hennink et al. (2011), an inductive coding process was chosen. This means that codes were developed from the data itself rather than being imposed by the researcher. The transcripts were manually coded using a thematic analysis approach. This process started with identifying important points in each interview, such as quotes or passages that highlighted specific challenges, behaviors or perspectives related to data transfer. Moving on, these findings were compared across interviews to identify areas of overlap. When similar issues were raised by multiple interviewees they were grouped into broader codes. These codes were helpful in sorting the data into clusters of issues that were repeatedly mentioned across interviews. Furthermore, close attention was paid to direct

quotes that referred to frustrations or limitations and contradictions in workflows between departments.

In the first phase, each transcript was reviewed line-by-line to generate initial codes reflecting explicit practices, bottlenecks or opinions shared by the interviewees. These codes captured diverse elements such as tooling decisions, communication methods, data conversion issues and documentation strategies. Examples of codes that were identified include: “Employees choose tools based on personal experience”, “No live links between Ansys and Tekla”, “Data loss when converting data files”, “Visual overlays used to compare models”, “PDFs used to communicate changes” and “Too many project types and clients to standardize”. These codes were generated inductively, based directly on the language used in the transcripts and without applying any preconceived thematic framework.

After establishing a robust set of codes, they were grouped into broader categories so that patterns across interviews could be identified easier. The relationships between different codes were examined to develop themes. The themes were then grouped into larger categories based on their similarities (Rosala, 2022). This process included both frequency analysis and an assessment of the context of the underlying issues. For instance, codes such as: “Tool usage depends on license availability” and “Different people do the same task in different ways” were grouped under the category Person-dependent decisions, which contributed to the broader theme of Fragmented and person-dependent workflows.

The final stage involved grouping categories into overarching themes that directly addressed the research sub-questions. These themes reflect systemic issues rather than isolated problems. This is aligned with the recommendation of Hennink et al. (2011) to prioritize themes that carry explanatory power and relevance to the research question. The themes were refined through a repeated review process. Specifically, each theme was carefully evaluated again to confirm it accurately represented the qualitative data. This process included combining overlapping categories and codes to better distinguish the themes from one another. Ultimately, the guiding principle was to ensure that each theme was clearly defined and aligned with the research questions. Furthermore, as a crucial final step in the analysis, each theme was reviewed and refined by cross-referencing it with the interview data to ensure it accurately captured the participants' experiences. This step was important for preserving the accuracy and integrity of the analysis. Finally, the themes were adjusted to enhance clarity and focus, especially regarding topics such as the need for standardized workflows and the lack of automated integration between tools.

These themes represent recurring systemic bottlenecks in the current workflows at Iv and its divisions:

1. Fragmented and person-dependent workflows

This theme captures how current workflows are inconsistent and highly dependent on individual preferences, experience and tool availability. This lack of standardization leads to fragmented processes and reinforces inefficient data handling across teams. This theme is related to sub-question 2.

2. Lack of automated integration between tools

Despite the use of advanced engineering software like Ansys, Inventor and Tekla, there is no true live or automated integration between these tools. Data exchange continues to rely

heavily on static files such as STEP or IFC, which often cause metadata loss or model misalignment. This theme illustrates the technical limitations and the absence of robust cross-platform data continuity, reinforcing the need for process mapping. This theme is related to the second sub-question.

3. Manual and redundant quality control

Due to software incompatibilities and disconnected data flows, teams rely on labor-intensive quality control measures like visual overlays, manual cross-checks and color-coded verification schemes. While effective in catching discrepancies, these methods are time-consuming and increase the risk of human error. This theme highlights a strong argument for automated consistency checks within a mapped process structure and it is connected to sub-question 2.

4. Project and software complexity

Many projects at Iv involve multiple tools (Ansys, Tekla, SCIA Engineer) each with its own data format and limitations. Interdisciplinary handoffs and changes related to transport or fabrication introduce even more complexity. An effective process map must be flexible enough to accommodate these layers of software and workflow complexity, while also offering clear specifications for data translation and versioning. This theme is related to sub-question 1.

5. Communication challenges and informal collaboration

Instead of using standardized platforms or documentation methods, teams often rely on informal tools like PowerPoint slides, check prints or verbal updates. This is efficient at a small scale but quickly breaks down across international teams and shifting time zones. Standardized communication flows must be embedded into the process map to reduce information loss and promote traceability and so this theme is related to the first sub-question.

6. Inflexibility of parametric models

While parametric modeling is powerful, it can be a double-edged sword. When projects move quickly or change direction, fully parameterized models become difficult to adapt. The process map must guide when and how parametric models are best used and where flexibility should be preserved to accommodate design iteration. This theme is related to sub-questions 1 and 4.

7. Project variety and lack of reusable standards

Due to the diversity in project types, client needs and contract formats, efforts to standardize processes across Iv have historically struggled. Previous attempts were not broadly adopted, often due to lack of scalability. This theme emphasizes that for process mapping to be adopted at a larger scale, it must offer reusable components that can adapt to different project types without requiring full standardization. This theme is related to sub-questions 2 and 4.

Figure 9: Coding process of the qualitative data

3.6 Reflexivity

Given the researcher's dual position as both an member of the organization and an investigator, particular attention was paid to maintaining reflexivity throughout the research process. This position offered easy access to participants and an familiarity with software tools and organizational workflows. However, it also introduced possible risks of bias, which were carefully handled by using strict methods. To minimize the influence of prior assumptions, the interview process was designed to give priority to participant-led narratives by letting them guide the flow of conversation. The researcher employed subtle redirection techniques, like returning to pre-established questions, only when it was necessary to refocus on relevant

topics without disrupting the participant's thought process. This approach follows common qualitative research practices that suggest mixing structure with flexibility to capture genuine opinions and perspectives.

Being close to the research setting helped interpret responses more accurately, especially when dealing with technical terms and unspoken organizational rules. Nonetheless, efforts were made to maintain analytic distance by applying the inductive, data-driven methods described by Hennink et al. (2011). Coding and theme development were grounded in the data itself rather than pre-existing assumptions, ensuring that findings were reflective of participants' lived experiences rather than the researcher's prior knowledge. This combination of familiarity with the context and careful consideration of the research method and inductive analysis contributed to the development of meaningful insights.

3.7 Trustworthiness

To ensure trustworthiness and thorough analysis, multiple validation strategies were applied as suggested by Hennink et al. (2011). To ensure that findings were not based on isolated opinions, it is important to triangulate the responses. The responses from different roles (e.g., engineers vs. managers) and projects (e.g. Offshore, Naval) were compared to identify patterns consistent across contexts. For example, both engineers and project managers highlighted problems with file conversions and delayed updates. When a problem is echoed by different roles, it is considered a validated issue worth highlighting in the findings. Additionally, the original language used by participants was preserved where possible to capture the intended meaning and verbatim quotes are included. Finally, codes and themes were documented and iteratively refined to make sure they were transparent and could be reproduced. These strategies made the findings more reliable and kept the analysis in line with the best practices in qualitative research.

3.8 Ethical Considerations

Because this study involved human participants, it went through a full ethical review based on established ethical standards. A fundamental aspect of an ethical interview approach is protecting the participants' rights. Before beginning the interview, participants were informed about the study's purpose and the structure of the interviews. They were also made aware of their right to give informed consent and their freedom to withdraw from the study at any time, with their anonymity guaranteed throughout the process (TU Delft, 2024a). Each participant signed a consent form, which was securely stored by the researcher. Additionally, both the Data Management Plan and the Human Research Ethics Checklist were submitted via LabServant, TU Delft's lab safety management system, to ensure compliance with institutional safety and ethical standards (TU Delft, 2024a).

4. Results from interviews

To investigate the current barriers to seamless data transfer between structural analysis software (such as Ansys, SCIA Engineer or SACS) and structural design software (such as Tekla Structures or Autodesk Inventor), a series of in-depth semi-structured interviews were conducted with engineers and designers at Iv-Consult and its associated divisions. Chapter 4 summarizes the insights gathered from these interviews and organizes them into key themes that highlight the challenges faced in current workflows.

Once themes were identified using the thematic analysis explained in Chapter 3, they were cross-referenced across interviews to assess which ones were systemic. Each theme corresponds to a bottleneck in the data transferring process. A bottleneck leads to delays, rework or data inconsistency and it was categorized as “critical” if it was mentioned independently by multiple participants or it impacted both structural analysis and design teams. From the coded data, seven recurring and impactful bottlenecks were identified. These bottlenecks were not chosen randomly but based on frequency of mention, severity of impact and cross-role relevance.

Once the bottlenecks were defined, interview sections were mapped directly to each theme. Illustrative quotes were selected that clearly demonstrate the problem in context. This served the purpose of grounding the findings in real-world experience as well as building a credible narrative which is supported by multiple perspectives. Particular attention was paid to remarks that indicated friction points, inconsistencies in practices or suggestions for improvement.

This qualitative, bottom-up approach allowed the extraction of key themes from complex, technical narratives and their presentation in a structured format. Through a combination of inductive coding, thematic clustering and trustworthiness checks, unstructured interview narratives were converted into well-founded insights. The findings provide a foundational understanding of the current pain points in Iv’s data transfer workflows. Finally, they directly inform the design of a future process map aimed at mitigating these inefficiencies.

4.1 Fragmented and person-dependent workflows

A common theme across all interviews is the high degree of workflow fragmentation. One of the potential reasons mentioned is that tool selection and data handling practices are often driven by individual experience or preference, instead of standardized organizational protocols. To be more specific, the lack of a standardized procedure for software selection was raised by several interviewees. PM1 said: “Some people like to do everything in Ansys… others use Rhino or Tekla. It just depends on the person, not the project.” This directly informed the bottleneck regarding person-dependent workflows. In another questioni, PM1 remarked: “You can do the model in Ansys and it could take 100 hours, but if you do it in Inventor it would take 20 hours. People don’t know they can start it there and spend a lot of time for nothing.” This statement clearly pointed to a knowledge gap and lack of standardized workflow, which emerged as a common thread across multiple interviews.

Therefore, it is often the case that engineers typically select software based on familiarity or license availability, which leads to significant variability across teams and projects. This person-dependent approach contributes to inconsistent data structures and greater reliance on manual communication between disciplines. This often causes inefficiencies that could otherwise be avoided through guided workflows or process mapping.

4.2 Lack of automated integration between tools

Despite the growing interoperability features of engineering software, a live or automated data link between structural analysis and structural design platforms is virtually nonexistent in current practice. Most teams rely on manual data exchange via STEP or IFC files, which are prone to issues because of their incompatibility with the receiving software. The main issues are:

- Loss of element metadata (e.g., plate thickness, beam cross-sections)
- Model misalignment (e.g., centerline vs. solid geometry)
- Time delays in updates, especially when multiple teams or time zones are involved
- No beam transfer capability between Inventor and Ansys, which limits parametric workflows.

As SE2 mentioned, “in an ideal world we could couple everything to each other, but now it only works between Ansys and Inventor, not between Ansys and Tekla”. He continued by saying that “there is an active interface program by Ansys itself but it’s still not good enough because it cannot take all the information into account, like the beams”. This lack of integration slows down iterations and introduces risks of inconsistency between models.

In another case, SE1 described the problem with incompatible element types: “If you export from Ansys, you only get one reference line the centerline. Whereas in Tekla you need the full 3D model of the element, so someone has to model it again, because that’s not automatic from the IFC file”. Furthermore, both PM1 and SE2 emphasized that STEP file exchange can lead to misinterpretations and rework. SE1 also commented that “data exchange via STEP files is actually pretty dangerous because then there is a chance that you lose information or you just miss a change and that’s when stuff gets misaligned”.

4.3 Manual and redundant quality control

Data transfer between software platforms is often manual and so quality control processes are necessary. Engineers and designers regularly perform overlay checks, visual comparisons and use color coding (e.g., assigning colors to plate thicknesses) to validate model consistency. SE2 commented that “the checking process is best done just in 3D models, one on the one screen and one on the other and you just tick them all off”. However, SE2 also noted that “although it’s a manual process, it's still doable, but basically you have to do it every time you issue a report or calculation, you have to redo it because stuff might have been changed and that's a risk”. In addition, SD1 and SD2 emphasized the repetitive nature of manual comparison between models, often relying on color-coded visual checks. These measures are effective for identifying inconsistencies, but they are labor-intensive and heavily reliant on individual diligence. On the other hand, SD1 and SD2 agree that when comparing two versions of the same model for them “the check print is easier… because we see directly the change, while with the STEP file we need to compare what’s in our model and what’s in the file”.

4.4 Project and software complexity

Most engineering projects at Iv involve multiple software platforms and disciplinary handoffs. For example, it is common for a structural analysis to be conducted in Ansys or SACS, while modeling and documentation are completed in Tekla. The use of various file types (STEP, IFC, XML, PDF, Excel) adds another layer of complexity to data transfer. For instance, SD1 said

that “while Tekla works best with IFC files, most of the engineering programs have problems with IFC files. So because Tekla can work with STEP files as well, they receive a STEP file from Ansys whenever needed”. In large-scale projects such as this offshore platform, engineers must also account for fabrication constraints, transportation loads and multiple design revisions. Without centralized control or an integrated model environment, changes introduced at later stages often require rework across disciplines.

4.5 Communication challenges and informal collaboration

Due to the lack of a centralized, real-time data environment, teams often depend on informal communication methods (e.g., check prints, PowerPoint slides, calls and emails) to convey changes. SE2 noted that the colleagues in a specific office location “are very close to each other and they just do their thing, they ask their colleagues if they can make a model for them and then somebody makes a model”. While effective in isolated instances or smaller offices, these informal practices scale poorly, especially in large, international teams working in shifts across time zones.

Almost all interviewees highlighted the successful use of shared legends, material naming conventions and color coding. SD1 remarked that in order to reach an agreement on the shared legends “we are sitting together for hours and hours to explain what we want to see on drawings, we have a sort of thinking pattern”. It was also mentioned by SD2 that “before there was even one drawing, we had made a plan and that’s hours and hours and hours, because we want to indicate it correctly on drawings”. Currently this is something that is discussed in the beginning of each project in collaboration between the structural engineers and the structural designers. However, the absence of a formal organization-wide data protocol can lead to misunderstandings and duplicated effort.

4.6 Inflexibility of parametric models across project phases

Several experts expressed caution about over-relying on fully parametric models. While parametric design offers benefits in terms of speed and consistency, it can also introduce rigidity that complicates iterative design. If early modeling decisions are locked into a parametric structure, later changes may require extensive remodeling. For this reason, some projects deliberately maintain a flexible separation between analysis and design models, even though this limits automatic synchronization. In practice, a one-way data transfer from analysis to design is common, with selective updates being revalidated manually.

4.7 Project variety and lack of reusable standards

The wide variety of project types, client requirements and contract structures makes it challenging to create a widespread solution. As a result, process automation and standardization efforts (such as the "Information Box" system developed internally in 2015 which was mentioned by CM1) have struggled to gain long-term adoption. These systems require significant up-front investment in macros, scripting and version control. Many teams are unable to justify these costs due to tight schedules and varying deliverables. Nonetheless, interviewees consistently expressed the desire for standardized, reusable process frameworks, particularly for recurring project types where automation can be cost-effective.

Table 4: Summary of key challenges identified

Category	Challenge
Workflow	Person-dependent setup, lack of process maps or decision guidelines
Software Integration	No live link between Ansys, Tekla, Inventor; limited beam/surface transfer
Quality Control	Manual overlays and checks, missing general identifiers
Data Formats & Transfers	Incompatible STEP/IFC/PDF exchanges
Communication	Informal methods dominate (emails, calls, check prints)
Parametric Model Use	Rigid systems hinder flexibility in iterative or conceptual design phases
Standardization	Hard to maintain due to project diversity and client-driven constraints

4.8 Justification for a process map

A consistent theme throughout the interviews was the need for better structure and guidance. Multiple interviewees emphasized the absence of flowcharts and decision rules. PM1 noted that “we started process maps a few years ago but didn’t develop them… people just ask their colleagues what to do”. Consequently, the interviews revealed a range of technical, procedural and organizational challenges that prevent seamless data transfer between structural analysis and structural design software. These challenges are deeply interconnected and often made worse by project scale, interdisciplinary collaboration and the absence of standardized processes. While there are workarounds in place, such as color coding or file exchange protocols, these are typically manual and inconsistent. The findings clearly support the need for a structured process map and decision-making framework to improve data flow efficiency and reduce coordination overhead in engineering projects.

In Figure 10, the Work Breakdown Structure (WBS) synthesizes the current procedures followed during data transfer between structural analysis and structural design teams at IV. It reflects empirical findings from interviews conducted with engineers, designers and project managers across multiple departments. The WBS maps each phase of the offshore topside design process, highlighting both the flow of information and the tools typically used. This breakdown serves as the baseline for identifying inefficiencies and developing a proposed optimized process map.

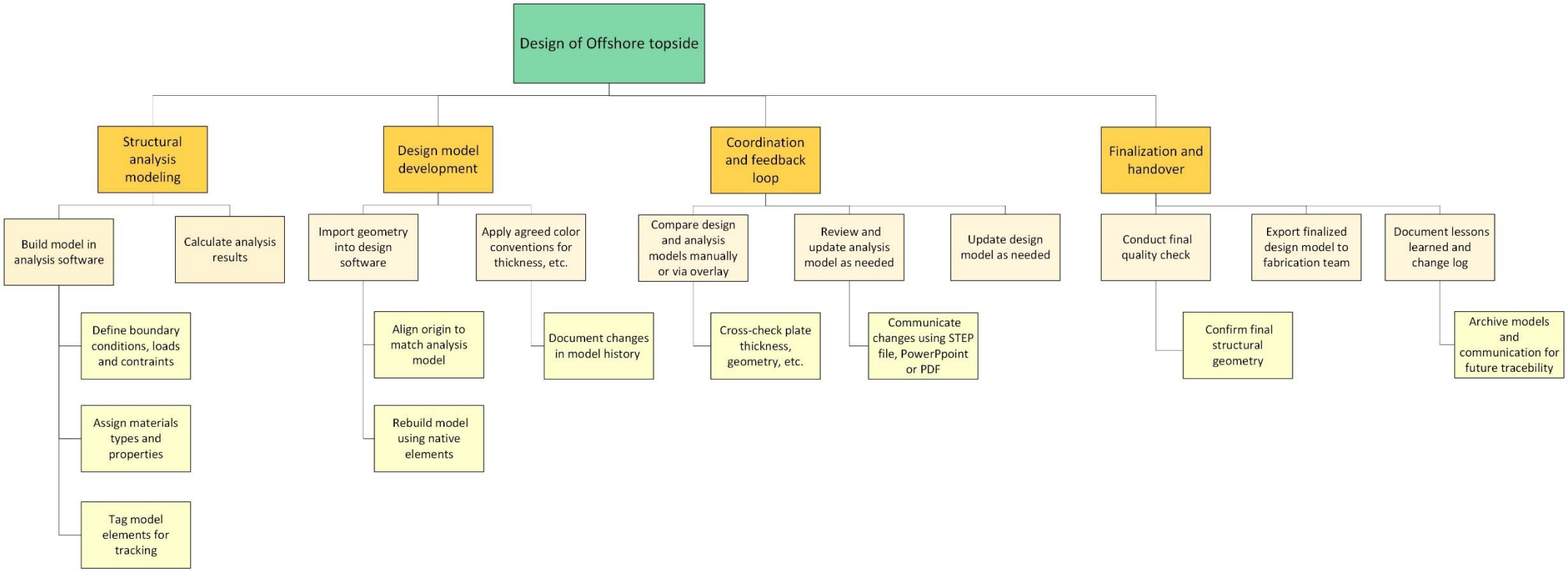


Figure 10: WBS of current procedure

5. Development of the process map

5.1 Characteristics of proposed process map

Based on the bottlenecks identified through qualitative interviews, the development of a structured process map is essential to address the recurring challenges faced during the exchange of data between structural analysis (such as Ansys, SCIA Engineer and Bentley SACS) and structural design software (such as Tekla or Inventor). The following sections present the essential components that this process map should include, each strategically aimed at resolving a key bottleneck in the current workflow.

5.1.1 Standardized software selection and workflow initialization

One of the most frequently cited issues across the interviews was the fragmented and person-dependent nature of current workflows. Structural engineers and designers often choose software based on their individual familiarity or the availability of licenses, resulting in inconsistent and inefficient processes. To mitigate this, the process map should introduce a standardized framework for software selection. This could include a decision tree that guides users in selecting tools based on the project characteristics and its structural needs, such as whether the structure primarily involves beams or stress skin plates. Additionally, roles and responsibilities should be defined clearly, indicating who is responsible for initiating the modeling process and ensuring that all necessary licenses are available. It is understandable that available skilled personnel depends on scheduling conflicts with other projects. However, the effort should be made to ensure the person with the most appropriate skills is assigned each role. Moreover, a reference matrix can help match software capabilities to specific project needs, such as recommending Tekla for fabrication geometry, Inventor for parametric design and Ansys for detailed stress analysis. In general, the modeling should begin in a design-oriented platform like Inventor, which is quicker to use in early stages, before transitioning to analysis software for detailed simulations.

5.1.2 Clear data handoff protocols between software

The lack of automated integration between tools is another important bottleneck. Data transfers typically occur through STEP, IFC or XML files, which often result in the loss of metadata, misalignment of model geometries and delays due to time zone differences. The process map should therefore include a detailed protocol for data exchange between software platforms. For example, most engineering programs work best with STEP files, while Tekla specifically works best with IFC files. This should specify how to export and import models correctly, ensure that model origins are aligned to prevent misplacements and include standardized legends for thickness, material types and other key attributes. A compatibility checklist should also be introduced to help engineers anticipate known limitations, such as the inability to transfer beam elements from Inventor to Ansys or mismatches arising from centerline versus solid geometry representations.

5.1.3 Semi-automated quality control process

Manual and repetitive quality control checks remain a labor-intensive part of the current workflow. Structural designers often perform visual overlays or use color-coded legends to ensure model consistency, but these methods are time-consuming and heavily reliant on personal diligence. To reduce the burden of these checks, the process map should include semi-automated quality control steps. These would include clear instructions for conducting

overlay comparisons between models in Ansys and Tekla, as well as standardized color schemes for key parameters like thickness and material type. Most of the interviewees mentioned how helpful they find it now, so scaling it up and standardizing it would be an important first step. A model comparison log should be maintained to document all stages of verification. In addition, structured checklists should be provided to assist teams in reviewing geometry, material definitions and element attributes either through visual overlays or through automated identification matching.

To make the quality control process less intensive, the proposed checks should run within an openBIM workflow. Practically, each handover (analysis to design and back) should generate an IFC file that becomes the neutral target for verification of results. Running checks on IFC avoids vendor lock-in and stabilizes what is being compared. The minimum information that must be present at each exchange is then expressed in a machine-readable Information Delivery Specification (IDS). For example, the IfcPlate and IfcBeam need material, thickness, grade and identifier. IDS validation becomes the first quality control step that automatically notes missing or faulty properties before any manual overlay occurs.

5.1.4 Multi-software coordination framework

Given that most projects at Iv-Consult involve multiple software tools and frequent disciplinary handoffs, the process map should include a clear coordination framework. This framework should define which software is responsible for different phases of the project and indicate which teams own and manage specific data during those phases. Standardized naming conventions and version tagging should be established for all files to reduce confusion. This is currently happening, but the process map should also include it as a step in the new workflow.

5.1.5 Formal communication and change tracking methods

The smaller size of some offices and the familiarity between colleagues has led to a reliance on informal channels such as emails, check prints and phone calls to manage updates. While practical in small teams, these methods are inefficient and prone to error in larger, distributed teams and for bigger projects. The process map should incorporate formalized procedures for managing communication and tracking design changes. The designers have certain preferences for how changes are communicated and these should be included in the process map. For example, they prefer it when the structural engineers send them the required changes in a check print rather than a STEP file. This way they can just review what is changed from a text, instead of visually comparing the two versions of STEP files for changes. Furthermore, a clear version control protocol should be defined, along with the already existing daily export of IFC files to ensure consistent understanding across all project teams, particularly those spread across multiple time zones.

Detected clashes, whether caught by the IDS or by the subsequent visual overlay/legend check should be recorded as BCF issues linked to the affected IFC element, with saved views and attachments (screenshots of overlays and color-by-rule legends). In this way, the “model comparison log” becomes a structured, model-referenced trail that carries location, assignee, date of change and status, preserving traceability across iterations. Because IDS results are structured, recurring failures (mismatched thickness on plates) can be tracked using BCF, turning communication into a feedback loop that improves upstream modeling behavior.

5.1.6 Guidelines for parametric model flexibility

Several interviewees highlighted the limitations of parametric modeling when applied rigidly across all project stages. While parametric design enables consistency and automation, it can hinder flexibility during iterative design phases. To address this, the process map should include stage-specific guidelines on when to use parametric models and when to switch to non-parametric approaches. Clear instructions should be provided on which elements should be editable components during early design stages to avoid the need for extensive remodeling later.

5.1.7 Reusable process components and templates

The wide variety of project types and client demands makes it difficult to implement a universal approach. However, for recurring project types, reusable components can significantly improve efficiency. For the scope of this research, the process map will include flow templates tailored to a typical project of an offshore platform. These templates could later be customized for other projects if needed. Where terminology varies between teams and tools (e.g., material grades), the IDS should reference the buildingSMART Data Dictionary (bsDD) so that properties and values are bound to shared definitions and units, reducing “local dialects” and improving cross-platform interpretability. It should also provide access to a repository of shared scripts, macros and conversion tools. Guidance should be offered on when full automation is feasible, based on factors such as the phase of the project, its size and complexity. Finally, it should be a modular structure so that it will allow teams to adapt the process map to their specific needs without discarding the whole framework.

5.1.8 Centralized data platform integration

While not essential for initial implementation, the introduction of a centralized data platform (or Common Data Environment, CDE) could significantly enhance collaboration and transparency. Tools like Trimble Connect, Navisworks or Autodesk BIM 360 can facilitate real-time model sharing and coordination. If adopted, the process map should guide the setup of a CDE, including folder hierarchies (e.g., “01-WIP,” “02-Shared,” “03-Published”), access controls based on roles and routine update schedules. Allen et al. (2021) advise that the best practice is to set up a Template Project, so that it is easy to create additional project CDEs. A template project is simply a BIM 360 Docs project with folders and Role-based permissions. When you create a new project in BIM 360 Account Admin, you can choose your Template Project and “Copy Project Settings.” An information manager, who is independent from the design team, should oversee the integrity and security of the environment, ensuring that protocols are followed and that data remains consistent throughout the project lifecycle. It is important to note that they are not a BIM coordinator and have no design responsibility and no responsibility for clash detection or model coordination (Cohesive BIM Wiki,2024).

The process map outlined above aims to systematically address the current bottlenecks in data transfer workflows at Iv-Consult. By introducing structured protocols and clear communication methods, this approach not only mitigates inefficiencies but also lays the groundwork for scalable, future-proof collaboration across teams and disciplines. Its proposed modular structure will ensure that it can be tailored to a variety of project types, enabling Iv to move toward a more integrated digital design environment.

5.2 Design of BPMN process map

Using the information from the interviews as well as the already developed WBS as inputs, a process map was drafted. In Appendix B: Process map of current situation the first draft of the developed process map is presented. It illustrates the current processes within Iv and it is used as a reference to develop the final process map that represents the optimal process in Figure 11. As it was explained Chapter 2.12 Characteristics of BPMN, the BPMN process modeling method was chosen as the most appropriate to represent the data transferring process within Iv. The purpose of this map will be to facilitate the transferring process by visualizing it and serving as a guideline for the employees involved in the process.

There are several tools available for designing BPMN process models. They can range from ease-to-use web-based editors to advanced enterprise solutions. The website bpmn.io offers quick modeling solutions. However, it was too rigid for the purposes of this model and didn't allow enough flexibility with the elements, especially with message flow symbols. Camunda Modeler is widely used, but it required downloading and only the demo version was free. General-purpose diagramming tools such as Lucidchart also provide BPMN templates. However, the basic version does not include the needed icons for a clear representation of the chosen process. Similarly, Microsoft Visio includes BPMN templates in the upgraded version it, but the cost is too high. However, the version provided by TU Delft has enough flexibility and can import the required icons to serve the purposes of this thesis. Consequently, Microsoft Visio was chosen as the best tool for the design of the process map.

The first step in the development of the map was the division of responsibilities to each actor for the activities of the design process. There are 8 rows in the map, which are called swim lanes or pools (zur Muehlen et al., 2010). The activities within individual swim lanes are performed by one actor. Five of them represent a role performed by employees in the process (Project leader, Information manager, Structural designer, Structural engineer and Quality manager). The remaining three are called "Exchange" and represent the point in the process when information is sent from one pool to another. The design process should begin with the determination of common conventions for the naming and coloring of elements as well as the creation of a central database for reusable elements. This is then shared with the structural designers and the engineers. This way, even before the first sketch, everyone should be aware of the way the elements should be drawn and inconsistencies can be prevented. The database for reusable elements can also save designing time further on in the process.

Moving on, keeping in line with the established conventions, the structural designer draws the preliminary design and sends it to the structural engineer. He then begins the structural analysis by defining boundary conditions, loads and constraints. He assigns the necessary material types and thickness to each element and tags them accordingly to help with tracking later on. Finally, he calculates the loads based on this design. If the results from the analysis are acceptable he shares the model with the designer. Otherwise, the process is repeated until the results are satisfactory.

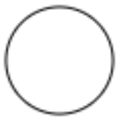
The designer uses the analysis model to create the new design. He needs to align his model with the origin of the analysis model and rebuild it using elements from the design software. He should also keep in mind and apply the agreed color and material conventions. In the end of this process, he should do a quality check and send the design to the engineer. If the quality is acceptable, the engineer should review and update his model if needed. If the design is not

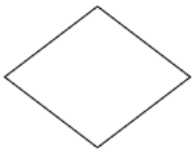
acceptable, then the engineer must redo the analysis and restart the loop. When the feedback loop is finished, the quality manager does another quality check to completely confirm the final geometry. The final design model is then sent to the fabrication team to begin fabrication and construction. In the end, a final quality check is done to completely erase the possibility of inconsistencies or mistakes and the information manager documents the lessons learned. He also archives the models as well as the communication log for future reference.

In Appendix C: Process map of optimal process with markings for changes, the final map is presented with markings highlighting the proposed changes and the currently missing links in the company's standard procedures. The most important update is the use of the proposed guideline for file exchange, so that employees are familiar with the most compatible file type for each specific data handover. Currently, the exchange of data is done using STEP or IFC files depending on the software used, but there are more formats available. The diagram in Figure 12 will provide their overview to the users of the map. Another addition is that quality checks should be done using IDS and BCF (buildingSMART's standards). At this stage, quality control is done via informal communication (calls or emails), PDFs and check prints. The new method will ensure consistency and reliability of the exchanged data. Similarly, bsDD should be a part of the shared database that already exists to make object definitions and properties more reusable across projects. Finally, an extra activity (Define FE model extend and prepare FE model) was added after feedback from an employee to help make the steps of the structural analysis more explicit for future users. The two versions of the map can be easily compared in Appendix B: Process map of current situation and Appendix C: Process map of optimal process with markings for changes.

To help with the understanding of the process map, in Table 5 the legend is presented which explains the meaning behind each symbol.

Table 5: Legend for process map symbols

Symbol	Meaning
	Start event: It indicates the initiation of a process or an event sub-process and have no incoming sequence flow (von Rosing et al., 2015).
	End event: It indicates where a path in the process will end. A process can have more than one end. The process ends when all active paths have ended. End events have no outgoing sequence flows (von Rosing et al., 2015).
	Message: Receive information to start a process or in the middle of a process, either in the flow or attached to the boundary of an activity (von Rosing et al., 2015).

	Data: A data object represents the data that are used as inputs and outputs to the activities of a process. Data objects can represent singular objects or collections of objects (von Rosing et al., 2015). It includes a clip to indicate the connection with the guideline for exchanging models via a hyperlink.
	Data store: A Data Store is a place where the process can read or write data (e.g., a database or a filing cabinet). It persists beyond the lifetime of the process instance (von Rosing et al., 2015).
.	Activity: It indicates a regular type of task.
	Gateway: It is used to control how process paths converge and diverge within a process (von Rosing et al., 2015).
	Sequence flow: It is represented by a solid line with a solid arrow-head and is used to show the order (the sequence) in which activities will be performed in a process (von Rosing et al., 2015).
	Message flow: It is represented by a dashed line with a solid arrow-head and is used to show the flow of messages between two separate process participants (business roles) that send and receive them (von Rosing et al., 2015).
	Data Association: It is represented by a dotted line and is used to associate data (electronic or nonelectronic) with flow objects. Data associations are used to show the inputs and outputs of activities (von Rosing et al., 2015).

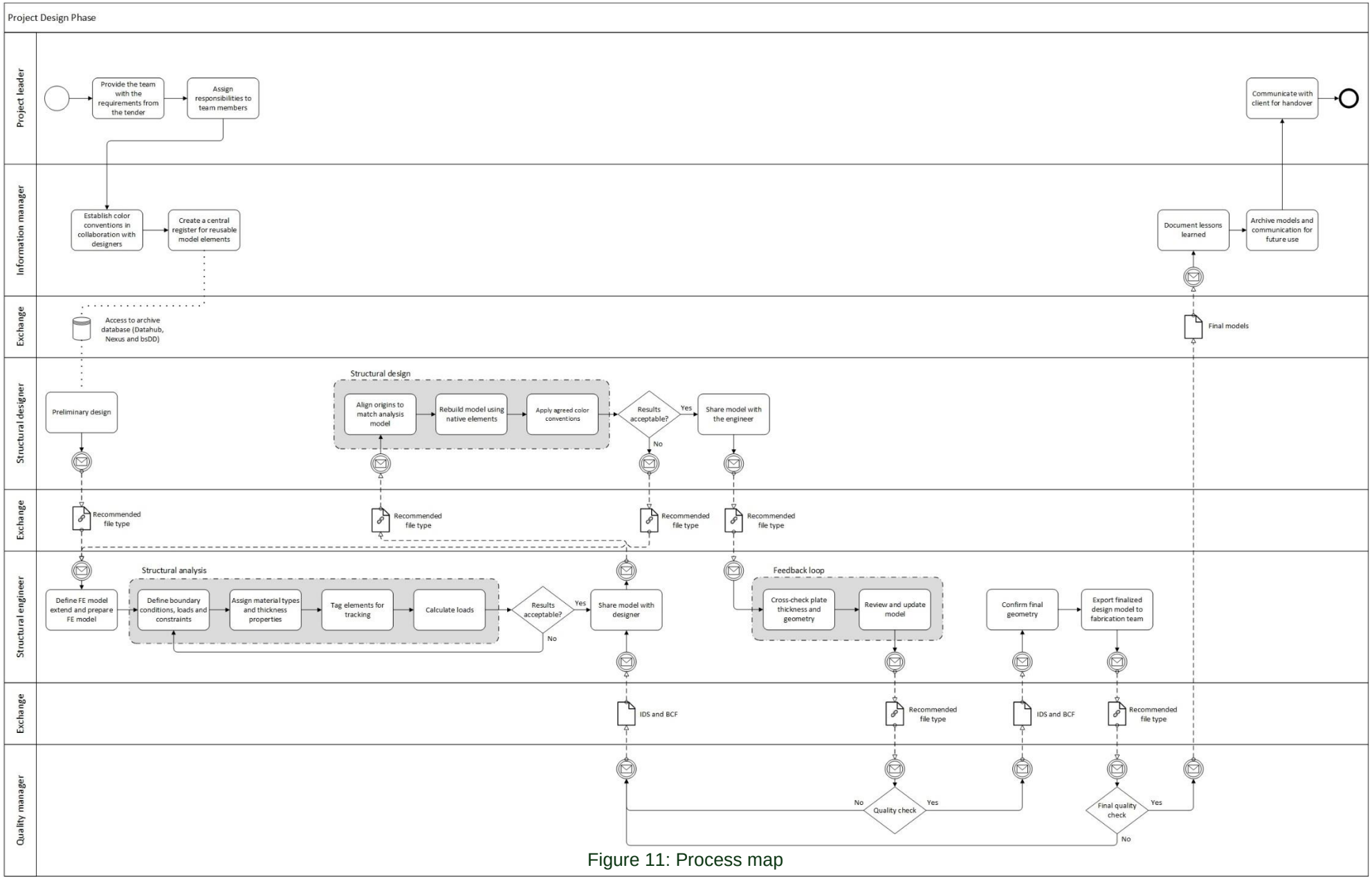


Figure 11: Process map

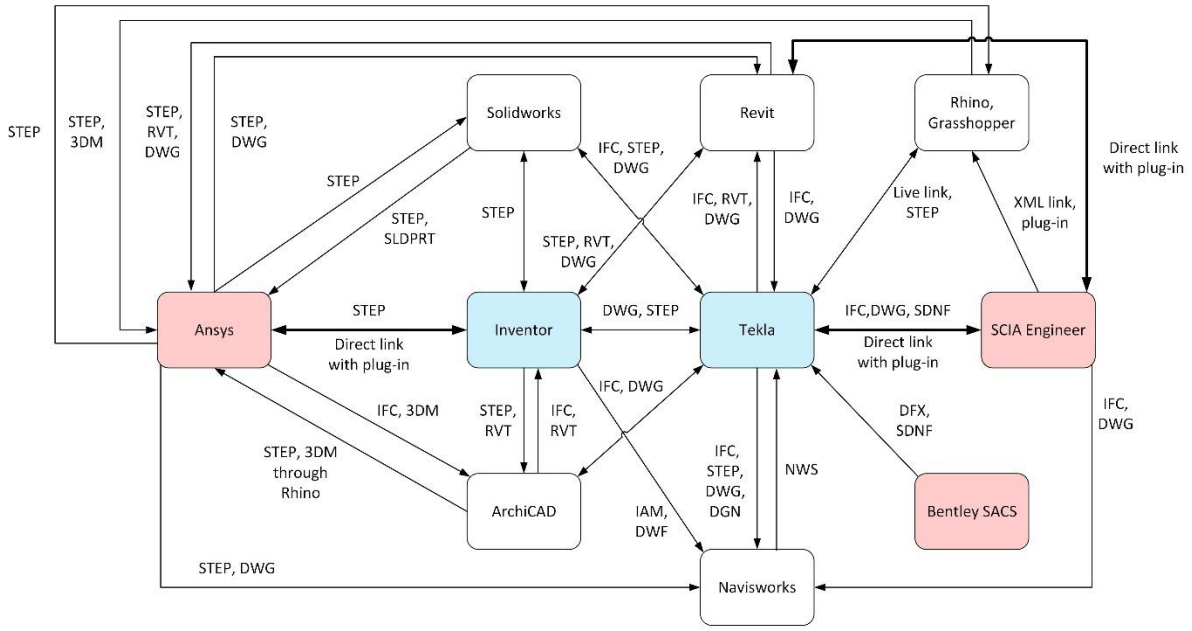


Figure 12: Explanation for file exchange

In Figure 12, the compatible file types for the exchange between software are presented. This should be used additionally with the process map, to guide users in the step of “Exchange”. The structural analysis software are the ones in the red rectangles, while the blues one are the structural design software. The white rectangles represent software which are used within Iv, but are considered outside the scope of this thesis. The bold arrows represent direct bi-directional links between software, like between Tekla and SCIA Engineer. This means that SCIA Engineer can exchange data with Tekla and Revit in both directions (SCIA, n.d.). Changes made in SCIA Engineer can be reflected in Tekla and vice versa. This ensures that structural and architectural models remain synchronized throughout the design process. Of course, there is also the option of data transfer with a file export. The benefit of the file export is that one user can send his model to his colleague who may be more experienced in using the other application (SCIA, n.d.). A general feature and advantage of the link is that it can transfer either the whole model or just a selected part. Therefore, it’s possible to have more analytical models for one structure, e.g. a steel part, a concrete part etc.. At the end of the transfer, the whole transfer report can be displayed and saved.

As it was previously mentioned, IFC is a widely adopted open format for exchanging BIM data. It enables seamless collaboration between platforms such as Tekla and SCIA Engineer. STEP (.stp) files are used to transfer detailed 3D CAD models, especially between Inventor or Tekla and analysis tools like Ansys, preserving geometry and product structure. Tekla older than 2025 cannot export step files, only import them (Trimble, 2025). Even in Tekla 2025, imported STEP files are reference models only, not parametric Tekla objects. Tekla handles IFC files better. So STEP import is most useful for geometry exchange with mechanical CAD (SolidWorks, Inventor, etc.) where IFC may not be supported. DWG is the native format of AutoCAD and is commonly used for 2D and 3D drawings. It can be imported into SCIA Engineer, Tekla or Inventor for structural modeling. It is important to note that Bentley SACS can use DXF file which is an AutoCAD format to import files into Tekla, but not the other way around. A DXF file is simpler that DWG and so easier to read by different software tools. However, DWG contains richer information and can support 3D geometry. SDNF (Steel Detailing Neutral File) allows the exchange of element geometry and connectivity between

Tekla and Bentley SACS or SCIA Engineer. RVT is the Revit project file format and it contains comprehensive BIM data that can be imported from Tekla to Revit. A 3DM file is a Rhino 3D Model file, used primarily by Rhinoceros (Rhino), which a powerful 3D modeling used within Iv to optimize the design parameters through iterations. Many CAD programs like SolidWorks, ArchiCAD and Ansys can import or export 3DM files. A IAM file stores a 3D assembly made up of multiple IPT files (Inventor Part files). It defines how parts are positioned, constrained and interact with each other.

5.3 Evaluation of process map using the proposed specifications

In order to assess the quality and effectiveness of the developed process map, the specifications proposed in Chapter 2.10 Specifications for effective process maps will be applied as a first step. These specifications, which combine the principles of Moody (2009), the Seven Process Modeling Guidelines (Mendling et al., 2010) and the Guidelines of Modeling (Becker et al., 2000), provide a theoretical framework for determining whether a process map manages to clearly communicate process workflows. The following sections evaluate the process map against each specification, discussing both compliance and areas where improvements were made.

- Clear and consistent symbols

They are necessary to ensure that each element represents one specific concept, avoiding confusion. This principle comes from semiotic clarity and perceptual discriminability (Moody, 2009), where the goal is to make sure that users can easily distinguish between different types of activities and exchanges. The process map complies with this specification because it uses standard flowchart symbols. Circles are used for start and end events, rounded rectangles for activities, diamonds for decision points and swim lanes for roles. The symbols are applied consistently throughout, allowing readers to follow the logic without difficulties.

- Intuitive design

This means that symbols and labels should be self-explanatory and naturally communicate their meaning. This relates to semantic transparency (Moody, 2009), where symbols should “look like” what they represent and systematic design (Becker et al., 2000), where the map is structured logically. The process map is intuitive because the sequence flows in a clear left-to-right manner and the process order is shown naturally by the arrows. The activities are also labeled in common technical terms, using verb-object activity labels (Mendling et al., 2010). The overall design helps users understand the meaning of steps without needing additional explanation.

- Manageable complexity

A successful process map must present information without overwhelming the user. This is achieved through complexity management and graphic economy (Moody, 2009), which means using as few elements as possible and decomposing large models (Mendling et al., 2010). Another way to manage complexity is syntactical correctness (Becker et al., 2000), meaning that the process map follows the formal rules of the chosen notation. In BPMN, for instance, this includes using one start and one end event, proper connectors and standard gateway symbols. The process map fulfils these requirements because it adheres to widely recognized process flow conventions, with a clear start point, end point and logical flow of activities. It also maintains focus on the essential activities and avoids unnecessary branching. When needed

it uses swim lanes to separate responsibilities, which makes the process easier to navigate. This way the map remains readable without overloading the viewer.

- Explicit relationships of activities

These show how different tasks depend on and connect with each other and ensures cognitive integration (Moody, 2009) and semantic correctness (Becker et al., 2000). This specification emphasizes that activities should not appear isolated but instead show their upstream and downstream dependencies. The process map performs well because for example the flow clearly illustrates how structural designers and engineers interact, with data exchanges shown at various points. Feedback loops and decision points further support the dependency and show to the viewer how each activity leads to the next.

- Visual optimization

It relies on using multiple visual variables such as color, shape and size to improve comprehension and make important elements stand out. According to visual effectiveness and graphic economy (Moody, 2009), process maps should use at least three visual distinctions to enhance understanding. The process map partially complies with this requirement. While shapes and swim lanes are used effectively, all the activities are the same color. Only a darker grey is used to separate the structural analysis and design processes from the rest. Because of the company setting, no more colors were added to keep it professional. Relevance of content (Becker et al., 2000) is another aspect of the optimization of the visuals. It dictates that the process map should contain all necessary information but avoid unnecessary detail. The map respects this because it focuses on the essential interactions between the information manager, structural designer and structural engineer, while excluding the steps that follow the fabrication of the design as they are considered out of its scope.

- Support graphics with text

This means that labels should complement symbols, following the principle of dual coding (Moody, 2009). Text makes symbols easier to understand, especially for users unfamiliar with the notation. The process map respects this requirement because each activity has a correct label which describes its function. The are following the guideline of Mendling et al. (2010) which says to use verb-object tags. For example, the correct name which is used is “Define boundary conditions, loads and constraints”, instead of “Boundary conditions, loads and constraints definition” which is confusing. Overall, the combination of graphics and labels is helpful for the user.

- User orientation

It refers to cognitive fit (Moody, 2009), which means that the design of the process map matches the intended audience. For example, managers may need a high-level overview, while engineers benefit from detailed workflows. The map follows this specification because it is made for a technical audience. Terms like IFC, STEP and boundary conditions are specific to engineering workflows. The sequence represents detailed modeling and validation processes familiar to professionals in this field. While this makes the map less accessible for non-technical stakeholders, it aligns well with its likely users. The guideline of comparability or related content (Becker et al., 2000) makes sure that process maps can be cross-checked against other models by maintaining consistent notation, structure and level of detail. This map

is a standalone artifact, but it does use standard flowchart conventions, which makes it easy to align with other maps in the future.

- Error prevention

This involves structuring the map in a way that reduces misunderstandings and follows guidelines such avoiding OR connectors (Mendling et al., 2010) and economical design (Becker et al., 2000). It also includes clearly outlining what happens when a process fails or results are not acceptable. The process map follows this guideline by including decision points for quality checks and showing where the “no” paths lead and so what happens in case of a mistake.

5.4 Summary

PART II: Qualitative methodology & Design translates practice into evidence. Through semi-structured interviews with multiple roles at Iv (engineers, designers, project/quality, information and commercial managers), the study captured how data actually moves between analysis and design software and where the exchange usually breaks down. An inductive, thematic analysis was conducted, which was supported by transcript cleanup, iterative coding and triangulation across roles. Of course the appropriate ethical considerations were taken into account. From this a coherent picture of the workflow as experienced from daily workers emerged.

In the end, the analysis resulted in seven codes, which represent behavior patterns in the process. Workflows are fragmented and person-dependent and tool choices and handovers are shaped more by individual familiarity with software and license availability rather than by shared procedure. Also, automated integration is limited. Teams mostly depend on STEP or IFC file exchanges that often result in the loss of metadata if the receiving software is not compatible with them. They often misalign analytical and physical representations as well. Additionally, quality checks rely on labor-intensive overlays, check prints and color schemes. Most of them are effective methods but repetitive and error-prone. Handovers are further complicated by the use of multiple software and mixed model formats, while communication relies on informal channels that work within a single office but do not scale across locations or time zones. Finally, parametric models which are powerful in theory, can become rigid across phases and the diversity of project types and client demands undermines the reuse of elements.

Taken together, these patterns explain why interoperability problems remain despite mature file formats and capable tools. The issues are as much organizational and procedural as they are technical. PART II: Qualitative methodology & Design therefore converts the themes into actionable design requirements for the process map. It must standardize software selection and initialization and make data-handoff protocols explicit (format, direction, owner). A minimum quality control set with clear accountability should be included. Change tracking and versioning should be formalized and reusable templates for recurring project types should be created. The resulting BPMN-based map is not just a visualization but an operational specification that targets the observed bottlenecks. The specifications from PART I: Literature & Framework are used to theoretically evaluate it and prepare the ground for the quantitative evaluation that follows.

PART III: QUANTITATIVE METHODOLOGY & FINDINGS

PART III: Quantitative methodology & Findings tests, at scale, the practical value and adoptability of the BPMN-based process map developed in PART II: Qualitative methodology & Design. Using a mixed-methods design, it complements the earlier interviews with a quantitative survey to measure perceived benefits, fit with current workflows and readiness for organizational change. A four-point Likert scale (forced choice) was used to measure employee's attitudes, with items structured and ordered to minimize bias and support reliable descriptive analysis.

The survey gathered 16 responses (primarily Iv-Consult, with additional input from Iv-Offshore & Energy and Nevesbu). Before responding, participants viewed a short video explaining the process map to ensure basic understanding. Results indicate a consistently positive assessment of the map's core aims, because respondents most strongly agree that it can reduce design errors and improve data reliability and collaboration and save time. To interpret the readiness for adoption, the findings are connected with Kotter's eight-step change model. The data suggest a solid base for empowering change and short-term wins, but highlight there is still work to be done on communicating the developed map. So PART III: Quantitative methodology & Findings provides quantitative evidence that the process map is both useful and viable and it identifies the organizational practices required to realistically implement it.

6. QUALITATIVE RESEARCH METHODOLOGY

6.1 Mixed-methods Research

Building upon the discussion of qualitative research presented in Chapter 3, it is important to note that the chosen research methodology of this study is Mixed-methods Research (MMR). This method is a research methodology that collects, analyzes and interprets both qualitative and quantitative data methods to address complex research questions (Dawadi et al., 2021). By merging these two methods, mixed-methods research generalizes findings to the whole population and supports an in-depth understanding of the issue. As was explained in Chapter 3, the qualitative approach provides a deeper understanding of the issue being investigated, focusing on the participants' experience. It relies on methods based on "multiple meanings of individual experiences which are socially and historically constructed with the intent of developing a theory or pattern" (Swanson et al., 2005). Moreover, it is preferable in studies that seek to explore processes over time and examine context-specific dynamics (Creswell, 2012).

On the other hand, the quantitative approach collects data from a large number of participants. This way, generalizing results to a broader context is possible (Dawadi et al., 2021). According to Swanson et al. (2005), quantitative research is characterized by "cause and effect thinking, reduction to specific variables, hypotheses and questions as well as the use of measurement, observation and the test of theories". These techniques are useful for identifying relationships among variables (Swanson et al., 2005; Creswell, 2012). Although qualitative and quantitative methodologies have distinct characteristics, they complement each other (Hayashi et al., 2019; Johnson et al., 2007). Quantitative methods are better suited for explaining and testing phenomena, while qualitative approaches are essential for exploring and understanding them (Bekmezci et al., 2025). For this reason, this study adopts a mixed-methods research that relies on the strengths of both qualitative and quantitative methods.

6.2 Characteristics of quantitative research method

The main structure of quantitative research has remained the same for centuries across many scientific disciplines (Bekmezci et al., 2025). It always involves the systematic collection, analysis and interpretation of numerical data to test hypotheses (Ghanad, 2023; Bekmezci et al., 2025). The data obtained are statistically analyzed to reach comprehensive conclusions that can be examined and then published. When quantitative studies are carefully designed and controlled, they can ensure that the outcomes are valid and objective effectively because the influence of external variables is minimized (Bekmezci et al., 2025).

According to Creswell (2002) and Ghanad (2023), the key characteristics of quantitative research can be summarized as follows:

- Describing a problem statement by presenting the need for an explanation of a variable's relationship.
- Offering new literature by answering research questions with high reliability, explaining the research challenges and generating a demand for the research direction.
- Creating precise, quantifiable, observable purpose statements, research questions and hypotheses.
- Planning all research phases before data collection.
- Collecting numerical data from a sample of the study by using tools such as questionaries.
- Findings are based on larger sample sizes.
- Using statistical analysis for identifying characteristics, analyzing patterns, comparing groups or connecting variables.
- The numerical and statistical data are presented in non-textual forms like tables, charts or figures.
- Interpret the results by comparing them to previous research and predictions.
- Providing the unbiased study report by utilizing standard frameworks and assessment standards, while remaining impartial and unbiased.

According to (Swanson et al., 2005), the quantitative research process can be viewed as a five-step process as outlined here:

1. Determining basic questions to be answered by the study
2. Determining participants in the study (population and sample)
3. Selecting the methods needed to answer questions (variables, measures of the variables and overall design)
4. Selecting the analysis tools
5. Understanding and interpreting the results

So to start applying the above steps, it is worth noting that the questions this qualitative study aims to answer are the final two sub-questions of this thesis. To be more specific, they are the following:

SQ3: What are the perceived benefits of implementing process mapping specifications for data transfer in real-world construction projects?

SQ4: What are the main factors influencing the successful adoption of process mapping for facilitating data transfer between structural analysis and structural design software?

6.2.1 Sample size

So the next step in the process is determining the participants of the study. Conducting quantitative experiments requires careful planning to guarantee randomization and the correct formation of control groups. This process is expensive and time-consuming, (Bekmezci et al., 2025). In any investigation, the population represents the broader group to which the study's conclusions are applicable. Through the use of statistical sampling techniques, researchers can select smaller groups or samples, that reflect the characteristics of this larger population. To ensure that results can be generalized, it is crucial that the sampling process is random and unbiased to allow every member of the population an equal chance of selection (Swanson et al., 2005; Kumar, 2018). This enhances confidence that the findings are representative of the population as a whole and are not influenced by unique traits within the chosen sample.

However, in human resource development (HRD achieving full randomization is usually difficult, since data collection is often limited to specific companies or departments (Swanson et al., 2005). This limitation applies to this study as well, where the sample had to be selected from within the company. To maintain balance, an equal distribution from key roles (structural engineers, structural designers, information managers and quality managers) was selected. It is also important to note that quantitative studies generally require larger sample sizes than qualitative research to ensure statistical reliability (Bekmezci et al., 2025). So keeping in mind that nine employees participated in the interview process, at least double that amount should be included in the quantitative experiment. This was a personal choice, given the limited time available for contacting participants as well as the corresponding size of the company.

6.2.2 Surveys

Moving on, the methods needed to answer questions should be carefully selected. Descriptive research is regarded as the most suitable technique for identifying characteristics, frequencies and patterns within a given population (Ghanad, 2023). It focuses on understanding what, where and when the issues occur and not on investigating the underlying reasons behind them. Therefore, to gather descriptive data survey-based techniques are commonly employed (Ghanad, 2023). A key strength of the descriptive method is its ability to collect information within participants' natural environments which ensures greater authenticity and quality of responses (Ghanad, 2023). Descriptive research also relies on visual representations, such as graphs to help audiences interpret data patterns. In this study, a video was made to explain the process map to the participants of the study. It included an explanation of the symbols and the goals of the map as well as an animated overview of the map.

Once data is collected, descriptive statistics are applied to summarize and interpret the findings. Since it is impractical for individuals to comprehend large volumes of raw data, descriptive statistics simplify information to capture the main trends and relationships (Ghanad, 2023). The main forms of descriptive research include surveys, case studies and observations. The chosen method for this study is survey. Quantitative studies depend on systematic measurement to analyze relationships between variables, typically through structured instruments such as questionnaires or standardized tests (Bloomfield & Fisher, 2019). In survey research a series of well-constructed questions to a sample of participants are distributed and they respond via written or digital formats. To ensure data accuracy, they should include both open-ended and closed-ended questions (Ghanad, 2023). Finally, it is important to note that the findings can be generalized to the larger population with more reliability than the data collected through a case study.

6.2.3 Likert scale

The questionnaire in this study was designed to systematically collect information on participants' attitudes and perceptions. The Likert scale was selected due to its widespread use and established effectiveness in measuring attitudes within education and the social sciences (Joshi et al., 2015). A typical Likert scale consists of a series of statements describing real or hypothetical scenarios relevant to the research topic (Joshi et al., 2015). Respondents indicate their level of agreement with each statement on a graded scale, usually ranging from *strongly disagree* to *strongly agree*. This allows researchers to convert subjective attitudes and opinions into quantifiable data, thereby facilitating statistical analysis of responses. Additionally, Likert-type scales contribute to measurement reliability and validity.

To maintain the accuracy and credibility of the study's findings, it is important to ensure the reliability and validity of measurements. A measure is considered valid when it effectively captures what it intended and reliable when it consistently produces similar results under comparable conditions (Swanson et al., 2005). It is important to note that a measure can be reliable without necessarily being valid. For instance, self-ratings may yield consistent but inaccurate or objective results (Swanson et al., 2005). To improve validity and reliability, researchers rely on objective, numerical data over subjective interpretations (Bekmezci et al., 2025). Reliability is typically evaluated by examining the consistency of results across repeated or alternative versions of the same instrument. Validity, on the other hand, is more complex to prove. It is often determined by comparing study findings with existing theoretical frameworks (Ghanad, 2023). Together, these ensure that the data collected is both dependable and meaningful for interpretation (Bekmezci et al., 2025).

6.3 Choice of 4-point Likert scale

The selection of an appropriate number of response alternatives on a Likert scale has been a subject of debate since its development (Joshi et al., 2015; Cox, 1980). Researchers have always debated how different numbers of response categories affect its reliability and validity (Joshi et al., 2015). Some scholars have argued that reliability is independent of the number of scale points (Bendig, 1953; Boote, 1981; Brown et al., 1991; Komorita, 1963; Matell et al., 1971; Peabody, 1962; Remington et al., 1979). Others have claimed that reliability is maximized using seven-point (Cicchetti et al., 1985; Finn, 1972; Nunnally, 1967; Ramsay, 1973; Symonds, 1924), five-point (Jenkins et al., 1977; Lissitz et al., 1975; Remmers & Ewart, 1941), four-point (Bendig, 1954b), or three-point scales (Bendig, 1954a).

Chang (1994) argues that simply adding more points to a response scale does not automatically improve its reliability. In fact, increasing the number of response options can sometimes encourage patterns in answers. This can falsely raise correlations within the same measurement method and may result in respondents the scale incorrectly. For example, participants might ignore certain intermediate categories or treat options such as *disagree* and *strongly disagree* as interchangeable throughout the questionnaire (Chang, 1994). Although theoretically a larger number of categories could offer more precision, it may also cause confusion. Ultimately, the ideal scale length is one that gathers sufficient detail, while avoiding complexity that could introduce errors (Cox, 1980).

According to Cox (1980), the optimal number of points depends on several factors:

- the capability of the scale to transmit information
- the respondents' ability to choose among alternatives,
- the amount of information available from the stimuli,
- the information needs of the researcher.

According to Joshi et al. (2015), the ability of respondents to interpret and choose scale points depends on cognitive effort and memory span, which can be different among individuals and may also be influenced by the mode of communication employed in the study. While increasing the number of response options can enhance content validity, unnecessary long scales often lead to confusion and respondent fatigue (Joshi et al., 2015). Earlier research has also demonstrated that scales with too few categories lack reliability, while those with too many tend to heighten variability and measurement error (Churchill et al., 1984). As a result, Cox (1980) emphasized that there is no single optimal number of scale points. In contrast, the choice should be guided by the research context, participant characteristics and the intended level of precision.

For this study, a four-point Likert scale was determined to be the most suitable format. This removes the neutral midpoint and forces respondents to take a clear position (Garland, 1991). The four-point design was considered a balanced compromise between the commonly used three-point and five-point scales. In addition, because participants are familiar with the topic under investigation, they are expected to hold clear opinions that do not require the additional response options provided by six- or seven-point scales.

6.4 Neutral point

As a result of the 4-point Likert scale, the neutral option will be removed. So now the scale will have the following options: *Strongly agree – Agree – Disagree – Strongly disagree*. The decision to exclude the neutral response category from the Likert scale was made to obtain more definitive and meaningful responses from participants. Removing the neutral option encourages participants to express a clearer position of agreement or disagreement. This approach aligns with the study's objective of capturing directional attitudes and perceptions, rather than neutrality or indecision.

Many researchers favor this approach, arguing that participants should be prompted to make an explicit choice instead of reverting to a neutral category (Garland, 1991). Excluding the midpoint can be beneficial when it does not compromise the reliability or validity of the scale. Matell and Jacoby (1972) found that the frequency of midpoint selections declines as the number of available response options increases. Their findings revealed that roughly 20% of respondents chose the midpoint on three- or five-point scales, while only 7% did so on scales with seven, nine or more categories. Therefore, they recommended to minimize the use of the midpoint by either removing it entirely or increasing the number of response points. Because this study has chosen not to overwhelm participants with a lot of responses alternatives, the mid-point was excluded.

When the goal of a study is to capture specific attitudes or preferences, a forced-choice format that removes neutrality can generate more meaningful results. As Friedman et al. (1999) point out, neutral categories such as "undecided" or "uncertain" can serve as an easy alternative for respondents who wish to avoid expressing an opinion, even when they likely have one.

Eliminating these options decreases the likelihood of participants “opting out” of meaningful decision-making and so strengthens the clarity of the findings. Nevertheless, the exclusion of the mid-point must be considered carefully. If a significant portion of respondents genuinely lacks an opinion, being forced to choose between agreement or disagreement may introduce response bias (Friedman et al., 1999). This can create the illusion that more participants hold definite opinions than they actually do. However, when respondents are well-informed and familiar with the research context, as is the case in this study, the risk of bias is minimal. Therefore, a forced-choice design is an appropriate and justified decision.

Another factor influencing this decision is the issue of social desirability bias, which occurs when individuals select responses that they believe will be viewed favorably by others. Garland (1991) demonstrated that removing the neutral category can mitigate this because it makes participants reveal their genuine opinions rather than concealing uncertainty behind neutrality. As a result, responses become more authentic and varied, without changing the general direction of participants’ views.

Empirical studies have produced mixed results regarding the effects of excluding midpoints. On the one hand, Worcester and Burns (1975) note a tendency toward more positive responses, but Garland (1991) reports the opposite. This points to outcomes are context-dependent. Given that participants in this study are familiar with the research topic and are expected to hold clear views, the removal of the neutral category is appropriate. This design choice is expected to enhance the precision of the data and produce a more accurate representation of participants’ attitudes and perceptions.

6.5 Structuring the questionnaire

Great care was taken in writing the survey questions to make sure they were clearly phrased, neutrally worded and balanced. The words used as descriptors in rating scales play a critical role in shaping how respondents interpret each response category (Friedman et al., 1999). Worcester and Burns (1975) observed that descriptors which are grammatically opposite are not always perceived as psychological opposites by respondents. For instance, while “tend to disagree” may suggest a relatively strong negative sentiment, “tend to agree” does not convey an equivalently strong positive attitude. Consequently, scales that appear linguistically symmetrical may, in practice, introduce subtle imbalances. To avoid this issue, this study used clearly defined response categories (Strongly agree, Agree, Disagree and Strongly disagree*)*.

The wording of survey questions was also carefully considered to avoid implicit bias. Certain questions can unintentionally suggest a preferred attitude. For example, Sterngold et al. (1994) demonstrated that phrasing such as “How concerned are you about…” presumes concern to be the appropriate response and so it pushes participants to worry. To prevent such directional bias and avoid assumptions about participants’ behaviors or feelings, every question in this study was neutrally framed.

Another design consideration involved the orientation of scale points. Previous studies by Friedman, Herskovitz and Pollack (1993), as well as Friedman, Friedman and Gluck (1988), revealed that putting Strongly agree on the left-hand side of the scale can lead to systematically higher agreement levels compared to when it appears on the right. According to Friedman et al. (1999), an unethical researcher could exploit this by placing desired responses on the left side of the scale and so biasing the direction of responses. To mitigate such effects, this survey presented the options in a natural ascending order (1- Strongly

disagree, 2- Disagree, 3- Agree, 4 – Strongly Agree). In summary, the structuring of the survey questions was guided by evidence-based principles aimed at ensuring balance and consistency. Equal attention was paid to the choice of descriptors, the orientation of scale options and the sequencing of items, which supports the overall reliability and validity of the data collected.

Before completing the survey, most of the participants attended a brief five-minute presentation. The presentation was part of one of their regular team meetings and involved an explanation of this study's goals and research gap, namely that process maps are often designed in the AEC industry but not implemented in practice. Because many attendees had not been interviewed and so they did not have an overview of this study, the presentation served as both an introduction to the thesis and an explanation of the research questions being pursued. To avoid misunderstandings with a technical (non-managerial) audience that might be unfamiliar with the term, the concept of the process map was explained, each phase of the map and the responsibilities for each role were reviewed and the symbols used to create the map were described.

Participants were informed to expect a survey that would include a video to address any remaining questions. The link for the survey and the video can be found in Appendix D: Video included in the survey. The video followed almost the same structure as the presentation but offered the advantage of being viewed at the participants' own time and pace, allowing them to focus more and potentially understand it better. The short video animation was created in PowerPoint to accompany the survey and provided a visual and interactive explanation of the map's content and intended use. This approach was chosen to capture participants' attention and to ensure that responses were as informed as possible within the limited time available.

The survey took 36 minutes to complete on average. For a 20-question survey with a 4-minute explainer video, that is a strong sign that participants were engaged and took their time. It suggests they watched the video carefully (and may have re-watched parts) and thought through their answers rather than rushing. The survey was created with a target time of 15 minutes. So this higher completion time increases confidence in the results. It shows people likely understood what was being asked and gave considered responses, not quick guesses. While time alone can't prove careful answering for every person, the average here is much higher than expected from a quick, superficial survey, which supports the quality of the data.

The survey was framed as a focused, practice-oriented assessment of the proposed process map. It combined two purposes: to validate perceived benefits of the map (error reduction, time savings, collaboration and data reliability) and to measure adoption readiness using items aligned to Kotter's change model (urgency, leadership support, clarity of vision, communication, empowerment, short-term wins and willingness to institutionalize). Responses used a four-point Likert scale (Strongly disagree to Strongly agree) without a neutral midpoint to elicit a clear stance. The target population was engineering and design staff across Iv group, capturing multiple roles to reflect real project contexts. Descriptive analysis then summarized patterns across items to link user perceptions with organizational enablers and barriers. This provided evidence for the process map's practicality as well as for the factors that influence its successful adoption.

7. Results from the survey

The survey was distributed to 31 employees across the entire Iv group. Respondents apart from Iv-Consult, included staff from both Iv-Offshore & Energy and Nevesbu. This was done in order to capture perspectives on the potential application of the process map within a broader working environment, rather than limiting feedback to those who were already familiar with the concept through prior interviews. It is important to note that the process map was developed primarily based on input from Iv-Consult and therefore reflects their specific workflows and procedures. However, by inviting employees from other departments to evaluate and provide feedback on the map, the survey aimed to explore how well the map could function and be adopted in other organizational contexts. Since it was not feasible within the scope of this study to obtain feedback from external companies, involving independent departments within the Iv group was considered a practical alternative to approximate external validation. This approach provided insights into the broader applicability and adaptability of the process map across different company environments.

Out of the 31 employees asked, 16 completed the survey, representing a response rate of 52%. The researcher initially aimed for a number of survey respondents at least double that of the interviewees (9), setting a target of approximately 20 responses. Although this number was not fully achieved, with 16 valid responses received, the final sample is considered sufficiently close to the target to support meaningful quantitative analysis. This level of participation is understandable given the one-week response window and the busy schedules of employees In terms of respondent background, representation was unfortunately not evenly distributed across departments. The majority (approximately 85%) were from Iv-Consult, although they were based in different office locations, which may have contributed to diversity in their perspectives. Regarding professional roles, most respondents were structural engineers (69%), while 6% were structural designers and the remaining 25% were team leaders with varying managerial responsibilities. In Appendix E: Results from survey, pie charts clearly show these distributions.

7.1 Validation of process map

An important goal of this study was to assess whether the developed process map is considered by potential users as a valuable tool for improving the efficiency and quality of data transfer between structural analysis and structural design software. To evaluate this, respondents were asked to indicate their level of agreement with four statements related to the expected benefits of using the map. These were question 5 (Figure 19 - “Using a standardized process map for data transfer will reduce errors in the design phase of projects”), question 6 (Figure 20 - “The process map will save time during project design phases”), question 7 (Figure 21 - “The process map will improve collaboration between structural engineers and structural designers”) and question 8 (Figure 22 - “The process map will lead to better consistency and reliability in transferred data”).

The average scores for these items were all in the positive part of the scale, indicating generally positive perceptions of the process map’s potential benefits. Specifically, Q5 (“reducing errors”) received the highest score of 3.40, followed by Q8 (“improving data consistency and reliability”) with 3.20 and Q7 (“enhancing collaboration”) and Q6 (“saving time”) both at 3.07 and 3.00, respectively. These results demonstrate a clear overall agreement that the process map would positively impact accuracy, efficiency and teamwork in design processes.

The strongest agreement was found in the belief that the map would reduce design errors (Q5) and improve data reliability (Q8). These two dimensions are closely aligned with the core purpose of the process map, which is standardizing the workflow of data exchange between software platforms. The results therefore validate the conceptual integrity of the map. It is regarded as a useful tool to directly address the most common and costly problems associated with poor interoperability, such as data loss, misalignment and inconsistencies between analytical and design models. These perceived benefits support the claim that the map provides a practical framework for improving data integrity and quality control, which are key success factors for BIM-based collaboration.

Respondents also agreed that the map could enhance collaboration (Q7) and save time (Q6) during the design phase of offshore projects. The lesser level of agreement may reflect the fact that collaboration and time saved often depend on broader organizational practices, such as communication channels and project scheduling that are out of the map's scope. Nevertheless, these responses show that users understand the map's potential to serve as a common reference point for engineers and designers, facilitating communication and reducing redundant tasks.

Taken together, these findings provide strong evidence for the validity of the developed process map. The consistently positive evaluations across all four benefit dimensions suggest that the tool is perceived as relevant, practical and aligned with user needs. In the context of this study, this validates the map's design objectives:

1. To standardize data transfer workflows, by reducing errors and inconsistencies.
2. To enhance efficiency by minimizing rework and confusion in the design process.
3. To improve collaboration across roles and disciplines involved in structural design.

7.2 Kotter's model of change management

In the following sections, the results of the rest of the survey questions are analyzed and connected with Kotter's model of change management. But first there is a small introduction to Kotter's model and its connection to the thesis topic. According to Appelbaum et al. (2012), the current rate of technological advancement and growing global competition will lead to a continuing need for change in the future. Businesses are constantly required to adapt to a changing environment in order to maintain their position in the market and even more so if they are to truly grow. They have to keep in mind that changes are an inevitable part of the current market. Whether or not an organization tries to constantly evolve, successfully implementing changes can be a major determinant of its short- and long-term success (Appelbaum et al., 2012).

It must be noted that approaches to change management can vary widely depending on the theory is being applied. Different theories may focus on change at the individual, team or organizational level and address different dynamics of transformation. Between them, the organizational-level theories (Kotter, 1996; Stacey, 2001) have received the greatest scholarly and practical attention. These theories provide leaders with strategies to realign their companies with broader corporate objectives (Sittrop et al., 2021). Notably, Kotter's (1996) model has served as a link between academic theory and professional practice because it translates complex research insights into actionable guidance for practitioners. His model is

still relevant today and is applied it to analyze and guide change processes in complex organizational environments (Sittrop et al., 2021).

Quantitative research relies on data collection and data analysis which is focuses on testing theories (Bryman, 2016). Keeping that in mind, Kotter's eight step change model will be used as an analytical framework to evaluate readiness for change management adoption. The model will guide the interpretation of survey results like urgency, coalition building and institutionalization of change. Kotter's eight stage process of creating a major change as detailed in Leading Change (1996) are summarized in Figure 13.

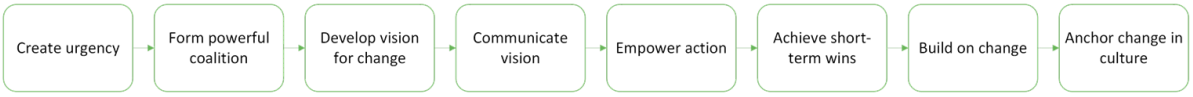


Figure 13: 8 steps of Kotter's model

According to Pollack et al. (2015), Kotter's framework puts emphasis on organizational culture which is characteristic of models developed for the private sector. While the model's effectiveness has been acknowledged, critics argue that it specifies what actions should be taken without providing sufficient detail on how to implement them effectively. In this research, the successful introduction of the proposed process map will depend heavily on the readiness and willingness of stakeholders to adopt new ways of working (Lenberg et al., 2017). Implementing new software tools or digital workflows often requires broader shifts in industry practice, which can be difficult to achieve (Racz et al., 2009). Established organizations are typically structured around existing routines and employees are already trained in the current processes. So it can be difficult to anticipate how innovations might influence professional practices. Even when new tools promise significant benefits, users may resist adoption due to the uncertainty and disruption that come with changes (Racz et al., 2009).

Kotter's eight stage process for creating a major change is one of the most widely recognized models for change management and yet there are few case studies in the academic literature that enquire into how this process has been used in practice (Pollack et al., 2015). There appears to be little research that enquires into the practicalities of using change management techniques to effect organizational change, either with regard to their suitability or appropriateness. The goal of this study is to analyze the results of the surveys and then make recommendations on how Kotter's model could be adapted to increase the probability of the successful implementation of the process map.

7.3 Kotter's steps and connection with survey

In the following sections, each step of Kotter's model for managing organizational change is analyzed in relation to the results of the quantitative research and supported by relevant literature findings. The purpose of this analysis is to evaluate the extent to which employees' perceptions of the new standardized process map align with the key stages of successful change implementation and provide answers to sub-questions 3 and 4.

7.3.1 Step 1: Create a sense of urgency

According to Kotter (1996), people are unlikely to change their processes especially when it alters their usual and familiar way of working, unless they have a compelling reason to do so. Other barriers that prevent the acceptance of new technology include lack of collaboration among project stakeholders, insufficient training and technical challenges associated with

software (Villena-Manzanares et al., 2021). So in the context of this study, the sense of urgency relates to employees recognizing that current design and data management processes in the AEC industry are becoming outdated and inefficient and the only way forward is to adapt to newer technologies. By framing the change as an opportunity to strengthen teamwork and remain competitive, a shared sense of urgency can be established that should motivate employees to actively participate in the transformation process.

The survey questions related to this step are question 3 (Figure 17 - “I believe there is a strong need to improve our current design process”) and question 4 (Figure 18 - “Continuing working with the old process could create inefficiencies or risks”). These items measure employees’ awareness of the need for change and their recognition of the limitations of existing workflows. The results show a moderate level of agreement with both statements, with Q3 and Q4 averaging 2.94, which lies just below the “agree” threshold. This means that most respondents recognize the need to improve the current process and understand the risks of continuing with the old one. They acknowledge some need for improvement, but the overall sense of urgency is moderate rather than strong. In other words, employees appear somewhat aware of the limitations of current practices but may not yet view the situation as critical or requiring immediate action. This finding indicates that additional communication and evidence of current inefficiencies may be needed to reinforce the necessity of change.

7.3.2 Step 2: Form a powerful coalition

The second step in Kotter’s model emphasizes importance of leadership commitment and collaboration among key stakeholders. A coalition is a group of individuals with sufficient authority, influence and energy to lead the change initiative throughout the organization. Effective change leadership requires visible commitment from senior management and active collaboration among key stakeholders. Senior management support is an important capability for design companies in the AEC industry, as they must recognize technological shifts in the competitive environment (Villena-Manzanares et al., 2021). Literature consistently indicates that companies adopting BIM and related digital tools benefit improve their final project design, making them more competitive. However, these benefits can only be realized if management takes an active role in championing the change and empowering others to follow.

Survey questions related to this step include question 12 (Figure 26 - “Lack of management support could make it difficult to adopt this process”) and question 13 (Figure 27 - “Upper management supports this new process map”). These items assess employees’ perception of how management involvement influences the likelihood of successful adoption. The results reveal a mixed picture. Question 12 received an average score of 3.33, indicating strong agreement that a lack of management support would make adoption difficult. In contrast, question 13, which directly measures the perceived presence of management support, obtained a lower average score of 2.53. This suggests that while employees recognize the importance of leadership engagement, they do not currently perceive strong active support from upper management for the new process map.

These results suggest that the coalition for change has not yet been firmly established. Employees understand that leadership involvement is critical but do not yet see sufficient evidence of managerial sponsorship or visible commitment. According to Kotter (1996), without a credible and motivated coalition to lead the transformation, it becomes challenging to sustain momentum or overcome resistance. Of course, the lack of active support for the

current process map was expected and should not be seen as alarming, given that this study represents a theoretical pilot initiative rather than a fully implemented organizational change.

7.3.3 Step 3: Develop a vision for change

The next step in Kotter's model involves developing a clear vision that communicates what the change is about, why it is needed and how it will be achieved (Kotter, 1996). A well-defined vision provides direction and aligns individual efforts toward shared organizational goals. A strong vision helps employees understand how adopting new workflows and digital tools contributes to broader company objectives such as efficiency, quality and competitiveness.

According to Villena-Manzanares et al. (2021), greater encouragement and involvement from top management lead to increased benefits from BIM adoption. The specific ways in which managers demonstrate support may vary. They may set clear action plans and milestones, communicate the project vision, secure necessary resources, participate in project meetings and initiate structural or procedural changes to enable successful implementation. These actions collectively form the backbone of a well-articulated change vision, ensuring that employees not only understand the purpose of the change but also feel supported in its execution.

Survey results related to this step correspond to question 9 (Figure 23 - "The goals of the new process map are clear to me"), which assesses the extent to which employees understand the aims and expected outcomes of the new workflow. The average score for this item was 2.73, slightly below the "agree" option. This result suggests that while some respondents grasp the general intent of the process map, there remains a degree of uncertainty or lack of clarity about its specific goals and practical implications. This could partly be explained by the way the goals of the map were presented in the short video accompanying the survey. Given the brief nature of the explanation, participants may not have fully understood its purpose or scope. It is reasonable to assume that if there had been more time to explain the process map in greater depth, this score might have been higher. Even so, the majority of the respondents have a clear idea of the goals of this process map.

This moderate level of understanding shows that the vision for change has been partially established but not yet fully internalized across the group. Employees recognize that the process map represents an improvement but may not fully comprehend how it aligns with the company's strategic objectives or their own daily responsibilities. This lack of shared clarity can limit engagement and slow the transition from conceptual awareness to active adoption.

7.3.4 Step 4: Communicate the change vision

The fourth step in Kotter's model focuses on communicating the change vision throughout the organization. Once a vision has been developed, it must be repeatedly shared in different forms and through various channels to ensure that employees fully understand and internalize it. Effective communication helps reduce confusion, builds trust and ensures that individuals at all levels are aligned with the organization's objectives and the reasoning behind the change. Kotter emphasizes that communication should go beyond formal announcements. It should be a non-stop dialogue that connects the "why," "what," and "how" of the change to employees' daily activities and responsibilities (Kotter, 1996).

In the context of this study, effective communication is critical because the process map represents a new approach to managing data transfer between software platforms.

Employees need to understand not only the technical purpose of the map but also its strategic value in improving collaboration, efficiency and data reliability. According to Villena-Manzanares et al. (2021), managers who communicate project goals frequently and clearly through meetings, progress updates and feedback loops, are more likely to foster acceptance and ensure successful implementation of technological initiatives such as BIM.

The survey result connected to this step comes from question 11 (Figure 25 - “The purpose of the new process map has been communicated effectively”). The average score for this item was 2.67, which falls below the “agree” threshold. This suggests that similar to the previous question, while some effort was made to explain the purpose of the process map, the communication may not have been fully effective or comprehensive for all respondents.

This moderate score may, in part, reflect the limited communication timeframe available during the survey phase. The main explanation was designed to give participants an overview of the map, but it may not have provided enough opportunity for discussion, clarification or follow-up questions. As a result, some respondents may have felt that the reasoning behind the process map and its expected outcomes were not fully clear. With more extensive communication, including opportunities for feedback or interactive sessions, this score would likely improve.

Interestingly, feedback from respondents in the question about extra comments reflected these mixed perceptions. Two participants expressed opposing views regarding how informative the video was. One respondent, already familiar with the process map, mentioned that the video was clear and he had no difficulty answering the questions. But he was uncertain about how others with less prior knowledge might perceive it. In contrast, another respondent who had no previous experience with the process map found the video helpful but stated that she would still prefer additional explanations about the goals of the map. These comments reinforce the idea that while the video served as a useful introduction, it was not equally effective for all audiences. Moving forward, this points to the need for varied and more detailed communication approaches.

7.3.5 Step 5: Empower action

The next step in Kotter’s model emphasizes the importance of empowering people to act on the vision. Once employees understand the need for change and the direction it should take, they must be given both the freedom and capacity to contribute to the transformation. Empowerment involves removing barriers that discourage participation and ensuring that employees have the necessary knowledge and resources to apply the change in their daily work. It also requires management to create an environment where individuals feel confident and motivated to take initiative, rather than focusing on resistance to change.

In the context of this study, empowerment refers to enabling employees to actively use and integrate the new process map into their regular workflows. Organizational factors such as company culture, leadership and knowledge management have a direct influence on the creation and diffusion of technological knowledge (Villena-Manzanares et al., 2021). A positive workplace culture that supports innovation, encourages open communication and values learning helps improve engagement, job satisfaction and overall performance. Moreover, Villena-Manzanares et al. (2021) have demonstrated that when senior management fosters such organizational factors, it can significantly improve the effectiveness of BIM technologies and related digital initiatives.

The survey questions related to this step are question 14 (Figure 28 - “I feel like I have the skills and knowledge to understand and apply the process map”) and question 15 (Figure 29 - “The process map can realistically fit into my daily workload”). These items assess both the individual’s self-confidence and the practicality of adopting the new process within their current work structure. The results show different levels of agreement between the two statements. Question 14 received an average score of 3.20, indicating that almost every respondent feels confident in their ability to understand and apply the process map. This is a positive result, suggesting that employees possess the technical skills necessary for implementation. This was expected in part because the map was created with them in mind. This result though proves the effectiveness of the map. In contrast, question 15 scored 2.87, reflecting more moderate agreement about whether the process can realistically fit within existing workloads. This suggests that while employees feel capable of applying the process, they may perceive time constraints or competing priorities as potential barriers to adoption.

These results suggest that the foundation for empowerment is partially in place. Employees appear to have the required skills, but the organizational conditions that would allow them to act freely and consistently are not yet fully established. Limited time availability, workload pressures or lack of managerial flexibility may slow down the ability to apply the process map effectively in practice.

7.3.6 Step 6: Achieve short-term wins

The sixth step in Kotter’s model focuses on the importance of achieving and recognizing short-term wins during the change process. Short-term successes provide evidence that the transformation is moving in the right direction which reinforces motivation and builds the credibility of the initiative (Kotter, 1996). They also demonstrate that the change is both achievable and worthwhile which encourages continued engagement and investment both from employees and management. Additionally, recognizing and celebrating early results helps sustain momentum and reduces the likelihood of resistance to change.

In the implementation of a new process map, early measurable improvements, such as reductions in design errors, faster data transfer or better collaboration can serve as proof of progress. However, optimal and desired solutions often take longer to develop and long-term improvements can require more resources than may be available within a company (Racz et al., 2009). Focusing solely on long-term outcomes may risk losing user confidence, as employees may turn to alternative tools or revert to old practices if they do not see immediate benefits. Therefore, identifying and communicating short-term improvements can help maintain enthusiasm, even if the overall transformation takes time (Racz et al., 2009).

Survey results related to this step connect with question 16 (Figure 30 - “Implementing the new process could deliver visible improvements within the first few projects”). The average score for this question was 3.00, indicating that respondents agree that the new process map has the potential to produce noticeable benefits early in its implementation. This suggests that employees hold realistic optimism about the short-term impact of the change, recognizing that improvements can be observed relatively quickly after adoption. This finding is really encouraging. It implies that employees view the process map as a practical and result-oriented tool, which is capable of demonstrating value quickly. This perception is particularly important in the early phases of adoption, as it helps sustain motivation and validates the change effort. In addition, the recognition of the map’s benefits mentioned in Chapter 7.1 Validation of process map is also critical for sustaining momentum in the adoption process.

7.3.7 Step 7: Build on change

The following step in Kotter's model focuses on building on change to create momentum after the initial implementation phase. Once short-term wins have been achieved, it is crucial not to declare victory prematurely but instead to use those successes as a foundation for further progress (Kotter, 1996). This step involves addressing remaining challenges and developing individuals within the organization as change agents who continue to drive transformation.

In the context of this study, "building on change" refers to reinforcing the early benefits of the process map and integrating it more deeply into the organization's standard ways of working. As the literature emphasizes, change initiatives require continued leadership attention, structured follow-up and alignment between the new processes and the company's broader priorities. According to Villena-Manzanares et al. (2021), when management actively encourages innovation and aligns technological initiatives with organizational objectives, it helps sustain engagement and extend the benefits of adoption over time.

Survey questions related to this step are question 10 (Figure 24 - "The process map aligns with the company's priorities which are efficiency and quality") and question 17 (Figure 31 - "The process map fits well with how we normally work on projects"). These items measure employees' perception of how well the process map integrates into the existing organizational framework and whether it aligns with strategic goals and established practices.

Question 10 received an average score of 3.13, which means that respondents agree that the process map aligns well with the company's core priorities of efficiency and quality. This is a positive sign, indicating that employees recognize the map's relevance and potential contribution to broader organizational goals. In contrast, Question 17 obtained a lower average score of 2.50. This shows that the respondents are equally divided on how much the map represents their way of working. A closer examination of the responses helps to clarify this result. The lowest scores (1-strongly disagree) for question 17 were given by two respondents who both work for Iv-Consult, the department most directly involved in developing the map.

Therefore, this finding does not indicate a general issue with the map's applicability across different companies. Instead, it likely reflects differences in project types and team structures within Iv-Consult itself. These variations influence how easily the process map can be integrated into specific workflows. By contrast, respondents from other departments, such as Nevesbu, expressed a positive view of the map's usefulness. One respondent noted that "the process map is a very good tool to show clearly the steps in the process." Furthermore, "the activities and decision points generally correspond with our workflows, but the process map is only applicable for Nevesbu when it would be adapted to our work methods (e.g., exchanges between software like CADMatic and FEMAP or Rhino and FEMAP)," These comments suggest that the map's overall structure and logic are correct and that minor adaptations would allow it to fit more closely with different departmental or software contexts. This result indicates that employees see the strategic value of the process map but may face difficulties in applying it consistently due to existing habits, workflow constraints or a lack of process standardization.

7.3.8 Step 8: Anchor change in the culture

The final step in Kotter's model focuses on anchoring the change within the organization's culture. This step is critical for ensuring that the transformation becomes a permanent part of the company's operations, values and identity. If change is not successfully institutionalized, there is a strong risk that people will gradually revert to familiar routines which would

undermine the progress achieved through the change effort (Kotter, 1996). To prevent this, organizations must embed the new approaches into their core practices, training systems and performance standards, ensuring that the new behaviors are sustained over time.

In the context of this study, anchoring the change involves ensuring that the use of the process map for data transfer becomes a standard part of project workflows. This requires not only technical adoption but also cultural acceptance, where employees view the new process as crucial to how work is carried out across projects. As (Amoah, 2019) highlights, for long-term success in BIM-based collaboration, it is essential that industry stakeholders, government agencies, educational institutions and end users are educated to fully understand the capabilities and benefits of such technologies throughout the project lifecycle.

The survey question linked with this step is question 18 (Figure 32 - “I am willing to adopt this process map as part of my standard way of working”). The average score for this question was 3.19, indicating that respondents more than agree with the statement and show willingness to incorporate the process map into their normal routines. This result demonstrates a strong level of personal commitment and suggests that the change has a solid foundation for becoming embedded in practice. This finding is very encouraging. It implies that employees not only understand and value the process map but are also prepared to integrate it into their day-to-day work. This willingness reflects an important cultural shift—from viewing the map as a theoretical or experimental tool to recognizing it as a practical, beneficial component of regular operations. The presence of such readiness among employees is a key enabler for long-term adoption.

7.4 Summary

PART III: Quantitative methodology & Findings set out the study’s mixed-methods approach and reported the quantitative findings that evaluate the proposed process map. Results showed consistently positive views of the map’s benefits. The strongest agreement was for reducing design errors and improving data reliability, with additional support for better collaboration and time savings. Interpreted through Kotter’s change-management lens, the data also revealed where adoption conditions are uneven. Urgency is present but moderate and most participants feel capable of using the map, but note workload constraints. Together, these findings confirm that the map is conceptually correct and useful, while highlighting that successful use depends on organizational support, not just user intent. This sets up the discussion on management strategies and practical steps to translate readiness into successful adoption.

PART IV: DISCUSSION & CONCLUSION

PART IV: Discussion & Conclusion brings the study together. It synthesizes the qualitative insights (interviews) and quantitative evidence (survey) to answer each sub-question and finally the main research question. The discussion first summarizes the specifications that make process maps cognitively effective and ready for implementation. It then interprets the current challenges in analysis and design data exchange and evaluates the perceived benefits of the developed map. Finally it identifies the organizational factors that enable (or prevent) its adoption, as they are interpreted through Kotter's change-management lens. In doing so, PART IV: Discussion & Conclusion addresses the main literature gap of this study (not just how to design process maps in AEC, but how to use them in practice) and outlines the thesis's theoretical and practical contributions, limitations and recommendations for future research.

8. Discussion

In Chapter 8, the results will be synthesized using the collected data to interpret the findings. Each sub-question will be addressed with the goal of answering the main research question. Additionally, the theoretical and practical contributions of this study will be presented, along with the limitations that should be considered for future research

8.1 Findings and Research outcome

To start with, the answers to the sub-questions will be provided, leading to the main research question.

The first sub-question is: *"What are the most important specifications and standards needed for developing an effective process map for data transfer?"*

According to the literature findings in PART I: Literature & Framework high-quality process maps require cognitive effectiveness, meaning that users can understand and interact with the model as well as implementation fitness, so that the model can be built, maintained and adopted. To combine these two demands, this thesis integrated Moody's Nine Principles, the Seven Process Modeling Guidelines (7PMG) and Becker's Guidelines of Modeling (GoM) into a single specification set. The resulting specifications define both what a high-quality process map must achieve and how to achieve it in practice.

The combined framework presented in Table 1, requires the process map to employ clear and consistent symbols so that each element represents exactly one concept and can be easily distinguished from others. The design of an effective process map should be intuitive, using standard icons, verb–object activity labels and a logically structured flow. To keep the model readable, complexity should be actively managed by minimizing elements and routing paths, decomposing large models when necessary and using only one start and end event. The map must make relationships explicit, by clearly showing dependencies between activities, feedback loops and data handovers. Visual optimization can be achieved by using a small set of visual variables (shape, line type and limited color) to emphasize sequence and category without overwhelming the reader. Dual coding means pairing graphics with precise text to reduce ambiguity. The framework is user-oriented, tailoring the level of detail to engineers and designers while remaining comparable across projects. Finally, it builds in error prevention through structured modeling conventions and clear quality-control paths.

An effective process map for data transfer should be delivered as a specification-driven artifact rather than a simple diagram. In this thesis, the recommended process map uses a BPMN notation with clear visual rules and lightweight organizational conventions so that models are not only readable but also adoptable in practice. BPMN is adopted as the notation standard because it operationalizes these requirements with a well-known vocabulary, formal execution semantics and broad tool support.

On the notation side, the developed map is evaluated based on the above specifications in Chapter 5.3 Evaluation of process map using the proposed specifications. To be more specific, it uses one start and one end event per level, separate tasks for activities and gateways limited to YES and NO to avoid ambiguity. Message flows represent information exchanged between roles and data objects for the archived database. Roles are expressed as swim lanes (project leader, information manager, structural engineer, structural designer, quality manager and an exchange lane for formal handovers). All task labels follow the verb–object pattern (e.g., “Define boundary conditions”). The guide for file formats recommended for file exchange is linked with the map, but is presented as a separate diagram, keeping in line with the specification of decomposing large models.

Because notation alone does not guarantee adoption, the specifications also specify organizational standards. For example, a minimum set of quality checks is embedded in the flow. Origin alignment, element-type mapping (centerline versus solids), material/thickness verification and comparison checks against previous versions. The map clearly shows who is responsible for each quality check, based on the swim lane the check happens. Moreover, while the map does not include explicit directions about naming and color conventions for models and elements, assuming they differ among companies, it states that they are an important step in the standardized process.

The second sub-question is: *“What are the current challenges to seamless data transfer between structural analysis and structural design software?”*

PART II: Qualitative methodology & Design answers the second sub-question by translating interview findings into a set of recurring and systemic barriers which are summarized in Table 4. These challenges show that data exchange between structural analysis and structural design tools at Iv is fragile. Firstly, workflows are fragmented and person-dependent. Tool choices and handover practices vary between offices and teams. This results in inconsistent and unpredictable data exchanges. Secondly, there is a lack of automated integration across the main tools, particularly Ansys and Tekla. Analysis tools use centerlines and meshes, while design tools require solids, detailed connectivity and fabrication constraints. Teams rely on STEP or IFC exports that often lose metadata (e.g., thicknesses, cross-sections) or misalign models (centerline vs. solid geometry). This is a result of exchanging files between software that are not compatible with each other. It also forces remodeling and manual recalibration of the model’s origins. Thirdly, quality checks are done manually. Overlay checks, color-coded comparisons and check prints detect issues but are time-consuming and error-prone, especially as iterations pile up. In the absence of standard QA practices, short-cuts and informal communication methods (calls, screenshots) are used. This create difficulties in tracing the person responsible for changes made.

A fourth challenge is project and software complexity which require frequent disciplinary handovers. Multiple software platforms (Ansys, SACS, SCIA, Tekla, Inventor) and mixed

formats (STEP, IFC, DWG/DXF, XML, PDFs) are used that make conversion issues worse and require extra work. This is unavoidable due to the different strengths of each software and the large size of created models. In addition, communication is informal (emails, calls, slides), which scales poorly across locations and time zones. Furthermore, parametric models can be inflexible across project phases. When model are made parametric early in the design process, that can hinder later adaptations and force remodeling. Finally, project variety and client-specific demands limit reuse of standards, so previous standardization or automation attempts are not easily adopted. These patterns are not isolated incidents. Instead, they are repeated across projects and teams and were marked as critical when independently raised by multiple participants or when they affected both analysis and design groups.

These challenges unfortunately reinforce each other. For example, semantic gaps and model mismatches increase verification effort, which under the pressure of time, pushes teams toward informal communication. This further degrades traceability and increases the need for rework. Likewise, project diversity encourages local solutions that lead to person-specific practices due to the absence of governance. This also leads to the increase of the next project's learning curve and variance. It is clear that the current challenges are not only technical (formats, multiple software) but also organizational. The interviews showed that seamless exchange fails when meaning is implicit, handovers lack structure and validation of results is manual.

These challenges directly dictated the objectives and requirements of the process map. It provides a solution to these issues whenever possible. To begin with, it standardizes the whole design phase of an offshore topside project, in order to battle person-dependent workflows and match project needs with the right tools and people from the start. Second, it defines the best file types for data exchange between the most commonly used software. Third, it proposes the use of openBIM flow for semi-automated quality control. Data neutral file formats like IFC are validated against IDS requirements, then confirmed via standardized overlays and discrepancies are recorded as BCF issues. Furthermore, it coordinates multi-software work by enforcing the use of naming conventions and version tagging. Additionally, it formalizes communication and change tracking, replacing informal updates with check prints, daily IFC exports and BCF-tracked issues so decisions are auditable. Finally, it proposes the creation of reusable templates and elements archived in a shared database that can be adapted to different project types.

The challenges identified explain recurring delays, rework and inconsistency in the current workflow. In short, interoperability problems persist because practices are variable, semantics are implicit and quality checks are manual. Addressing them requires specification-driven process mapping with explicit semantics and structured handovers for data exchange. These design principles were operationalized in the BPMN process map that was developed and presented in Figure 11.

The third sub-question is: *"What are the perceived benefits of implementing process mapping specifications for data transfer in real-world construction projects?"*

The survey results outlined in PART III: Quantitative methodology & Findings provide clear and user-driven evidence that this process map could be very beneficial for data transfer when adopted in real-world projects. All four items related to benefits scored on the positive side of the scale, with the strongest agreement for error reduction and improved data

consistency/reliability, followed by enhanced collaboration and time saved. These priorities align well with the map's purpose which is to standardize information exchanges, make responsibilities explicit and improve quality control processes.

Respondents most strongly believe the map will reduce errors and improve the reliability of transferred data. This directly targets the dominant failures identified earlier (metadata loss in exchanges and analytical–physical model mismatches). By describing what must be exchanged, how (formats, origins, naming, minimum attributes) and when, the map is seen as a practical mechanism for preserving intent across tools and iterations. In BIM-based collaboration, improvements in data integrity are closely tied to reduced rework and fewer coordination clashes.

Users expect the map to function as a shared reference that clarifies responsibilities and handoffs. Process maps visualize who does what, when, with which artifact and under which acceptance criteria. This shared visibility lowers frictions at discipline interfaces (engineer - designer) and supports predictable coordination, especially when combined with structured issue tracking and change logs. They do that by increasing user's awareness of the impact of one operation on another (Klotz et al., 2008). This way there are reduced instances where no one is performing a task because they think others are. Due to the multi-party nature of the sector, timely and accurate transfer of information among participants has become one of the key factors influencing the overall performance of construction projects (Chen et al., 2021). The implementation of advanced communication technologies enables participants to achieve efficient collaboration in terms of management.

While time gains received the most modest agreement of the four items, respondents still expect better efficiency thanks to the map. It would lead to from fewer loops, fewer "what's missing?" exchanges and clearer export/import routines. In practice, time savings are often complimentary effects of better quality and smoother coordination and the survey responses reflects that logic.

Beyond the survey results, process mapping is understood to deliver a visual "single source of truth" for the workflow (Klotz et al., 2008). Visualized flows help teams identify bottlenecks (e.g., repeated manual checks), explain unclear ownership and expose redundant steps. So they are enablers for continuous improvement. Standardized legends, naming and coloring conventions which are proposed by the map are used to stabilize expectations and reduce "local dialects." This, combined with structured communication (e.g., check prints for change requests, daily IFC exports, openBIM workflow), supports more reliable cross-site collaboration.

In summary, the survey results validate the process map as a useful and credible tool for improving data transfer practices. Users perceive strong benefits from implementing process-mapping specifications for data transfer. These perceptions are consistent with both the problem profile observed in practice and the known advantages of visual and standardized workflows. However, process maps should be perceived as the means of facilitating data transfer, not the goal. They can only offer guidance throughout the main critical stages of the project (Lawson et al., 2003). They can only be effective when people are willing to accept them and can clearly see real benefits from using them. Realization of the benefits depends on consistent use, organizational factors that influence adoption and feedback loops that make quality improvements visible (Lawson et al., 2003). The positive perceptions of its potential to

reduce errors, improve reliability and strengthen collaboration confirm that the process map effectively addresses real challenges in current workflows and offers practical benefits that align with both organizational goals and user expectations. Taken together, the results validate the process map's design objectives to standardize exchanges, enhance efficiency and improve collaboration. So that indicates a high likelihood of practical value when added in day-to-day work.

The fourth and final sub-question is: *"What are the main factors influencing the successful adoption of process mapping for facilitating data transfer between structural analysis and structural design software?"*

Process models like process maps are widely used in other sectors to simplify complex work and expose issues in the flow of information, yet their application in the construction industry remains limited (White et al., 2024). At the same time, recent studies point to a growing interest in implementing integrated software systems that contribute to project management (Baars, 2024). Considering these opposing views, the literature reveals a clear imbalance. Far more has been written about designing process models than about implementing them. Tzortzopoulos et al. (2005) argue that the limited and superficial guidance on implementation has encouraged an excessive focus on the design and form of the process models themselves, without appropriately considering their implementation. This narrow focus is producing overelaborate models that cannot be effectively implemented. Chen et al. (2021) similarly call for systematic investigation of the drivers and barriers to implementation, noting that the conditions for successful adoption are under-developed.

Crucially, effective implementation must be linked to organizational context and "soft" people issues (consensus, collaboration, motivation) which also remain insufficiently addressed (Tzortzopoulos et al., 2005). The literature has also not emphasized enough the explicit assessment of a model's usefulness at both organizational and project levels. Together, these gaps point to the need for a more integrated body of theory on process maps' implementation that can guide companies from design to day-to-day use (Tzortzopoulos et al., 2005). By identifying the factors that most strongly influence successful adoption, this study speaks directly to the gap of understanding why practical use succeeds or fails. It also clarifies what must be true in the organizational context for a process map to move from paper to practice.

The survey, interpreted through Kotter's model about organizational change, supports the literature's claim that successful adoption of the process map depends primarily on organizational and cultural conditions. First of all, a shared sense of urgency is present but not as strong as required. Respondents acknowledge shortcomings in current workflows and recognize the risks of continuing as-is, yet the need to change is not evenly spread among the company. Adoption therefore relies on whether the existing wish for change is consistently experienced as significant enough to justify changing established routines. Resistance to change is a major barrier to the successful implementation of any new process. Lawson et al. (2003) noticed in their studies that people frequently feel reluctant to use maps and procedures unless they feel a sense of ownership, but prefer to rely on their own past experiences as a guide. They also emphasize that a common failure and reluctance to use process maps is evidenced by the frequently observed gap between 'intentions' and 'practices' in projects and organizations. Therefore it is of upmost importance that organizations battle this natural instinct of resisting change by creating a sense of urgency to change.

Secondly, leadership commitment and a credible coalition are considered crucial for successfully adopting the new process map. Employees clearly believe adoption is dependent on management support. Active support from upper management is needed to shape confidence in the initiative and help increase momentum across teams. Another factor that influences the success of adoption is clear communication of the vision for change. Unfortunately, producing clear evidence of performance effects like measuring benefits from a process model use is a difficult endeavor, especially in project environments like construction (Tzortzopoulos et al., 2005). While the goals of the process map are generally understood, responses suggest that understanding is uneven and communication to date has not fully translated the purpose and expected outcomes across audiences. If the “why” and “what” of the change are only partially internalized, engagement from employees remains hesitant and the transition from awareness to consistent use is slowed down.

Moreover, empowerment conditions matter for the successful implementation of process maps. Participants report they have the skills and knowledge to use the map, yet they are less certain it fits within existing workload structures. This difference between capability and capacity frames adoption as a question of everyday feasibility. The map is created as a tool that people are capable of using and not as an over-complicated tool that has no change of actually being implemented. However, competing priorities and time constraints affect whether they actually will. So empowerment involves removing barriers that discourage participation and ensuring that employees have the necessary knowledge and resources to apply the change in their daily work.

A factor that until now has contributed to unsuccessful implementation of process maps is that in construction it is difficult to clearly compare results between projects due to their uniqueness. This means that it is also hard to establish links between the performance of a project and the use of a process model (Tzortzopoulos et al., 2005). A way to contest this, is celebrating short-term wins. If people experience visible benefits early in the implementation, it will contributes to willingness to try the new approach and provides psychological reinforcement during initial adoption. In the survey results, respondents showed that they expect to see improvements from the first few projects, which shows their belief that the map can yield tangible improvements. This could be very beneficial for the adoption of the process map.

Of course, alignment with the organizational priorities of the company is a very important factor and motivator to implement the map. If the process map is perceived as consistent with the company aims of efficiency and quality, employees are encouraged to adopt it. Additionally, the map should be reusable across different project teams, departments and companies if possible. If it includes components that fit different project types and doesn’t have to constantly be adjusted and redone, it would be easier for employees to use it as a guide for all of their projects.

To sum up, despite respondents’ strong willingness to adopt the process map, research shows that maps are often created but left unused. This isn’t because people don’t want to change, but because the right factors aren’t fully in place to help them turn good intentions into daily habits. The final factor influencing adoption is therefore the match between cultural readiness and organizational supports. On the cultural side, respondents already show a positive disposition toward change and a willingness to incorporate the map into routine work. On the organizational side, however, the mechanisms that sustain that behavior (clear and easily

understood goals, visible backing from leadership, consistent communication and a good fit with existing project practices) require more work. Until those conditions improve, even high willingness is not enough. In short, successful adoption depends on pairing people's willingness with solid organizational support, so the process map moves from a good idea to a normal and implemented way of working.

The main research question of this thesis is: *"What management strategies and organizational practices can support the successful adoption of process mapping specifications for data transfer between structural analysis and design software?"*

To bridge the intention–implementation gap of process maps identified in literature and explored in the answer of sub-question 4, the adoption enablers must be translated into concrete managerial strategies and organizational practices. The following strategies are proposed to operationalize the process map and make its use repeatable and resilient across projects.

From the technical side of the problem, the main suggestion is the adoption of buildingSMART's standards for data exchange. This will ensure that all software understand the information in the building model. This is a way to make the building industry work more efficient and produce more resource sufficient solutions. There is a need to document and share all information by one open format using one standardized terminology. buildingSMART International enables the development, creation and adoption of open digital standards for productive workflows. In turn, digital workflows help teams collaborate and communicate efficiency throughout all phases of the project and asset lifecycle. They are critical in projects involving many disciplines, software applications and organizations that must collaborate and exchange information to achieve success. Interoperable, open, international standards for BIM that transcend traditional design and construction phases offer substantial benefits and enable users to build a comprehensive digital environment for the entire project and asset lifecycle (buildingSMART, n.d.).

The use of buildingSMART and data neutral file formats will also ensure that the process map is independent of the software used in a project. This would make it easily reusable across different projects types. In practice, every analysis - design handover should use IFC as the neutral exchange. IFC is the best format for repeated exchanges only when both software implement it well. When both tools have mature IFC support, geometry, properties and references can be transfer both ways with minimal loss. The minimum required attributes for each exchange should be specified via IDS which would also serve as the first quality check. Detected issues and verification findings will be managed in BCF, linking each remark to specific IFC elements with saved views for traceability. This would make verification consistent across projects and software, reinforcing reliable, repeatable data transfer.

To solve the organizational problems of adopting the process map, the steps of Kotter's model should be operationalized. For the companies to stay competitive in the current AEC industry they must become more skilled at organizational change management. To start with, management should emphasize the specific risks of maintaining outdated processes and highlight the benefits of adopting the new process map. Failure to embrace change will prevent a company from realizing the full potential of the technology solutions (Maali et al., 2020). The capacity to manage change has become a key determinant of competitive advantage and survival. Therefore, companies need to adopt and use new processes, technologies and

innovations that may enable them to achieve their goals. So it would be beneficial to demonstrate clear examples of inefficiencies or errors in the current design process that the map could prevent. This would encourage more proactive engagement in the change process and reduce any remaining resistance to change.

In addition, consistent upper management support is essential to pursue practical adoption of similar process innovations in the future. So senior managers should actively support the process map, participate in its pilot implementations and allocate time and resources to demonstrate their commitment. Visible leadership actions, such as attending meetings related to the new process and recognizing employee efforts would help build confidence among employees. This would also reinforce the organization's seriousness about change. Also important is that the vision behind the process map is communicated consistently. This can be achieved through regular internal presentations, visual communication tools and ongoing dialogue about how the map contributes to efficiency, collaboration and data quality. Moreover, connecting the process map's objectives to measurable project outcomes would help employees see its direct relevance and benefits. Also clear, repetitive messaging supported by practical demonstrations, will help employees understand how the process map supports the company's wider goals and their own work. To further improve commitment to change, it is crucial to establish effective two-way communication channels, where employees can ask questions and provide feedback. This ongoing dialogue ensures that communication is not only top-down but also interactive and adaptive, which is essential for sustaining engagement and driving successful implementation. This shared understanding will be essential for preparing the organization for the change and adoption process.

Next, management should create opportunities to engage employees in the change process. This can include allocating time for them to experiment with the process map, by integrating its use into standard workflows and recognizing those who actively contribute to its improvement. Management can also actively involve employees in refining and adapting the process map based on their feedback and practical experience. Providing practical training sessions, peer-learning opportunities and channels for sharing best practices would further maintain momentum. It would be beneficial to encourage small-scale experimentation, rather than expecting immediate full-scale adoption. This would help employees gain confidence and integrate the change more naturally into their daily routines. By addressing workload and time constraints, leaders can ensure that employees are capable to act on the change, transforming awareness into practice. Of course, incorporating feedback loops will create a sense of ownership and ensure that the process continues to evolve with the company's needs and drive the change toward long-term adoption.

To fully capitalize on the benefits of the map, management should ensure that early successes are identified, measured and communicated widely throughout the organization. Concrete short-term wins could include smoother collaboration between design and analysis teams, fewer data-transfer errors or time saved in the early project phases. By documenting and sharing such outcomes, leaders can build confidence among staff and demonstrate that the change is producing real results. Recognizing individual and team contributions to these early achievements will further strengthen engagement and ownership of the process. So, while the overall transformation toward standardized data transfer practices may take time, the organization can maintain momentum by celebrating small improvements along the way.

Doing so reinforces belief in the change effort and supports the long-term implementation of the process map within daily workflows.

Finally, to fully anchor the change in the corporate culture, management should focus on formalizing the process map within company procedures. This could include integrating the process map into onboarding materials and quality management systems. Recognition and reinforcement also play a vital role in anchoring change. Managers should highlight successful applications of the process map, celebrate teams that use it effectively and communicate measurable benefits such as reduced errors or improved coordination. By consistently reinforcing these behaviors, leaders can ensure that the new way of working becomes part of the company's identity rather than a temporary initiative and the process map is transformed from a project-specific innovation into a lasting organizational capability.

8.2 Theoretical contributions

Process maps are widely promoted in the AEC literature, yet they are often designed and rarely implemented in day-to-day work. Prior research has tended to emphasize how to draw process maps rather than how to apply them successfully. So the specifications that make maps usable and sustainable in practice are left underdeveloped. This thesis addresses that gap by proposing a specification-driven framework that makes a process map verifiable and effective. It also proposes the conditions that lead to its successful adoption in practice.

The specifications presented in Table 1 can serve as a framework for future modelers designing their own process maps. Either before or after, the development of a process map, they can run through the framework like a checklist to ensure their design meets the requirements. They verify syntactic validity, the absence of OR gateways, the presence of explicit formats/directions/owners for every exchange, consistent verb–object labels for activities and acceptable complexity of the models. Together, these conventions can turn future process maps into a reliable and repeatable tool for data transfer across projects.

Based on the qualitative study, this thesis outlines the main obstacles to smooth data exchange between analysis and design tools. Although the evidence comes from Iv, these problems are not unique. Similar issues appear in many firms in the sector and the first step in solving a problem, is recognizing it. By grouping the recurring issues such as person-dependent ways of working, informal communication across teams, mismatches between analysis and design models and information loss during file transfers, the study makes it easier to see what solutions are likely to work. In this way, it adds to the BIM interoperability literature by turning various, practice-based observations into a clear list of common failure patterns that future, standards-based solutions can directly address.

The most important theoretical contribution of this study is how it addresses the literature gap concerning the failure of adopting process maps in practice. By combining the quantitative findings with Kotter's model of change management, the thesis identifies the most important factors that positively or negatively influence implementation. Specifically, adoption succeeds when cultural readiness (people are willing to use the map) is aligned with organizational support (a clear vision, consistent leadership support and celebration of short-term wins). Theoretically, if an organization takes these into account, it should result in the successful implementation of any developed process map that follows the specifications mentioned previously.

8.3 Practical implications

This thesis delivers a ready-to-use process map for data transfer between structural analysis and structural design software. Developed from real project practices and validated through a survey of potential users, the map was judged to accurately represent day-to-day workflows in offshore projects. It can be used by future employees to clarify who does what, when and with which artifact at each handover. It was also confirmed that through its use, it can reduce errors, improve data reliability, enhance collaboration and save time. In addition, because it captures problems and routines common across the AEC sector, it is transferable. Other organizations with comparable toolchains (from Ansys/SACS/SCIA to Tekla/Inventor and back) can adopt and adapt it to gain similar benefits. For them, the map offers a smooth path to measurable improvements. Teams can start with a pilot projects, use the map to track early wins (fewer data-transfer errors and faster acceptance of exchanges) and then add the refined flow into quality manuals and project schedules.

The open standards at its core help future-proof the approach across software updates and mixed software environments. IFC acts as the neutral file format for exchange, IDS defines what data *must* be present at each handover and BCF links issues to specific model elements. In most workflows this combination reduces rework, improves traceability and lets teams collaborate without being locked into a single platform. That said, data-neutral standards only deliver their full value when tools actually support them. Currently, for example, Ansys does not natively support IFC, which means pure IFC-based transfer between Ansys and Tekla is not yet possible. Even with the process map in place, this gap can still create friction, typically metadata loss and manual rework.

A solution to this problem could be to make compatibility an upfront decision. At project setup, project managers should assess the intended software against the exchange formats they actually need. If the project depends on frequent handovers, they should prioritize software that supports IFC for the roles that must exchange data frequently. Otherwise, when it is not possible to only use IFC, engineers can use STEP files to reference the geometry of their analysis and deliver the required attributes using XML or CSV files that are aligned with the IDS checklist. On the receiving side, designers will import the geometry, verify and apply the properties using IDS and link discrepancies in BCF.

Finally, when everything cannot be validated automatically via IFC and IDS, more manual checks are expected. The process map already embeds these gates and quality managers should use them to protect quality until native IFC support improves. In short, open standards remain the backbone, but file compatibility also influences execution. This means project and quality managers now have a concrete, standards-based mechanism to turn BIM interoperability goals into everyday practice by selecting tools with the right format support and by defining clear handovers. They can replace person-dependent workflows with a repeatable process that adapts across projects and teams.

8.4 Limitations

This study has a few limitations that should be considered when interpreting the findings and applying the proposed process map. First of all, time was not considered as a variable in the BPMN map. While this is typical for BPMN, it can be a drawback for users unfamiliar with the overall design process, as the map does not indicate expected durations or delays between activities. Second of all, the map currently functions as a standalone artifact. The purpose of

this thesis was simply to create and validate it. The way it can be included in the actual working process of a company remains to be seen. Furthermore, the map focuses on internal information exchanges during the design phase of offshore projects. It does not yet cover interactions with external stakeholders (clients and/or suppliers) or downstream phases.

Validation was conducted primarily within the company environment for which the map was designed (Iv-Consult), with limited input from external teams. This means that its contributions are most directly applicable to multidisciplinary engineering contexts with related analysis and design handovers. The implementation to similar domains that use different software and workflows is possible but will require local adaptation of exchange rules and attribute sets. The survey-based validation was unfortunately constrained by response rates and time. Recruiting a larger, more balanced sample proved challenging due to participants' workload and the thesis timeline. These constraints may reduce the statistical power of the quantitative findings and the precision of some estimates. Together, these limitations suggest that while the process map and thesis findings are useful and applicable, their effectiveness will depend on organizational integration and further validation in diverse project environments.

8.5 Recommendations for future research

Future research could build upon the findings to maximize the process map's practical impact and address the limitations. The next step should be a measured implementation in live projects. It would keep scope controlled, produce early evidence and steadily make the map a standard part of the process. The effort should begin with a short pre-implementation phase. A small pilot project should be selected with needed exchanges between analysis and design software. First of all, roles should be clarified: a Project lead for overall accountability and an Information manager to own the Common Data Environment, versions and IDS/BCF governance. The CDE should be structured with a simple design (01_WIP, 02_Shared, 03_Published) and include naming and versioning rules. For each handover, a one-page "exchange contract" can be created that specifies direction, identifies the IDS profile to be used and lists the specific points for quality control. Next the map should be explained to the team with two concise sessions: exporting/importing using IFC with IDS validation and raising/closing BCF issues with saved views.

Afterwards, the project should be executed using the developed map as a guideline. By this stage, team members will be familiar with the map and aware of the process's known pain points, so checks should focus on those exchanges in particular. Project managers should track simple performance indicators and compare them to similar projects executed before the process map. Important KPIs are data quality that can be determined by the average IDS failures per exchange (the trend should go down), average time from file exchange to passing quality control, number of geometry/property-related rework items per file and percentage of exchanges executed with complete artifacts (IFC + IDS report + BCF log). At the end of the small project, feedback from the employees should be taken into consideration and the new map can be adopted to 2-3 larger projects. Participants from the pilot project can act as trainers for people using the map for the first time.

If the results are satisfactory, the map can be promoted to mandatory in the quality assurance (QA) process of the company, instead of it being a standalone artifact. The map should become a standard part of the quality documents and internal audits of the company. This will shift its use from optional to mandatory which would ensure consistent adoption across teams

and projects. The shared database should be constantly updated and the benefits of the map's adoption should be reviewed. In addition, the scope of the map can be extended beyond internal design exchanges to include clients, suppliers and other phases of a project. This would require adding swim lanes and explicit links for external interfaces. Currently, information exchange with the client is done using 2D drawings. So defining an "external handover package" which would include 3D models in data neutral formats could save everyone a lot of time and reduce ambiguity between stakeholders. The overall process is summarized in Figure 14.

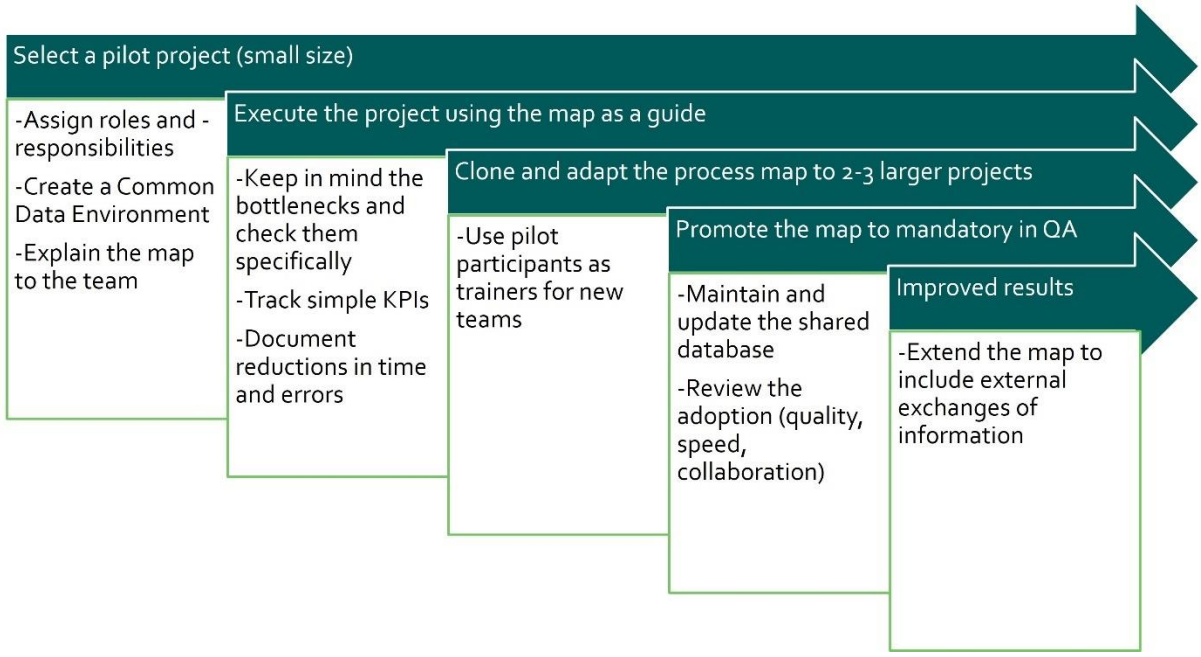


Figure 14: Future implementation process

Moreover, broader validation across different organizational settings and toolchains is advisable before wider external use. Future researchers should run pilots projects across departments (e.g., Iv-Offshore and Energy, Nevesbu) and other companies with at least one external software collaborator to test applicability across different software (FEMAP, ArchiCAD, etc.). They should collect consistent before/after KPIs such as error rates, rework hours and handover cycle time to quantify benefits and refine the specifications if needed. Finally, the management strategies and organizational practices proposed for the successful implementation of the process map should be also practically tested before wider adoption. Together, these steps would move the map from a well-designed artifact to an operational standard.

9. Conclusion

In conclusion, businesses in the AEC industry are constantly required to adapt to a changing environment in order to maintain their position in the market and even more so if they are to truly grow. Changes are an inevitable part of the current market. The current rate of technological advancement and growing global competition predicts a continuing need for change in the future. Whether or not an organization tries to constantly evolve, successfully implementing changes can be a major determinant of its short- and long-term success. The use of digital technologies and open standards are central to the evolution. They will allow for better decision-making and increased efficiency. This will result in cost savings for clients and improved outcomes for projects.

This thesis addressed a lasting research gap. Process maps for are often designed but rarely implemented in practice. Through mixed methods, the study moved beyond map creation to the practical conditions under which a map is actually used. Interviews analyzed recurring technical and organizational barriers to seamless exchange. They most important ones included lossy file transfers, manual quality control, model-type mismatches, informal communication and person-dependent workflows. These insights informed a BPMN process map that promotes the use of buildingSMART standards to standardize handovers and semi-automated checks. A subsequent survey validated the map's perceived benefits (error reduction, improved reliability, better collaboration, time savings). The results of the survey revealed the adoption factors that matter most, read through Kotter's model about management of organizational change.

Employees showed clear willingness to adopt the map and use it in their daily work as it aligned with strategic goals of the company. This is an encouraging foundation for the institutionalization of the map. However, willingness alone is not enough. Successful adoption depends on aligning cultural readiness with organizational support. A clear and shared vision, consistent leadership support, effective communication, removal of operational barriers (time/fit) and early demonstrable wins are the most important factors that influence the adoption of process maps. Put simply, empowerment of change requires both individual readiness and organizational support.

For management, the path forward is to translate conceptual alignment into operational reality. That means making open standards the default for exchanges, running quality checks on neutral models and integrating the process map with everyday governance. It also means reinforcing the behaviors that sustain change, such as feedback loops and recognition of change. This way the map is not a one-off artifact but a living component of how projects are delivered.

To sum up, this research closes part of the research–practice gap by outlining specifications for robust and effective process maps and identifying the organizational conditions that turn design intent into routine use. While further integration into routine workflows is still needed, the results indicate employee's readiness to adopt. With focused managerial support and open standard practices, the process map can move from a promising concept to a standardized workflow that improves quality, efficiency and interoperability across projects.

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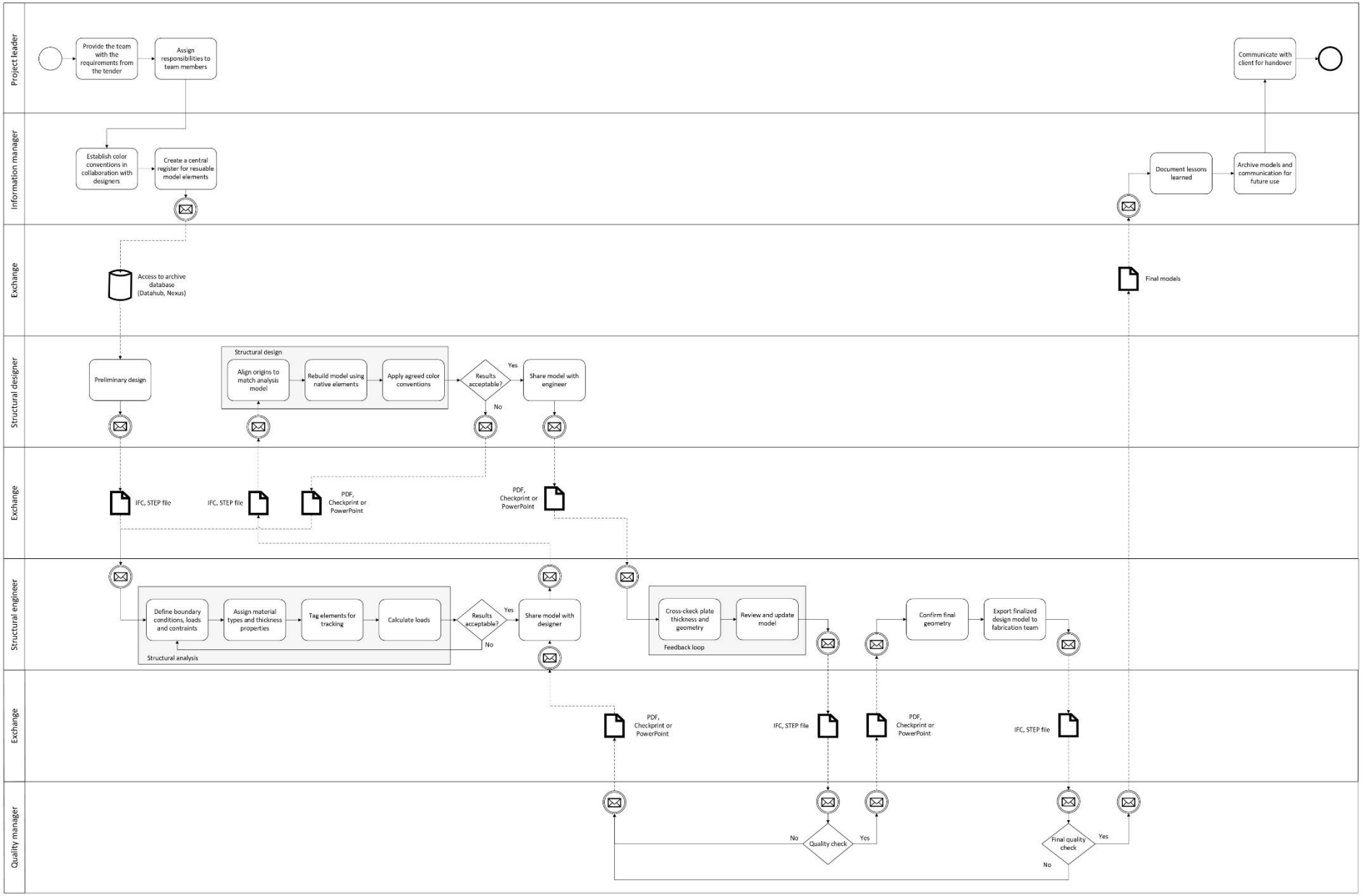
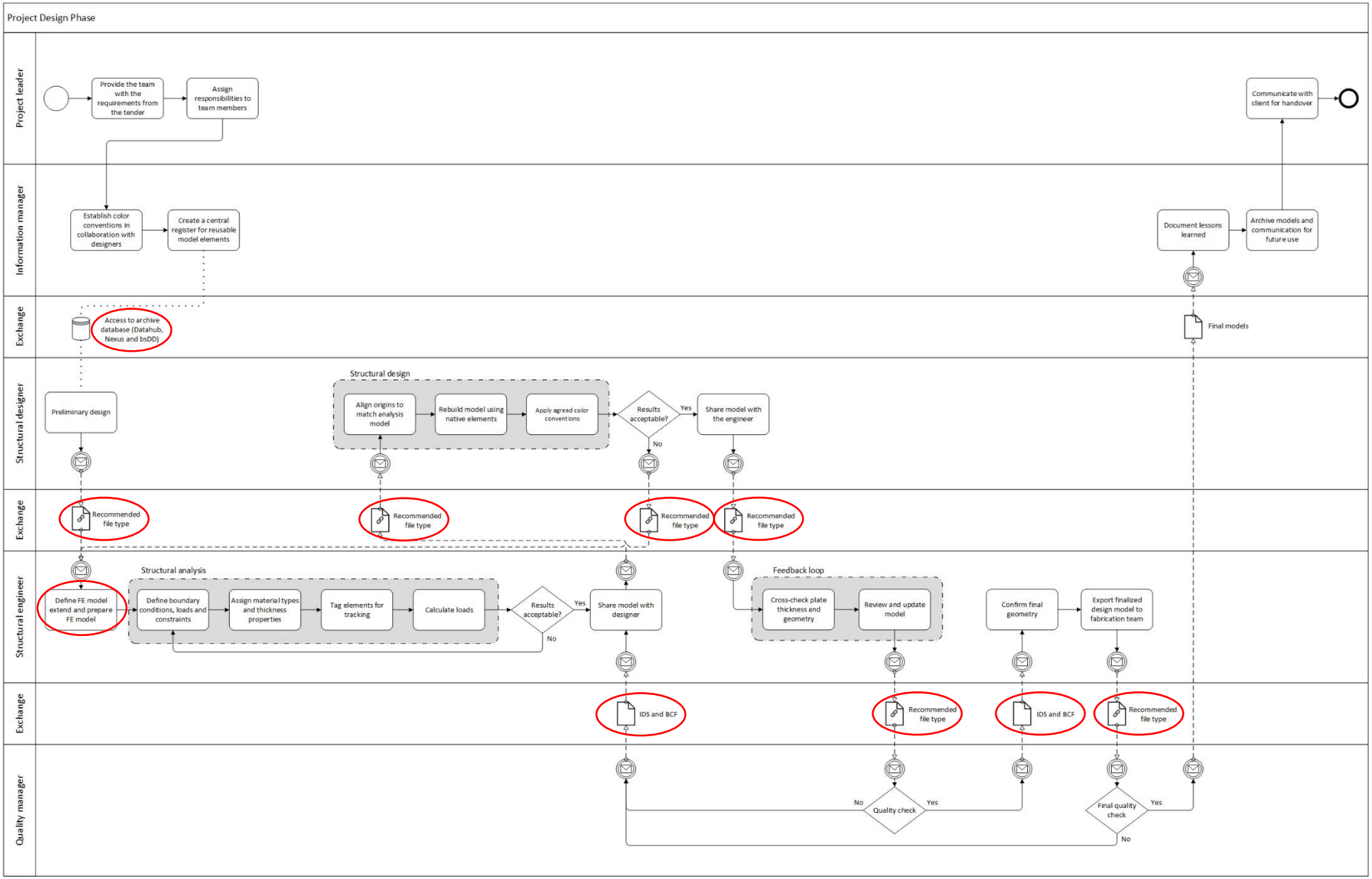
APPENDIX A: THEMATIC CODING OF THE INTERVIEWS

APPENDIX B: PROCESS MAP OF CURRENT SITUATION



APPENDIX C: PROCESS MAP OF OPTIMAL PROCESS WITH MARKINGS FOR CHANGES



APPENDIX D: VIDEO INCLUDED IN THE SURVEY

In this link the video that was included in the survey can be viewed. https://drive.google.com/file/d/1_zpHoq72efPpm4ByP6JnlGde2nf4lqtR/view?usp=sharing. It was included as a link in order to minimize the size of the document. All of the survey participants watched it carefully and repeatedly as indicated by the time it took them to complete the survey.

The survey can be found in the following link: Survey for employee feedback on developed process map – Fill in form

APPENDIX E: RESULTS FROM SURVEY

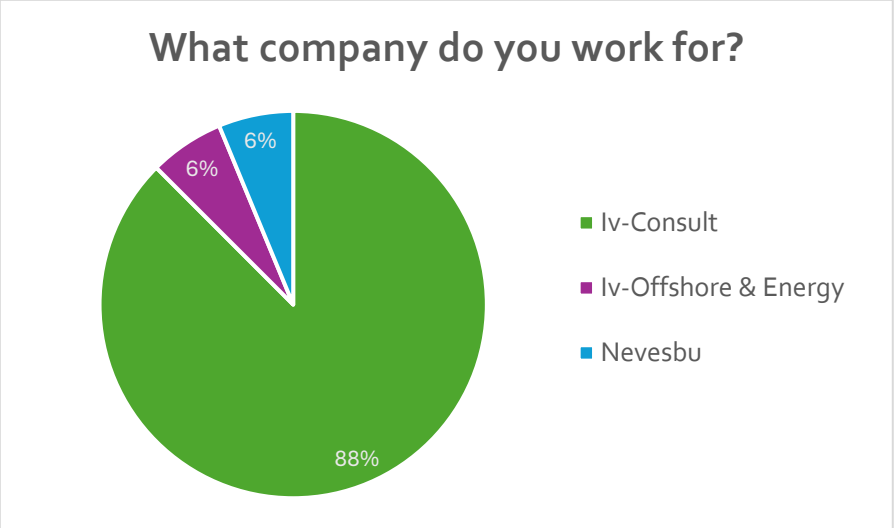


Figure 15: Survey question 1

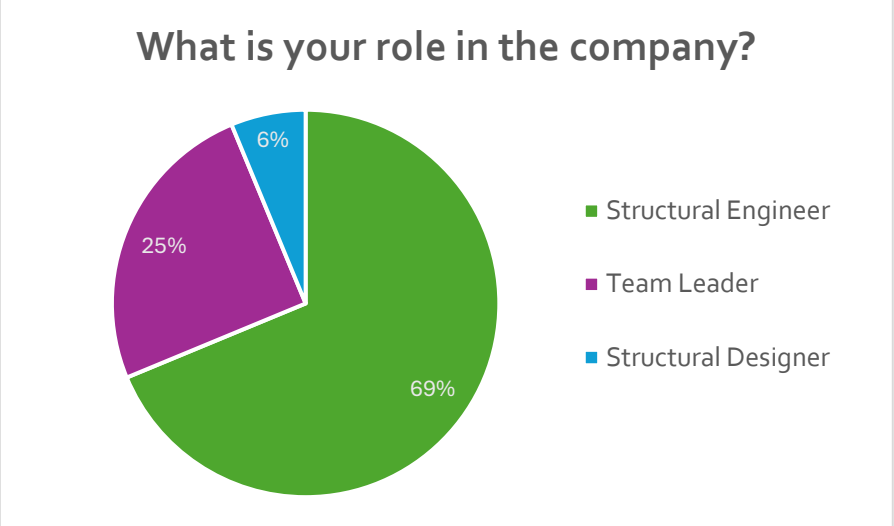


Figure 16: Survey question 2

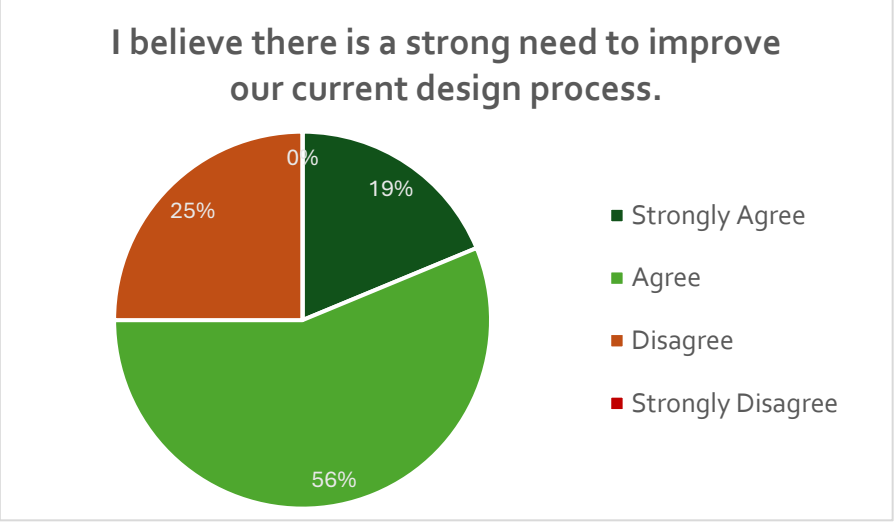


Figure 17: Survey question 3

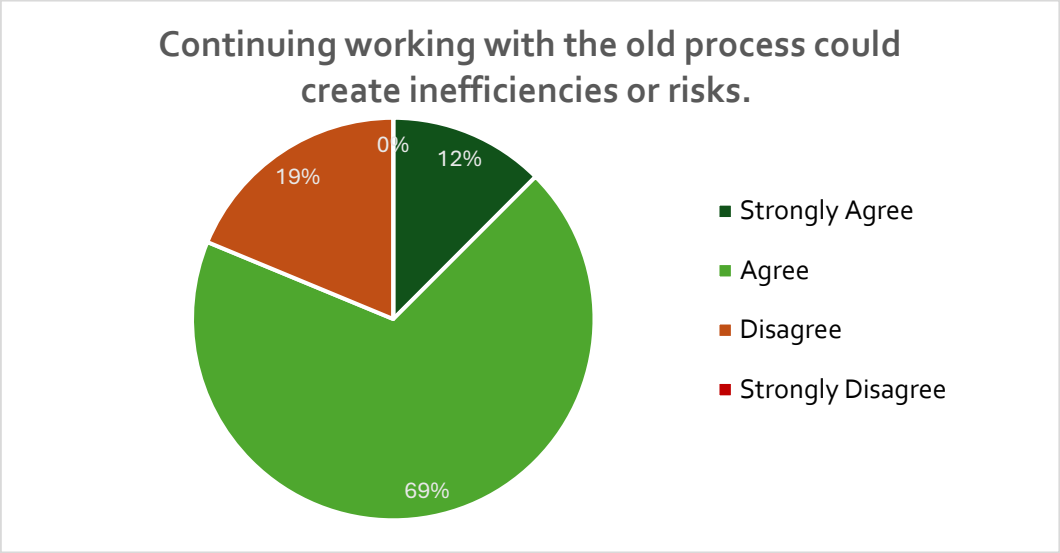


Figure 18: Survey question 4

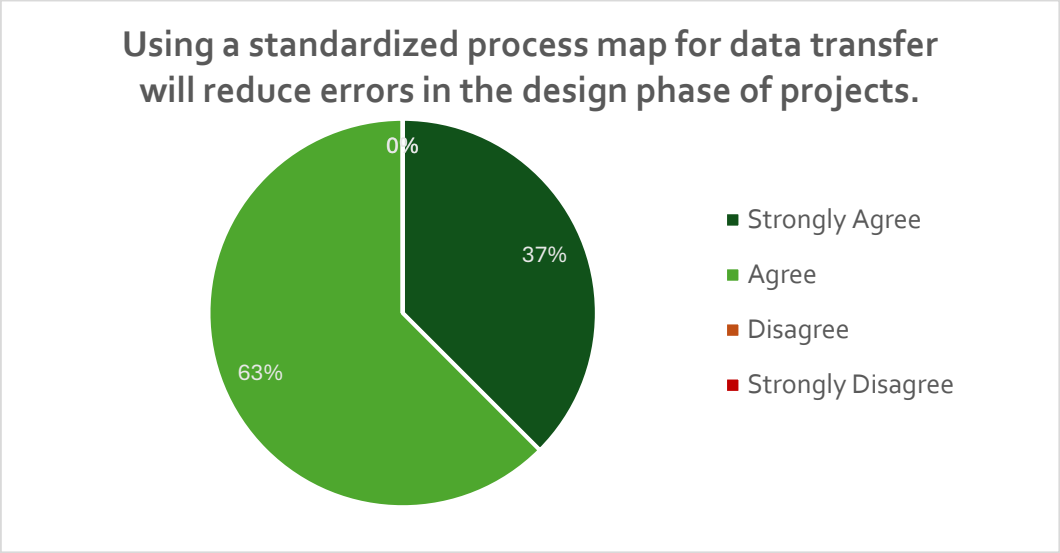


Figure 19: Survey question 5

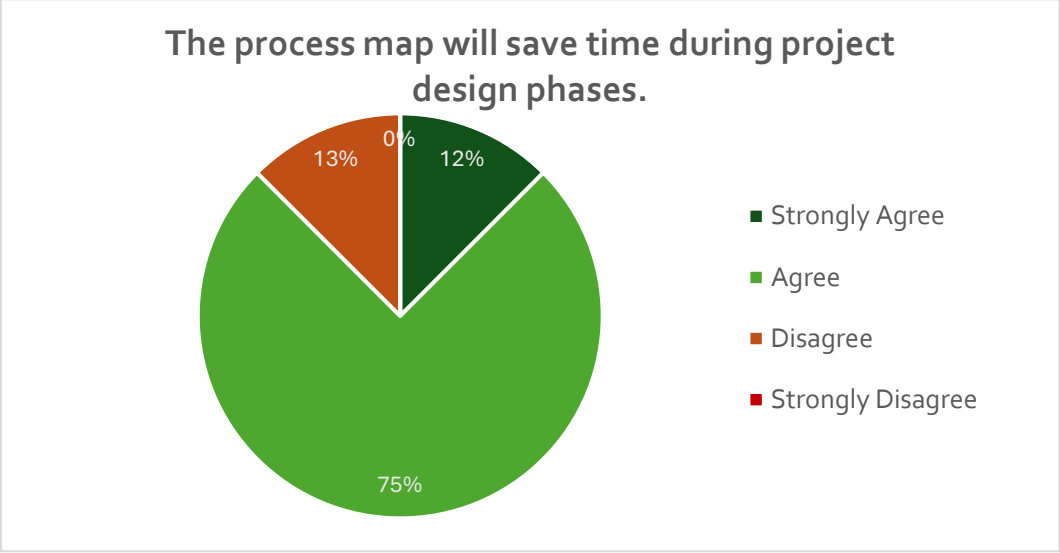


Figure 20: Survey question 6

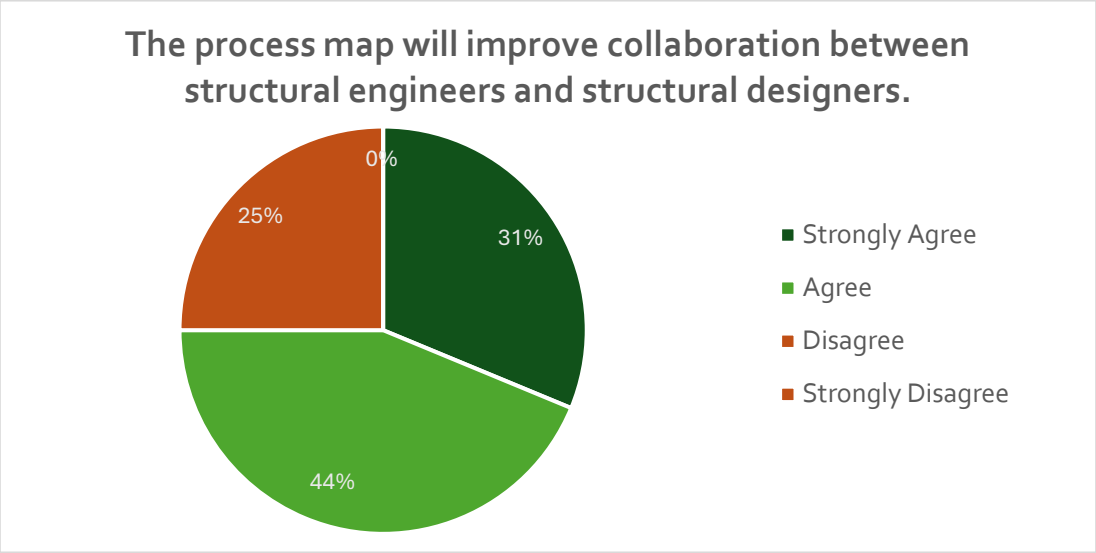


Figure 21: Survey question 7

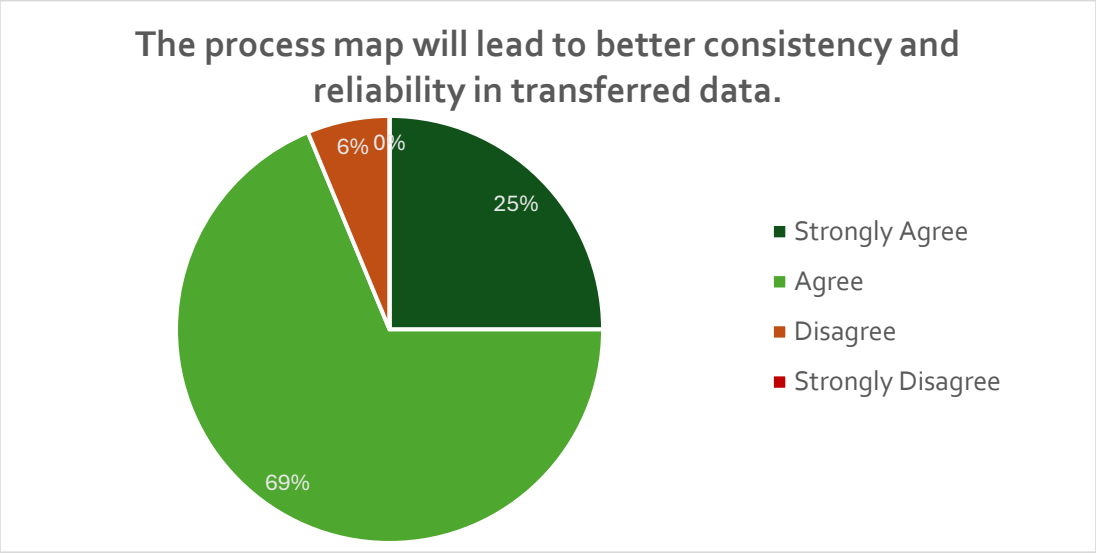


Figure 22: Survey question 8

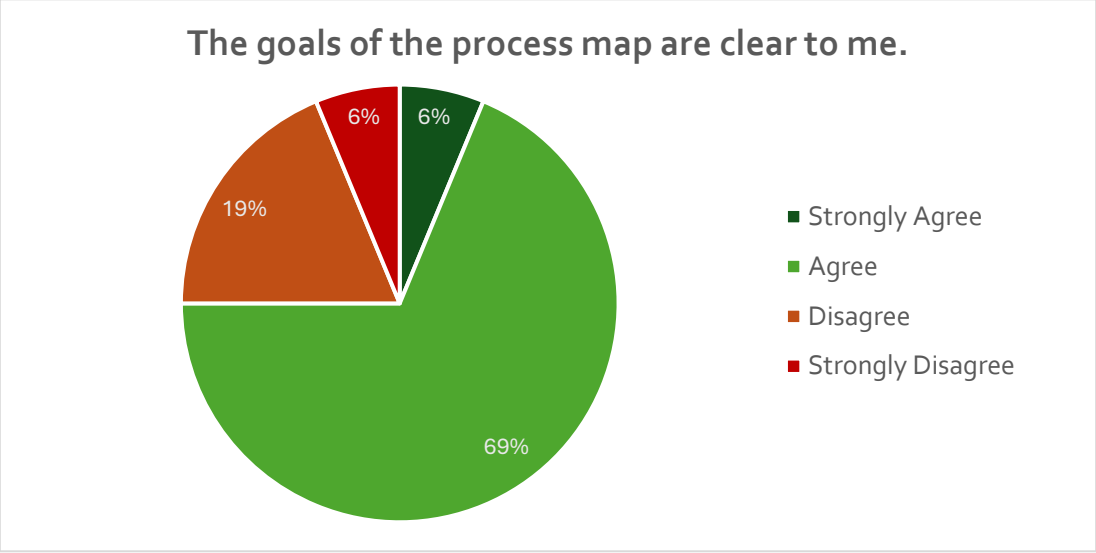


Figure 23: Survey question 9

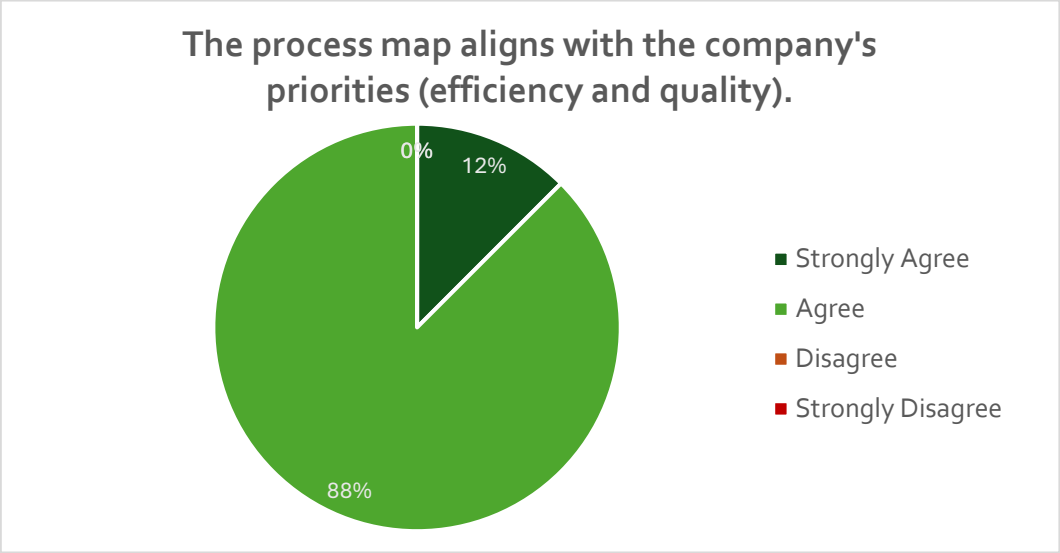


Figure 24: Survey question 10

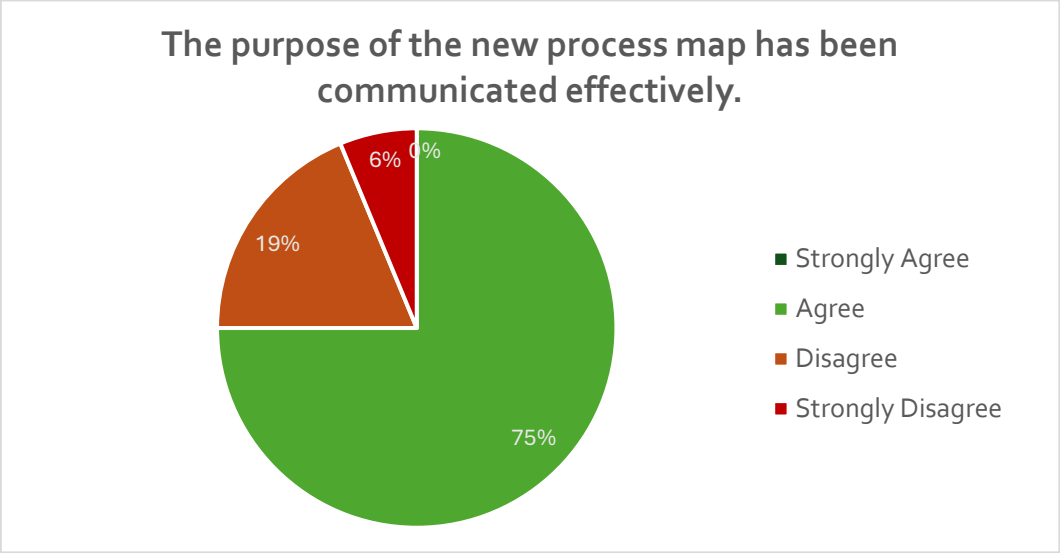


Figure 25: Survey question 11

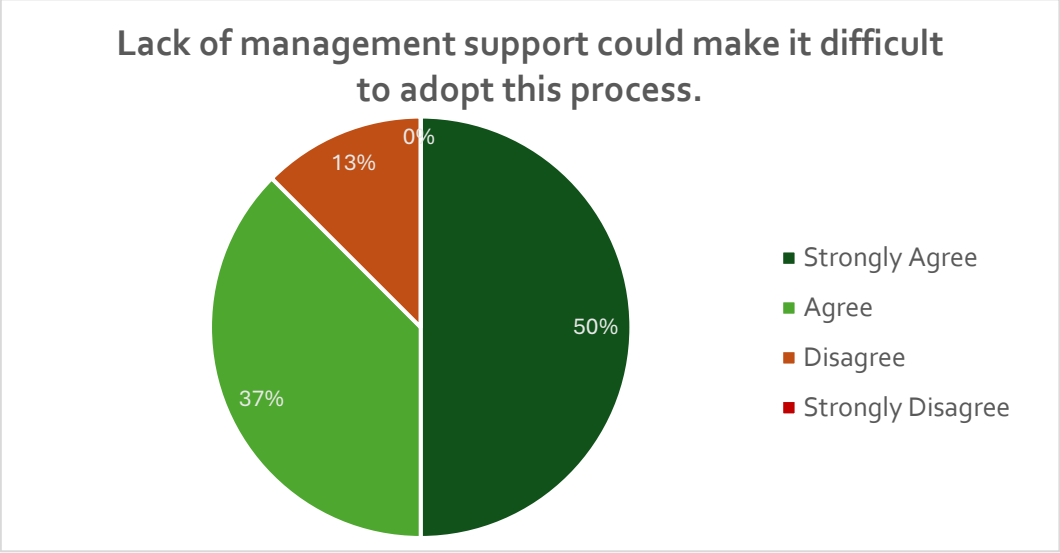


Figure 26: Survey question 12

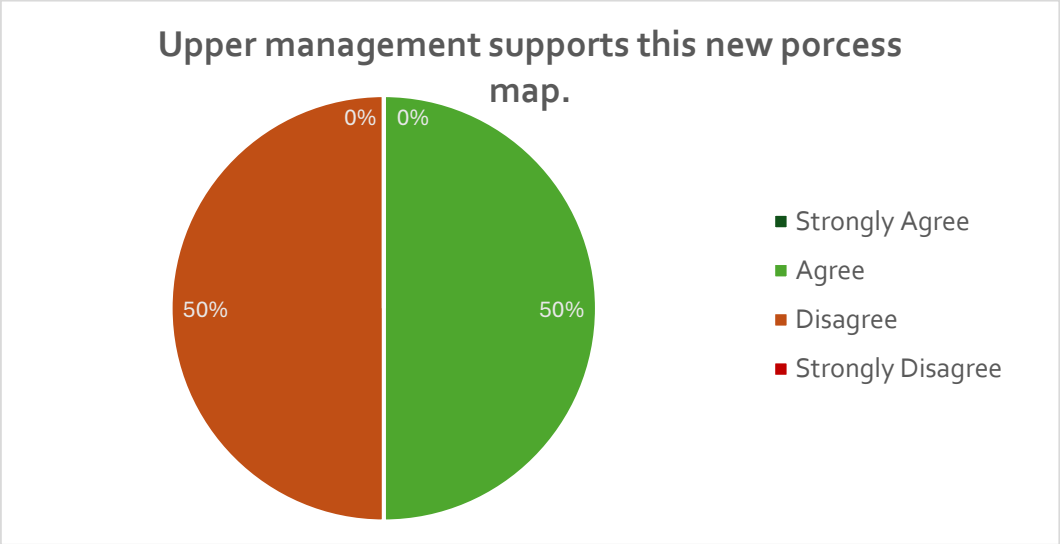


Figure 27: Survey question 13

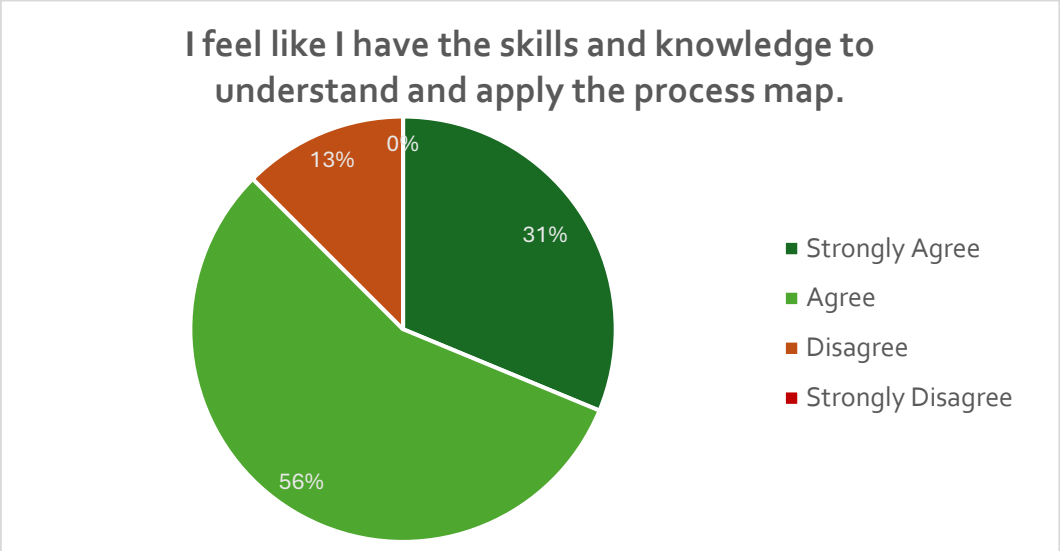


Figure 28: Survey question 14

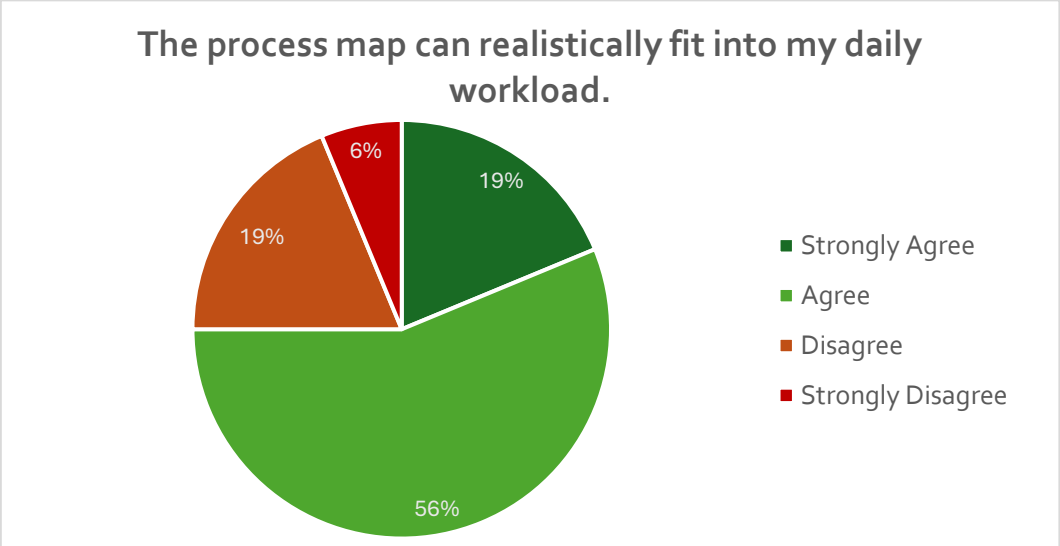


Figure 29: Survey question 15

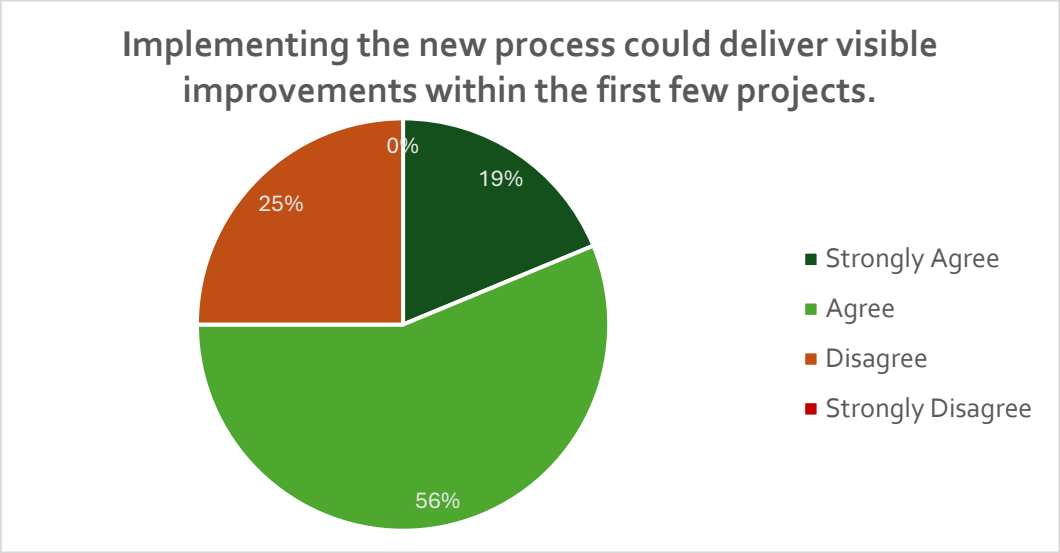


Figure 30: Survey question 16

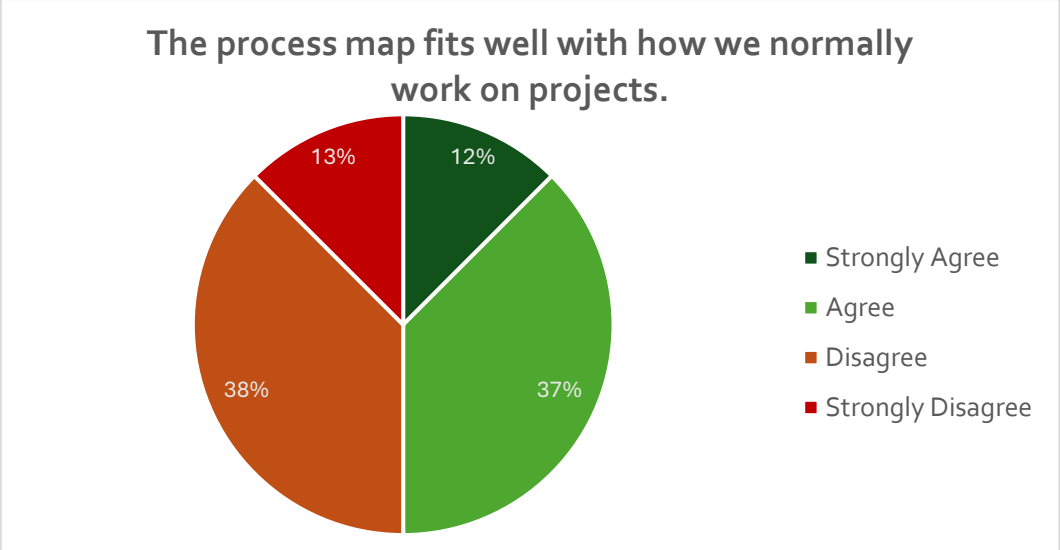


Figure 31: Survey question 17

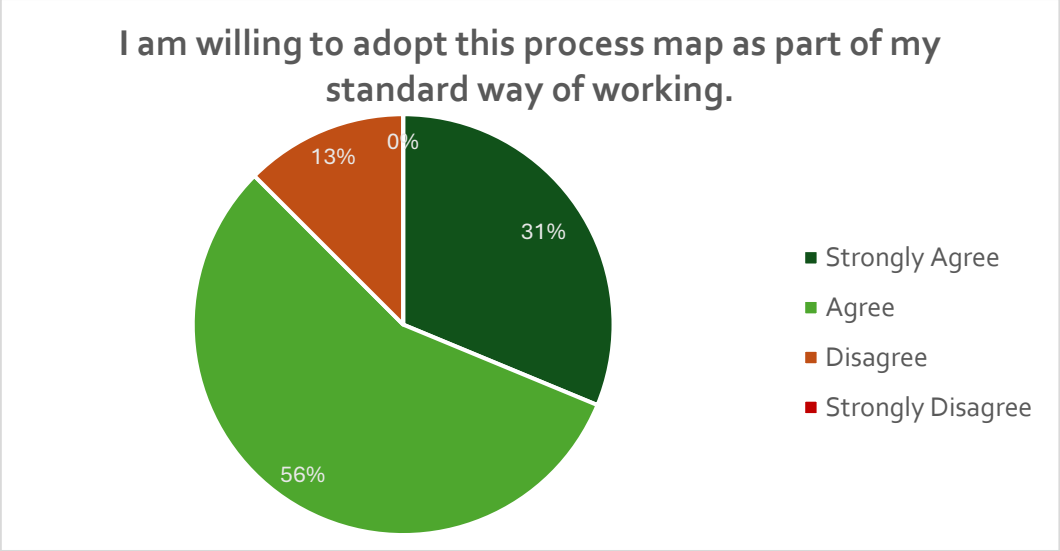


Figure 32: Survey question 18