MSc in Business Administration & E-Business

Appendix

Integrating Digital Twins into Offshore Wind Turbines: A Systems and Stakeholder Perspective

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Number of appendices: 11

Supervisor: Carsten Sørensen

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Appendix A: Theoretical Concepts out of Literature Review

A.1 Applied Theories

Author	Topic	What they wrote about	Practical Implications
Swanson & Ramiller (1997)	Organizing Vision Framework	Introduced the Organizing Vision framework, explaining how stakeholders form collective interpretations of technology, guiding its adoption and integration within organizations.	Organizing Vision helps ensure that stakeholders remain aligned in their understanding of digital twins' value proposition. Practical steps involve adjusting expectations around technical limitations and driving further engagement.
Zuboff (1988)	The Smart Machine: Automation and Informating	Differentiates between automation (technology taking over human tasks) and informating (technology generating new knowledge), emphasizing the impact of IT on organizational roles and structures.	Organizations must balance automation with human oversight to ensure that data generated by digital twins empowers rather than controls workers. Proper training for employees in interpreting data is crucial.
Burton-Jones (2014)	Revisiting Zuboff's Work on the Smart Machine	Revisits Zuboff's theory of the smart machine, further analyzing the implications of automation and informating on knowledge, authority, and organizational control.	Organizations should recognize the shift in authority brought about by IT systems like digital twins and ensure that managers are equipped with the necessary digital literacy to retain decision-making power.
Nambisan et al. (2017)	Digital Innovation and Distributed Agency	Explores the distributed nature of digital innovation, where multiple stakeholders contribute to the development and application of digital technologies, often across ecosystems.	Success in digital innovation depends on fostering collaboration across different stakeholders. Organizations need to develop protocols for effective communication and data governance between stakeholders involved in offshore wind projects.
Zammuto et al. (2007)	IT Affordances and Organizational Transformation	Argues that IT enables mass collaboration and process-oriented structures in organizations, transforming decision-making through real-time data-driven approaches.	Organizations must leverage the affordances of digital twins to improve decision-making processes. Managers should encourage cross-departmental collaboration enabled by digital twins to optimize project outcomes.
Kallinikos (2005)	Functional Simplification and Closure	Explains how technology simplifies complex processes through standardization but warns that interconnected systems create new interdependencies and vulnerabilities.	Organizations need to anticipate and manage the complexity that arises from integrating digital twins with existing systems. Emphasis should be placed on building interoperable data systems.
Tilson, Sørensen, & Lyytinen (2021)	Paradoxes of Control and Change	Discusses the paradox of control and change, where organizations must balance the need for stability with flexibility when adopting new technologies like digital twins.	Organizations must establish systems to ensure operational oversight while allowing flexibility to respond to changing conditions. Digital twin implementation strategies must balance control with adaptability.
Farjoun (2010)	Duality of Stability and Change	Argues that stability and change are interdependent forces in organizations, where stability provides a foundation for adaptation and innovation driven by technology.	Organizations should embrace the stability provided by digital twins for maintenance while encouraging innovation in workflows and decision-making. This dual approach supports long-term operational success.

Table 1 Summary Table of Applied Theories

A.2 Literature Review Visualized

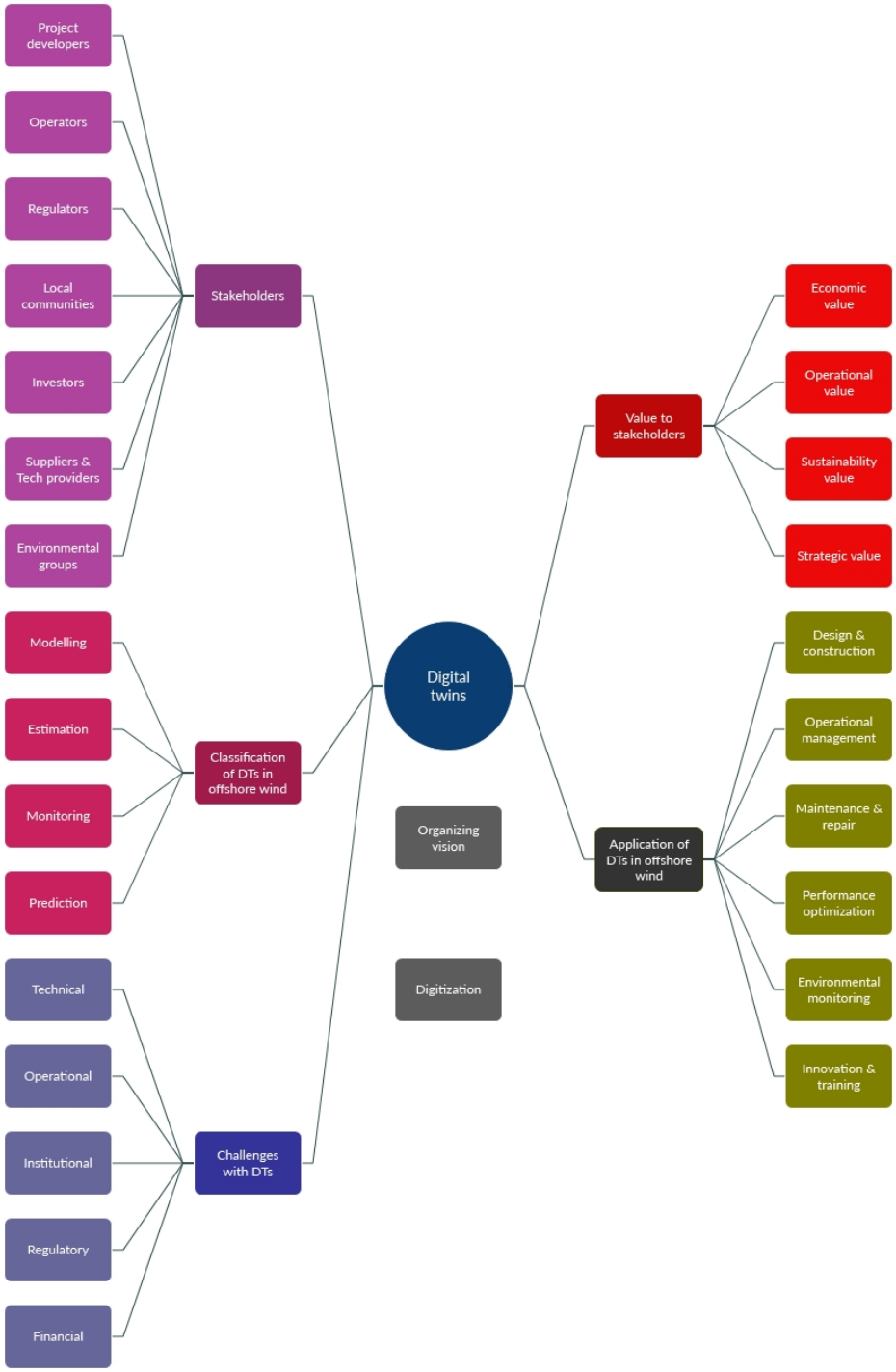

Figure 1 Literature visualized

Appendix B: Digital Twins

B.1 Global digital twin market size in the year 2020 and 2025

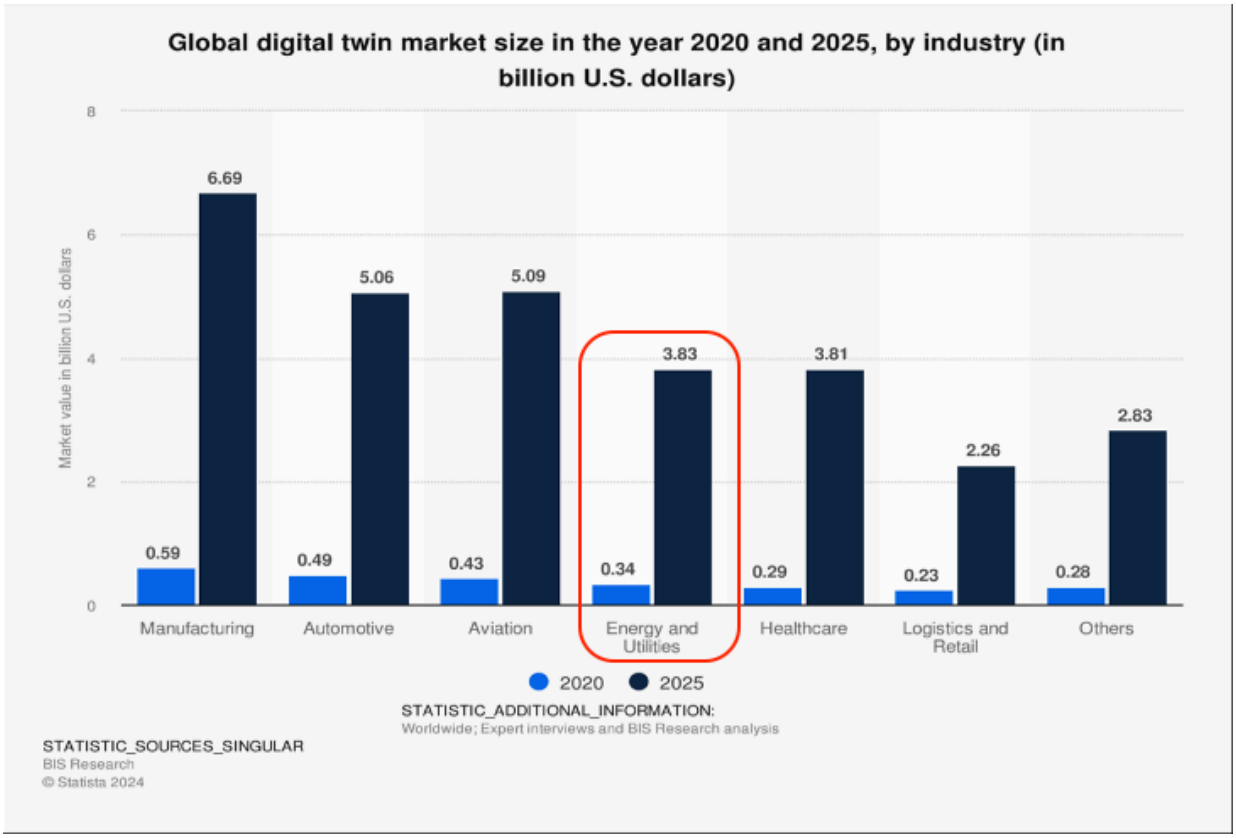

Figure 2 Global digital twin market size in the year 2020 and 2025, by industry (in billion U.S. dollars) (BIS Research., 2020)

Appendix C: Methodology

C.1 Theoretical Framework

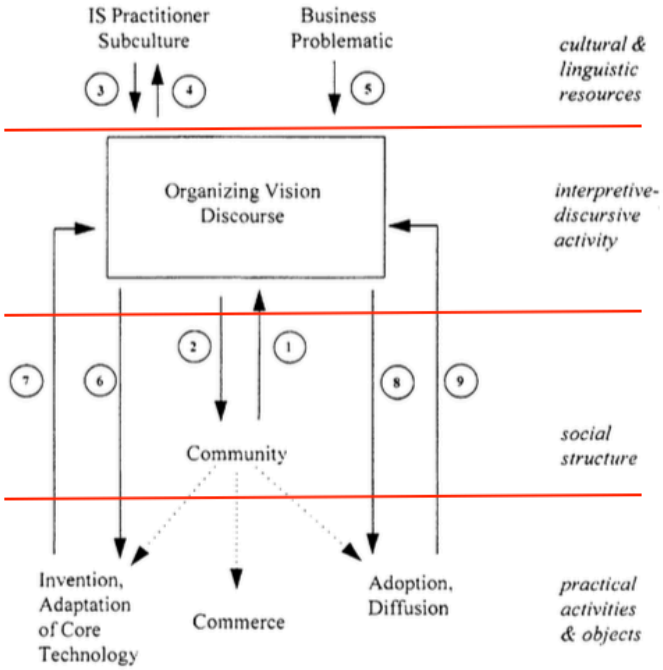

Figure 3 The institutional Production of Organizing Visions Adopted from Swanson and Ramiller (1997)

C.2 Research Framework

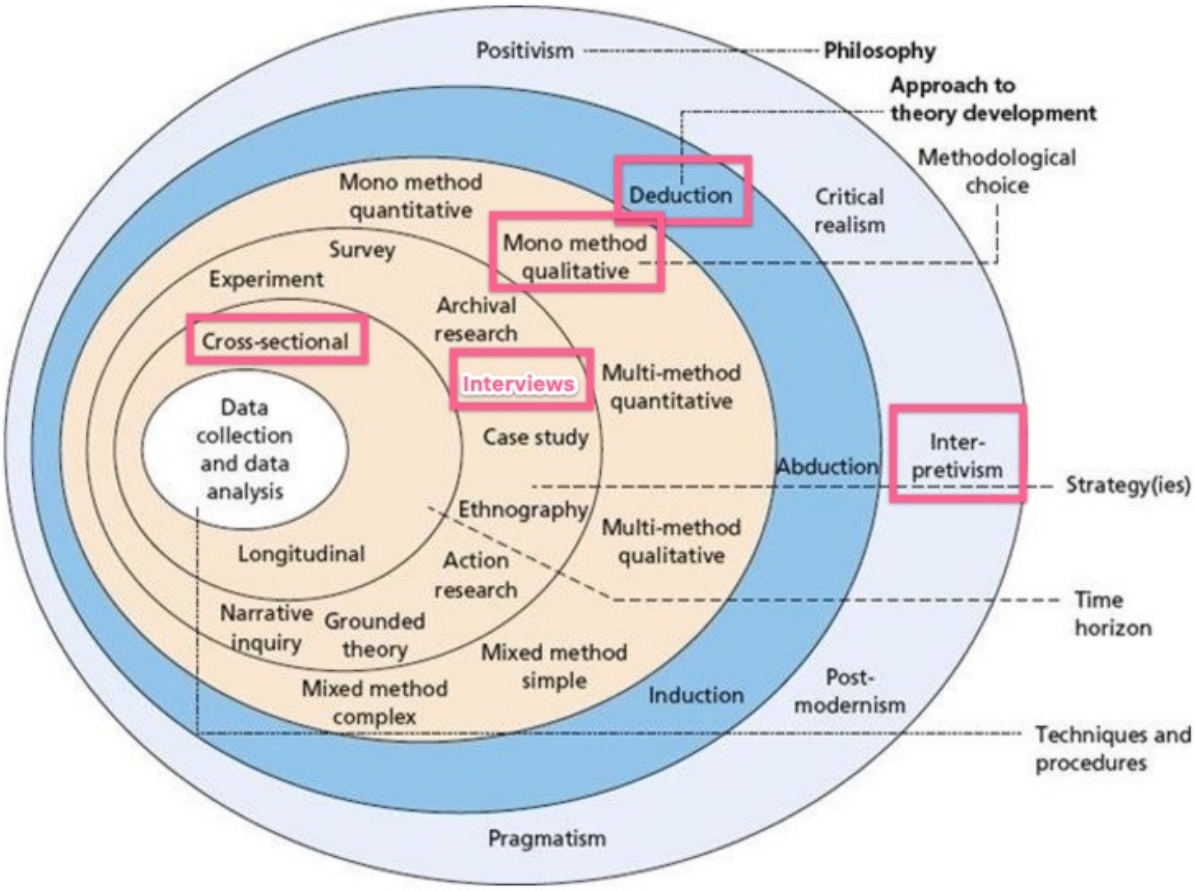

Figure 4 Research Onion with applied methodological approach; Source: (Saunders et al., 2019, p. 130)

Appendix D: Interview Consent Form and Questionnaire

D.1 Consent Form

Data controller student: Samuel Ziak

Title of assignment/project/Master Thesis: Integrating digital twins into offshore wind turbines

Supervisor of the assignment/project/Master's Thesis: Carsten Sørensen

During this interview, we will **explore the integration of digital twin technology within the offshore wind industry, with a particular focus on its organizational impacts and stakeholder engagement.** Our discussion will center on how digital twins are applied across various phases of offshore wind projects, and how these applications influence organizational transformation.

I hereby consent to the student's processing of data concerning me in connection with his/her degree programme at CBS. My personal data will be used in the aforementioned assignment/project/ Master's Thesis.

Consent Statement:

- The processing of my data in the assignment/project/Master's Thesis.
- My data to be disclosed to one or more students who are writing the assignment/ project/Master's Thesis jointly. The students have shared responsibility for the data.
- My data may be disclosed to CBS and to any external co-examiner in connection with supervision and assessment.
- My data may be published in anonymous form in connection with the publication of the assignment/project/Master's Thesis.

The data collected will be anonymized, and neither you nor the company you work for will be identified in the project. The transcription will be kept confidential and will not be included in the project. If the veracity of the interview is questioned, I will contact you to seek new consent for sharing the interview transcription with a limited number of people.

The transcription will be kept until a final grade is given for this project in December 2024.

The questionnaire begins on the next page.

D.2 Questionnaire

1. **Introduction and Background:**
    a. Can you briefly describe your role and responsibilities within the company?
    b. What is your understanding of the term "Digital Twin"?
        (DESCRIPTION) Digital twins are virtual replicas of as-built objects or actual processes and events, which mimic them in terms of behavior throughout the life cycle. It can be viewed either as product lifecycle or finished product. For our sake, we perceive digital twin as part of product lifecycle.
    c. Are digital twins directly / indirectly part of your work?
2. **Digital Twin Integration:**
    d. Can you describe how digital twin technology is planned (current or future) to be integrated within your projects?
    e. At what stages of the project lifecycle do you believe digital twins are most valuable, and why? *(Table provided for reference)*
    f. What specific objectives does your organization hope to achieve by implementing digital twins?
    g. How does your organization address the challenges related to the interoperability of digital twin technology with existing systems?
3. **Stakeholder Roles and Collaboration:**
    h. Who are the key stakeholders involved in the implementation (current or future) of digital twins in your projects, and what are their specific roles?
        (OPTIONAL) If you do not know – can you recommend someone who might know that I can talk to?
    i. From experience, how do you expect digital twins will impact collaboration between different stakeholders? *(Table provided for reference)*

Stakeholders	**Notes**
Project Developers	
Operators	
Regulators	
Local Communities	
Investors	
Suppliers and Technology Providers	
Environmental Groups	

Now we will discuss the needs and values. First, we will speak about "needs" and needs only. And only then about value in relation to digital twins.

4. **Needs:**

j. What are your needs as a stakeholder that you expect a digital twin can or will solve?
k. Which of the following needs are most relevant to your role? *(Table provided for reference)*

Specific Needs	**Notes**
- Planning in specific life-cycle phases - Identification of knowledge gaps - Part of the company's broader digitalization process	
- Specific means of decision-making - Supporting Business Cases	
- Lifetime extension - Cost optimization of O&M - Coordination in relation to other disciplines/stakeholders - Performance monitoring of specific topics - Supporting Business Cases	
- Specific areas of damage/abnormalities detection - Improvement of safety	
- Contributing to sustainability - Optimization of production (earnings)	

5. Value:

l. How do you perceive the value added by digital twins?
m. What do you think is the main value (if you have to choose one) provided by digital twins? *(come up on your own or get inspired from table above)*
n. Which of the following value areas do you believe are most significant in your projects? *(Table provided for reference)*

6. Challenges:

o. How does your organization address the challenges related to interoperability, data integration, and cybersecurity in digital twin implementations?
p. Can you discuss any other strategies or solutions that have been effective in overcoming challenges related to digital twin integration?

7. Future Perspectives:

q. How do you see the role of digital twins evolving in future offshore wind projects?
r. Do you wish for a standardization within the offshore wind market or would you prefer that it's more competitive than each company develops their own technology and keeps it within their sort of patent or knowledge?

Thank you for your time and insights today. Your contribution is invaluable to my research, and I greatly appreciate your participation. If you have any further thoughts or questions, feel free to reach out. I'll be in touch with the final outcomes of this project later this year. Thanks again!

Sincerely,

Samuel

Appendix E: Description of the Participants

E.1 Gender of the Participants

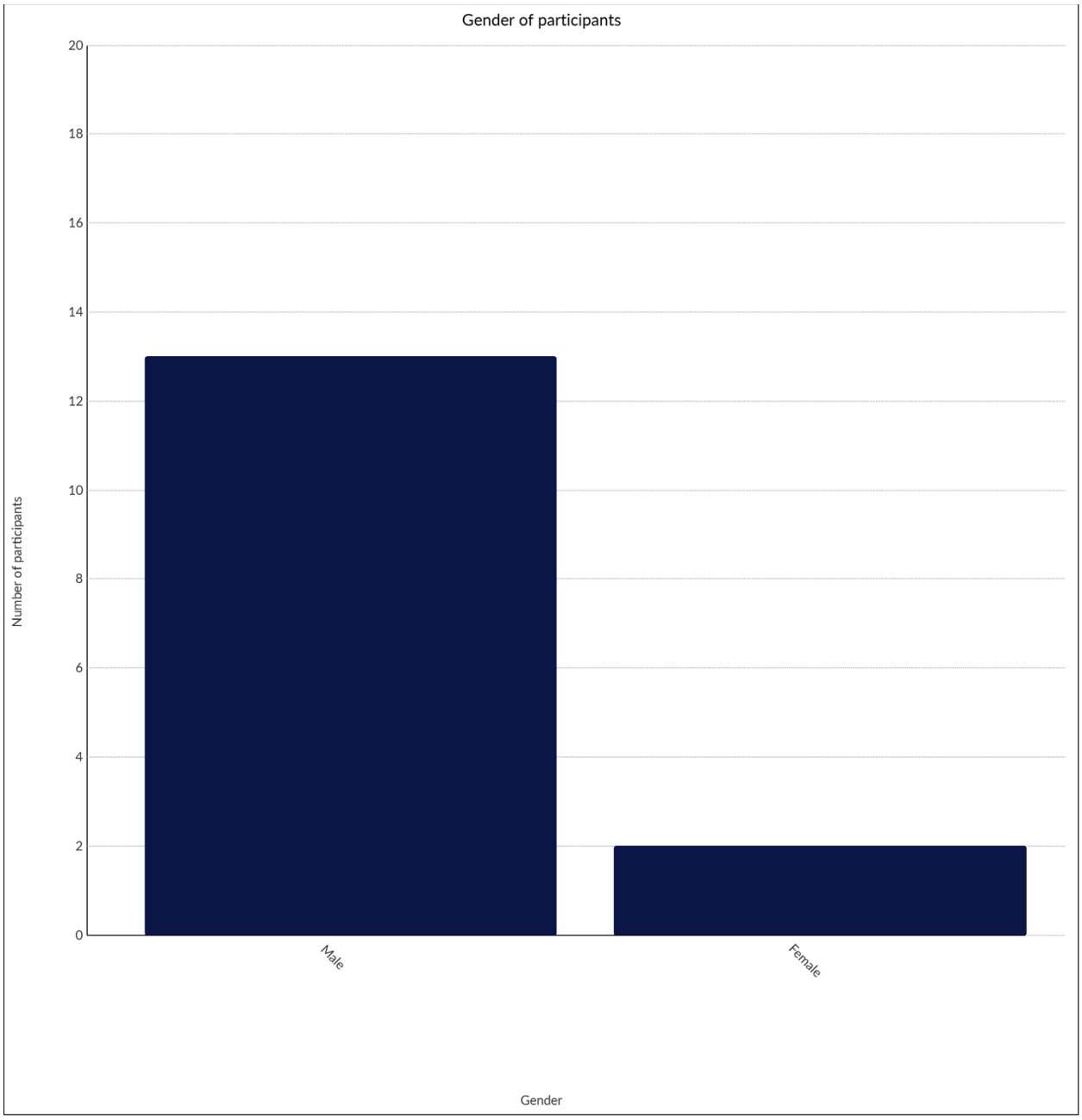

Figure 5 Gender of the Participants

E.2 Work Position of the Participants

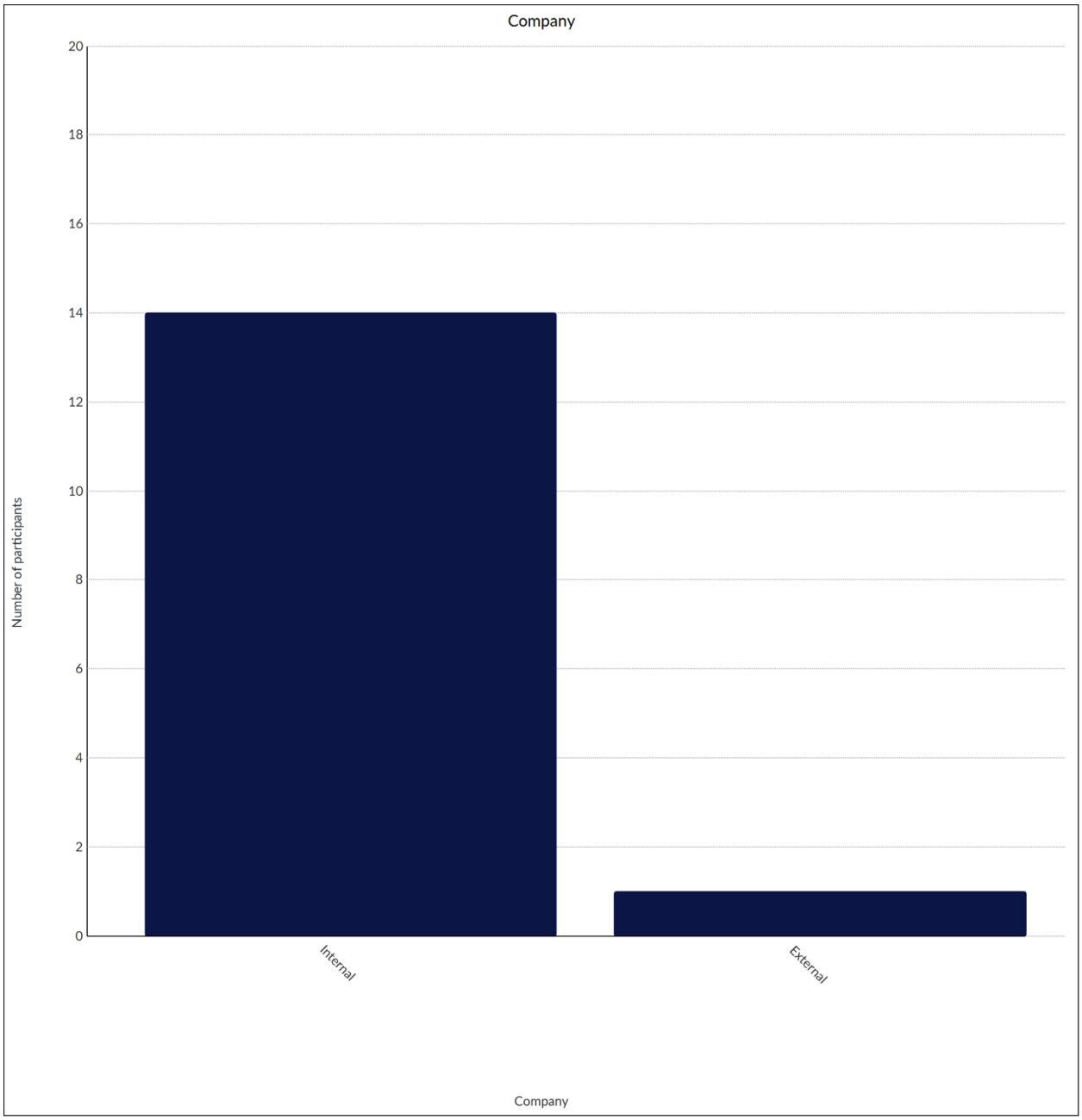

Figure 6 Work Position of the Participants

E.3 Business Unit of Participants

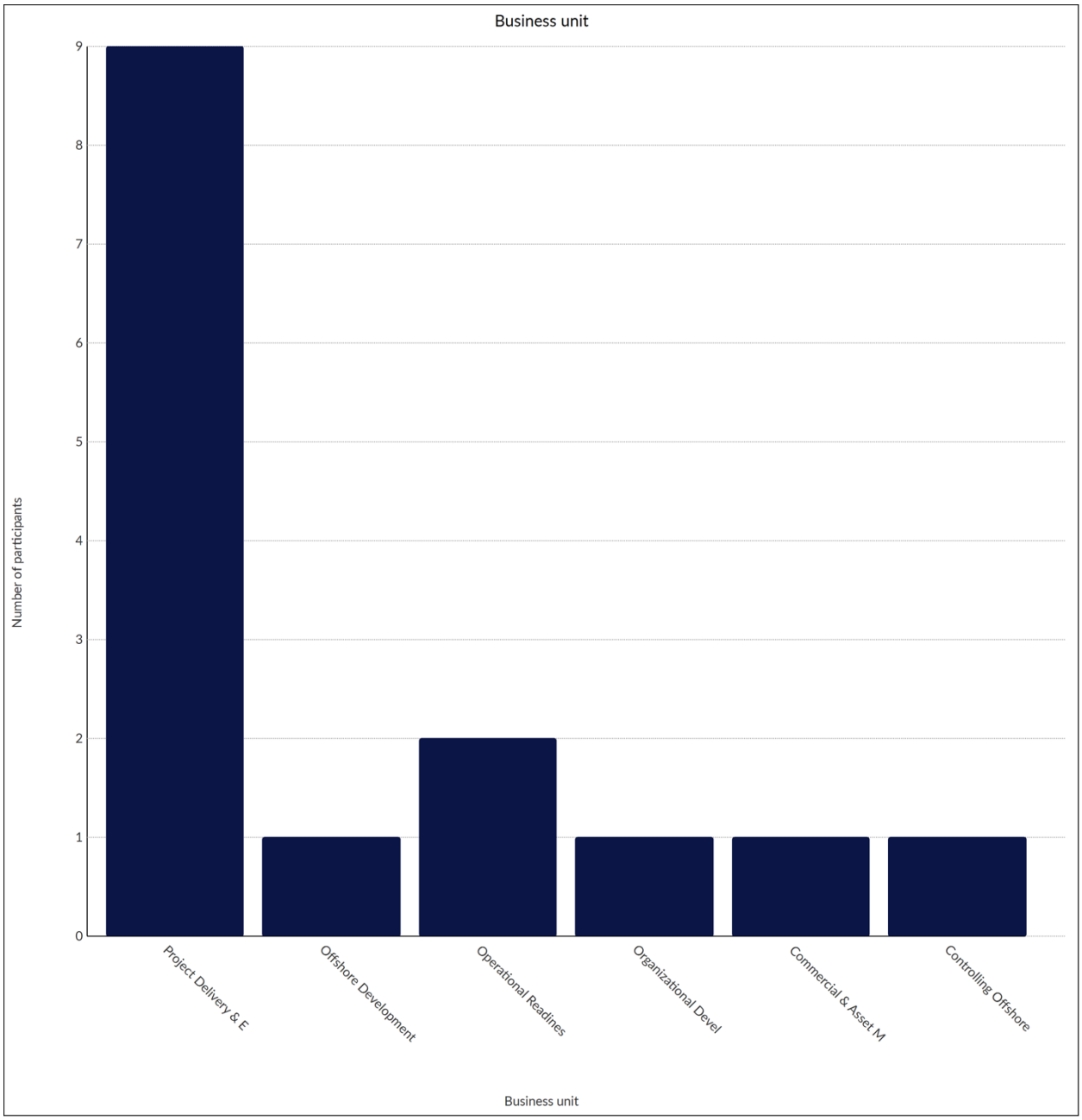

Figure 7 Business Unit of Participants

Appendix F: Summary Tables from Interviews

F.1 Summary Table 1

Question	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Understanding of Digital Twin	A digital twin is typically a digital replica of something physical, like a building, or even a process. Google Maps, for example, is populated with information like addresses, reviews, and opening hours	A digital twin is a virtual representation of an object or system designed to accurately reflect a physical object. It spans the object's lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help make decisions.	When we define a digital twin, for us, a digital twin is a prediction—a forecast—of something happening in the future, and it's something that we use to assess the risk of our decisions.	It's very important that we have a model, and you could say a calibrated model with the given environment and so on—this is what I consider the digital twin. I really like your focus on the entire lifecycle; that's quite accurate to me.	For me, a digital twin in its perfected form is a digital version of the physical assets offshore, where you can see what has been done on the asset, what it looks like today, and predict what it will need and look like in the future
Digital Twins in Work	Direct	Direct	Direct	Indirect	Indirect
Integration of Digital Twins in Offshore Wind	In offshore wind, digital twins are not that far along in terms of integration. The oil and gas industry is much further ahead because of the complexity and number of components involved. In offshore wind, there are fewer components, so the need isn't as urgent.	The plan is a three-year plan I developed with focus on increasing lifetime extension	We have real-time measurements, complete documentation of what's actually out there, and then on top of that, we also have human beings looking at the structure	In the very early stages, I struggled to figure out how to bank this—what the benefit would be to get it into the business cases	With SSI, they often communicate having a wind farm digital twin, which is a nice message from a communication perspective. But in reality, it's just one element—specifically assessing fatigue loads on foundations
Main Stakeholder	Typically, to do anything, you need money or the will to invest, driven by needs and value creation. Stakeholders are usually those who have a challenge they want to solve, like the people responsible for operations.	Investors	(No answer)	Project developers,	Operator and investor in the technology
Primary need	Challenge, usually related to cost	Lifetime extension	Make operations more efficient and informed by data	Improve business cases and extend lifetime for free. It is worth a lot	Lifetime extension
Other needs	Being in control of risk and safety. Improving efficiency in work and operations	But it's also about cutting costs or increasing earnings, and about sustainability, of course	Lifetime extensions, data-driven decision making	Cooperate with universities and regulars to enable to move the industry forward	So that's an important need where the digital twin, so to say, would help you show those stakeholders that

					they live up to the requirements for your asset
Primary value	Financial – economic value	Increasing your earnings.	Financial outlook, economic aspect is key	Economic and operational	assessing the remaining useful life of assets is highly valuable and important
Other values	Digital twins help you get the absolute maximum out of your structures while always being in control of risk and safety.	Extending the lifetime, reducing costs through optimization, and so on	Sustainability	Risk mitigation to enable partnering. Sustainability using less material	Another significant use case is operational data from production assets—analytics that optimize operations. Sustainability value
Challenges	Lack of experience understanding DT. Hard to invest if you do not understand	You are certain you could help the owner, but it's difficult for the owner to realize it	When dealing with such a project, the biggest challenge isn't technical—it's human	is the willingness to share data, for example, between turbine manufacturers and utilities. The openness between those organizations is one of the main challenges.	Do you have the broadband technology for data streaming available, and the whole architecture in your IT/OT landscape to bring all that data into data lakes and cold storage?
Other challenges	Stakeholder interested but lacks money	There are so many levels to pass where they have filters, and the message typically will not get to the top	Managing change across an entire organization is the most complicated journey.	There's also a challenge with data infrastructure.. Cybersecurity, intellectual property rights, and so on are big barriers.	As I mentioned with SSI, whereas outside, it means that the word digital twin can be diluted a bit and misunderstood
Future outlook	Ease collaboration between companies	Big worldwide database of all data transferring information for different purposes	Right now, we're in a bottom-up situation, where a small team is developing this and then telling the rest. Then there's a transition from bottom-up to top-down strategy.	In the future it could be in nature-inclusive designs, like monitoring fish populations around structures.	Then I think if you have that more perfected digital twin in the future—a digital twin that, for example, could also control your assets—you could use your digital twin to actually give instructions on what the operation will look like and change things in your turbine
Standardization	I'm for standardization across the industry. Then you can discuss which aspects to compete on and which not to	For standardization. Wind industry is famous for keeping things in silos and keeping the knowledge to themselves	I'm fully in favor of realizing that, yes.	Yes, to lead the way in the industry and share part of data to enable progress	The digital twin will continue to be there whether it will be less of a buzzword and more of people starting to understand the true application—that's maybe something that will happen over time.

Table 2 Summary Table out of Interviews 1

F.2 Summary Table 2

Question	Participant 6	Participant 7	Participant 8	Participant 9	Participant 10
Understanding of Digital Twin	My understanding of digital twin is that it's been a buzzword over the past five to ten years, covering many functionalities. In our context, particularly in foundations or structural analysis, I see it mainly as the collection and use of real-life data to back up our design assumptions made during the engineering phase, before a project is built	For me, in the basic sense, a digital twin is about visiting the data formation. I think of it as a number of models that describe the behavior and state of the turbine. But when you see it, you might think of 3D and VR, which aren't the focus here. For me, it's about taking models, typically design models that are certified, and deploying them at scale for mass consumption	What I would say is a digital twin is basically a model representing something physical out there. It doesn't necessarily need to be physical either, but it's representing a subject of interest, a model representing the behavior and processes of a system of interest	To me, there's a physical object out there in the world, and the digital twin represents the current state of that object. It can also predict forward, modeling future evolution of the state based on environmental effects, operational conditions, etc.	It's essentially a complete mirror of your assets. But the term is also used for simpler models, like basic 3D models or simpler algorithms. .So, in general, the term "digital twin" is used very broadly, which leads to confusion in the industry about what it means. This often results in different parties talking in slightly different "languages" when discussing technology.
Digital Twins in Work	Indirect	Direct	Direct	Indirect	Indirect
Integration of Digital Twins in Offshore Wind	For example, in a project, we set up a sensor system that provides data when the wind farm is commissioned, allowing us to continuously monitor what's happening.	We support various types, like MATLAB and Julia, and they can schedule how frequently these models are run, such as once a week or daily on turbines	Does that have a model of specific types of turbines, for example? And then how could we configure that? And in other business areas, we are working on standardizing.	We have some predictions from a couple of products brought in from the outside that one might label as digital twins for marketing purposes, but they're not truly digital twins.	Most of the digital twin work is handled by OEMs (Original Equipment Manufacturers). They integrate digital twins into their design processes.
Main Stakeholder	The generation department. The board making strategic investment decisions	Customers like major utilities	Project developers, operators and designers	Owner-operator role, so we're the end customer of digital twins	In the early or project phase, the developer is key. In the operational phase, it's the operator.
Primary need	One need is to identify opportunities that make business cases viable and optimize potential improvements.	DT can solve several things, but I think the main point is moving towards authoritative models—models we trust and dare to design with.	So, a need for a digital twin would be the need to verify some of the digital solutions or products that, as a supplier, we would be developing	There's no standardized test bench on the market to unequivocally establish their accuracy, which I'd love to see developed.	In the development, you know, it's really important that the digital twin is developed in close cooperation across all parties because otherwise, we're developing a solution that doesn't target the end customer at the end of the day.
Other needs	Another need is knowing it's safe to operate turbines even when unexpected events occur, such as minor	They ask for validation, and we can show years of operational data to demonstrate risk management. Operators benefit too, with virtual	Supporting a business case as you have up there. And also to better support decision-making. I mean, the better the digital twin, the better we can make	As an industry, suppliers and technology providers should collaborate more to provide comprehensive decision-making products rather than	For instance, optimization of production as well. The lifetime extension I could also see as part of it, specifically.

	structural damage or extended downtime.	sensors and lifetime counters that add value to service agreements.	decisions on rerouting energy, capacity constraints we have in the system,	just predictive ones. This would make it easier to justify the business case.	
Primary value	Where I'm most involved isn't the front end, so of course then it's the economic part that that plays in.	If I had been able to use digital twins to validate our models against historical data, I could have made decisions faster with less physical validation	That it increases the dependability of what we're developing.	So, they're mainly useful when you have an operational object, and their purpose is to make control and operational decisions	For me, it's either the economic or the operational part. Sustainability, yes, definitely I can see the value there. However, at the end of the day, the economic part is also important to set.
Other values	In regards to the validation part I think that's tapped into both the economic and the operational ability of it. But to have the control over what you are actually doing	From the customer's perspective, better models could enhance predictive maintenance or sell services that provide detailed insights, which is something we are beginning to explore	It could decrease the time to product. Or standardized interfaces	It's about balancing income, repair costs, and other factors with massive uncertainty and probability in those calculations.	Or it's in the operational phase where you get more intelligence by your digital twin and the ability to actually test something in your digital twin prior to testing it in the real environment.
Challenges	There's significant development potential in how we collect, transport, store, and preprocess large data volumes.	Customers might pay for lifetime counters for blade bearings across their wind farm. It depends on their internal business needs—some may want a full service contract, others might prefer just the digital twin service	But interoperability and standardization of technologies, I think, are the main challenges right now, especially since a lot of systems are actually very vendor-specific	But it's challenging. Turbine manufacturers, or OEMs, serve as a layer between the part manufacturers and the end users, which complicates integration.	It's crucial to determine the value you aim to create because there's a risk of having a very simple digital twin that doesn't provide much value, or spending so much on development that the digital twin's cost outweighs its benefits.
Other challenges	Another issue is managing the volume of data—determining the right granularity for storage, understanding the energy consumption related to IT use, and organizing data archives that remain usable as personnel change.	We also need to understand how to leverage that data internally. Operators typically have access to data, but they don't always have the design models or the broader perspective we have.	Nobody wants to work for a loss.	And this is the point: technology alone doesn't solve your problems. Data integration is always an issue: Are we measuring the right data? Is the data reliable? These problems persist, but the biggest issue is making the outputs useful.	At least I have been part of developing a digital twin in another company, and you shouldn't underestimate both the time, cost, and mapping it out to create your digital twin, to get the data in, and also to make it intelligent.
Future outlook	Safety is sort of the primary driver and that's also why we need to do the let's say getting rid of conservatives or adding risk as let's say two sides of the same coin but in a controlled way	From an OEM perspective, we want to offer digital twins as a service. In the past, we sold servicing of turbines, but now we need new revenue streams.	The wind industry is also quite complex, there are different classes of digital twins, and I think different parts of the industry, like structures, might be more interested in system-in-the-loop types of digital twins.	So, you have individual models for every single component, each updated with real data from the wind farm, predicting forward with environmental and operational inputs. That's when we're talking about digital twins. I'm not sure if that's the current roadmap.	I'm sure digital twins will become more prominent, and they are already used in some areas. But it's all about seeing the specific use case and driving it based on that.

Standardization	I think it would benefit us to, to have some openness on this in the industry	I think digital twins are still evolving, and it's important to understand how to scale this technology.	We should have standardized digital twin models.	What I'd really like is a standardized, accurate test bench with modern turbines and real data, operated by a trusted third party where suppliers and customers can participate. Customers like us provide data, and suppliers get their models tested, so they understand bias and error, making more informed, quicker purchasing decisions that benefit the whole industry	Is that what should be shared across the industry to see improvements? Of course, there are things you could share, but for me, it's not specifically about digital twins; it's more about standardization across the industry

Table 3 Summary Table out of Interviews 2

F.3 Summary Table 3

Question	Participant 11	Participant 12	Participant 13	Participant 14	Participant 15
Understanding of Digital Twin	So digital twin? I would say it's a type of mathematical description of the system that we are under—it's under our consideration. So basically, we expect to give the input to our system, and at the same time, the same input to the digital twin, and we are getting the same output from both of them. It's not necessarily nowadays just a kind of mathematical description. It could also be a visual description, a geographical description—it could be anything	But from the Structural Health Department and the Foundations Department, I've heard about it. My understanding is that it's a model of the wind turbine in the computer, kind of trying to replicate the real thing. You feed it with data and it can replicate the actual turbine and also forecast what happens if certain scenarios play out.	I would say it's basically a virtual wind farm. In that sense, it's having a virtual environment where you can try things without needing to do that on the operational wind farm. You can see how that works. It's basically a sandbox, I would call it. That would be my take on it,	So many use digital twins as a buzzword, and people have different perceptions of this buzzword. From my understanding, a digital twin is a digital representation of the real world and its behavior. So that means in my understanding it's not enough with just a computer model, a design computer model of some turbine, or if it was an offshore jacket or whatever it is.	I see two types of digital twins: the real-time digital twin and the retrospective digital twin. The retrospective digital twin is quite computationally heavy but simple in concept. It takes measurements from throughout the lifetime—say 20 years—and looks back at what has happened to the turbine The other kind, which is what most people refer to as a digital twin, is a real-time model that shows whether the turbine is experiencing more fatigue loads or higher extreme loads than anticipated.
Digital Twins in Work	Direct	Indirect	Indirect	Direct	Direct
Integration of Digital Twins in Offshore Wind	For instance, we have a component in the turbine like a reactor. We have a lot of data during the operation of this reactor when it was healthy, and we are using those data to create a kind of data-driven digital twin of that reactor component. And we are running this digital twin in parallel to the real systems	To my knowledge, the sensors are there. We developed the project and innovated the measuring devices on the turbines; we can capture the data we need.	(No answer)	So basically, that's what we have been working on for the last three years. We've basically just touched upon layer one and two, I would say. Right now, we have, I think, almost 200 wind turbines where we have sensors located in each one of the turbines. So, we get a lot of data coming in.	Last year, we did a lifetime extension for the first Danish offshore site, Horns Rev 1. We conducted a full simulation of what had happened over the past 20 years and evaluated if the turbines needed refurbishing or if we could extend their lifetime based on this digital twin.
Main Stakeholder	Operation and Maintenance	Between operators and investors. You haven't mentioned it, but part of my role is also the interface with the joint venture, so with our investors	Need to ensure the financial flow and that we have the funding in place.	Foundation Department—and Asset Management, who have sponsored the development. Additionally, Digital Engineering	Internal contributors are the foundation and wind turbine departments. Externally, I would look towards other project developers for potential partnership
Primary need	It's more related to the operation part because, in	My need is lifetime value optimization. Safety is always the	The only thing I can do is look at the benefit that the	I would expect that we can identify and quantify how	There are two main needs. First, with a real-time digital

	operation, we want to be able to detect failures as early as possible before they develop and cause secondary damage to the turbines.	first priority that needs to be guaranteed.	measure has, the financial impact, and then say that from a pure financial perspective, this would be the order you should execute them in.	conservative we are in the design—meaning how much additional lifetime we have compared to what we designed for.	twin, we can prevent major incidents by detecting when conditions exceed design levels, allowing us to intervene
Other needs	Before we start to build the park, we can have a digital twin of the park to see how it would react in the future and which aspects we need to consider.	That would also be helpful—you'd know which turbines to prioritize for fixing issues like corrosion. You can make decisions based on these kinds of models.	Financial perspective, it would be easier if you could replicate successful projects consistently. But things change over time.	Additionally, we should improve operations with real-time digital twins, focusing on safety and reliability	Second, we can better ensure the longest possible lifetime for the site.
Primary value	One person spent two weeks developing a small, tiny digital twin, and with that tiny thing, we were able to inform the team that a fan on the turbine was not working. Instead of sending person out on windfarm	. I would say digital twins, if they provide more insights into what we need to do on-site, offer good feedback for value optimization in terms of operations	It's not an immediate impact, that's clear. But I would say, in the end, if you're looking at the business case data and so forth, the advantage is in data gathering. The better the database, the better the decisions in the end.	So we account for the fatigue damages of the whole structure every day in, let's say, 500 points of interest all over the monopile and tower.	Extended lifetime, I would say. Remember, I'm only talking about offshore turbines.
Other values	Initially, they didn't want anything, then they accepted notifications, and now they want automatic actions without human intervention.	They also provide great insights for investors, especially when discussing major replacements towards the end of the asset's lifecycle. You need a business case to justify investments, and investors need to agree or not. If you gain time and can prepare decisions ahead, that's an enormous benefit.	But in the long run, with the data you are collecting or have in place, I would say it leads to more stable operations	This approach helps prevent critical failures and extends asset lifetime, which is valuable from a business perspective. Controlling operational safety means that we're not just scratching the surface; we're leveraging the data's full potential to optimize everything from fatigue management to operational strategies.	Minimizing OPEX costs—maintenance and operation costs—is also significant.
Challenges	And it also needs collaboration between suppliers, us as operators, and developers. Some components we don't have fully. It would be beneficial if OEMs could provide digital twins of their components when we are developing, to see what's the best match for us	My concern is that you only measure what you know, and you only know what you measure.	The challenge is, in the end, nobody wants to take the costs. It's like wanting the product but not wanting to pay for it.	If you write about the business case of digital twin technologies and sensors, don't forget the scale of work required for data infrastructure. It's a huge challenge and one that many have failed at in the past	Our biggest problem is getting detailed information on the turbine's design, assembly, and control.

Other challenges	As I mentioned, we cannot develop a complete digital twin of a turbine or wind park at once; we need to go component by component and then integrate them	And still, downtime and unavailability are very expensive, so it's better to do a little more maintenance a bit earlier than to risk having the turbine offline during the whole winter.	In the organization, it often comes back to having a customer in place. You shouldn't develop something without a use case.	Politics in a large company can also be challenging, as digital twins span different departments. There has been considerable debate about where this product should sit—within Foundations because it's monopile-focused or in Digital Engineering as it's a digital product.	My biggest concern is that we have detailed information about the foundations because we design them ourselves, but for the turbines, we don't have detailed designs for components like blades. This limits our ability to evaluate how well the turbine is performing relative to design
Future outlook	We also need to team up with other parts of the company for a real, comprehensive solution	Dashboards we have now that show the real-time status of the park—what's running, what has a problem. But you could also fast forward and see what the model predicts for the next half year. That would be the most advanced version I can imagine—not just the current situation but also predictions for the future.	Yes, I particularly think it's a super good tool. It could be beneficial, especially if you're investing in the same area. Gathering data without your own operations wouldn't be a bad move.	We're even developing a data-sharing platform, where our data will be accessible to the whole industry. We've already shared data packages with companies and students to explore, and I think this open approach is the right way to go.	I expect that in a few years, we'll be able to build very precise models based on actual data and measurements, allowing us to simulate how the turbine should behave and detect deviations.
Standardization	As I mentioned, you can get digital twins from OEMs; they could provide it to us, but some things related to our company—like how we use digital twins—should remain our knowledge.	There's so much to gain from the whole industry using the technology better. There's a broader societal benefit, and I think sharing is a good thing.	It depends. If you need funding and can solve it through partnerships, you should. If sharing data extends your database and offers mutual benefits, then it's worth considering. But if the gain from keeping it internal is greater, then don't share. It's a strategic decision.	We've published articles on our sensor systems, and I believe that's the right approach. We won't gain much by keeping this knowledge to ourselves. We will stay ahead because of ongoing development, so sharing only accelerates overall industry growth.	They (OEM) should share it, at least with their customers, so we can use it.

Table 4 Summary Table out of Interviews 3

Appendix G: Initial Codes and Themes

G.1 Initial Codes Grouped per Interviewee

Name	Files	References
01	1	40
02	1	44
03	1	36
04	1	50
05	1	42
06	1	44
07	1	37
08	1	55
09	1	42
10	1	39
11	1	38
12	1	40
13	1	30
14	1	65
15	1	20
Consent	15	15
Introduction	15	30

Table 5 Initial Codes Grouped per Interviewee

G.2 Initial Themes Derived out of Initial Codes

Name	Files	References
00 Consent	15	15
01 Stakeholder Perceptions of Value Creation from Digital Twins RQ1	15	100
02 Stakeholder Roles, Expectations, and Needs RQ2	14	70
03 Challenges in Adopting Digital Twins RQ3	15	101
04 Organizational Transformation and Impact of Digital Twins RQ4	15	109
05 Others	15	253

Table 6 Initial Themes Derived out of Initial Codes

Appendix H: Themes Comparison

H.1 Themes, Categories and Codes

Name	Files (Participants)	References (codes)
00 Consent	15	15
No	0	0
Yes	15	15
01 Stakeholder Perceptions of Value Creation from Digital Twins RQ1	15	**100**
001 Cost Savings		**18**
Minimal	3	4
Significant	9	14
002 Environmental and Sustainability Impact		**13**
High Perceived Benefit	7	12
Low Perceived Benefit	1	1
003 Long-term Strategic Value		**25**
Sustainable	10	20
Unsustainable	5	5
004 Operational Efficiency		**29**
High Impact	13	28
Low Impact	1	1
005 Risk & Safety Mitigation		**15**
In Control	6	12
Not In Control	3	3
02 Stakeholder Roles, Expectations, and Needs RQ2	14	**70**
001 Communication and Collaboration Enhancement		**11**
Improved	6	7
Unchanged	4	4
002 Expectations of Technology		**25**
High	11	19

Low	4	6
003 Role Clarity		**19**
Clear Stakeholders	8	15
Conflict of Stakeholders	3	4
004 Technological Needs		**15**
Unmet	7	10
Well-met	5	5
03 Challenges in Adopting Digital Twins RQ3	15	**101**
001 Cost of Implementation		**18**
High	9	17
Low	1	1
002 Data Security and Privacy Concerns		**9**
High	5	9
Low	0	0
003 Interoperability Issues		**20**
Insignificant	3	7
Significant	6	13
004 Regulatory and Compliance Barriers		**12**
Minimal	6	9
Significant	3	3
005 Stakeholder Resistance to Change		**12**
Strong	5	11
Weak	1	1
006 Technical Complexity		**30**
High	11	27
Low	2	3
04 Organizational Transformation and Impact of Digital Twins RQ4	15	**109**
001 Cross-functional Collaboration		**11**
Enhanced	5	7

Static	4	4
002 Cultural Change		**18**
Resistant	5	10
Transformative	4	8
003 Efficiency in Project Lifecycle Management		**18**
Certain phase	5	9
Entire life-cycle	5	9
004 Organization Process Changes		**12**
Marginal	4	4
Substantial	5	8
005 Real-time Decision Making		**18**
Improved	7	12
Unchanged	2	6
006 Standardization across industry		**32**
Retain knowledge	5	6
Share knowledge	13	26
05 Others	15	**253**
001 Introduction		30
Definition of digital twins		**15**
Work with digital twins		**15**
Direct	9	9
Indirect	6	6
002 Digital solutions		**15**
Cloud platforms	6	8
Dashboard visualization	2	3
Virtual world	3	4
003 Financial solutions		**48**
Business case improvement	8	13
Fatigue loads	4	13
Lifetime extension	7	22

004 Future outlook		**16**
Negative	2	2
Positive	8	14
005 Industry & Culture solutions		39
Conservatism	4	5
OEM	4	8
Offshore wind industry	4	9
Other industries	3	6
Training	2	2
Trust	4	5
Uncertainty	2	4
006 Technical solutions		**105**
Categorization	2	15
Composability	6	16
Design models	5	29
Integration	12	26
Predictive maintenance	4	6
Reusability	2	6
Time sensitivity	4	7

Table 7 Themes Comparison

H.2 Concept Map 01

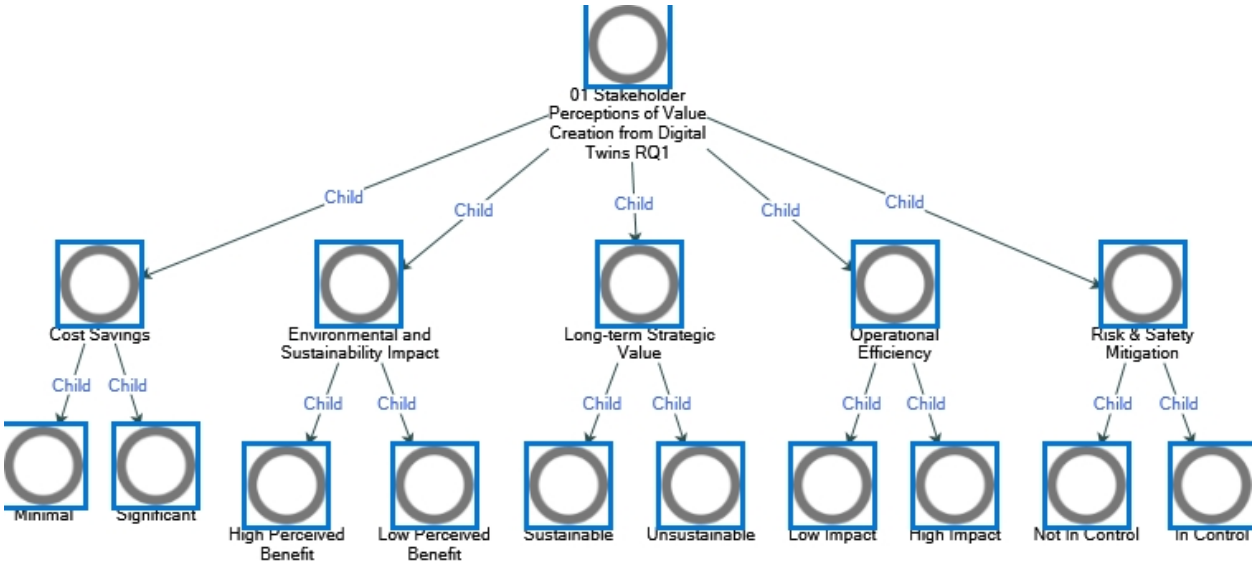

Figure 8 Concept Map: Stakeholder Perceptions of Value Creation from Digital Twins RQ1

H.3 Concept Map 02

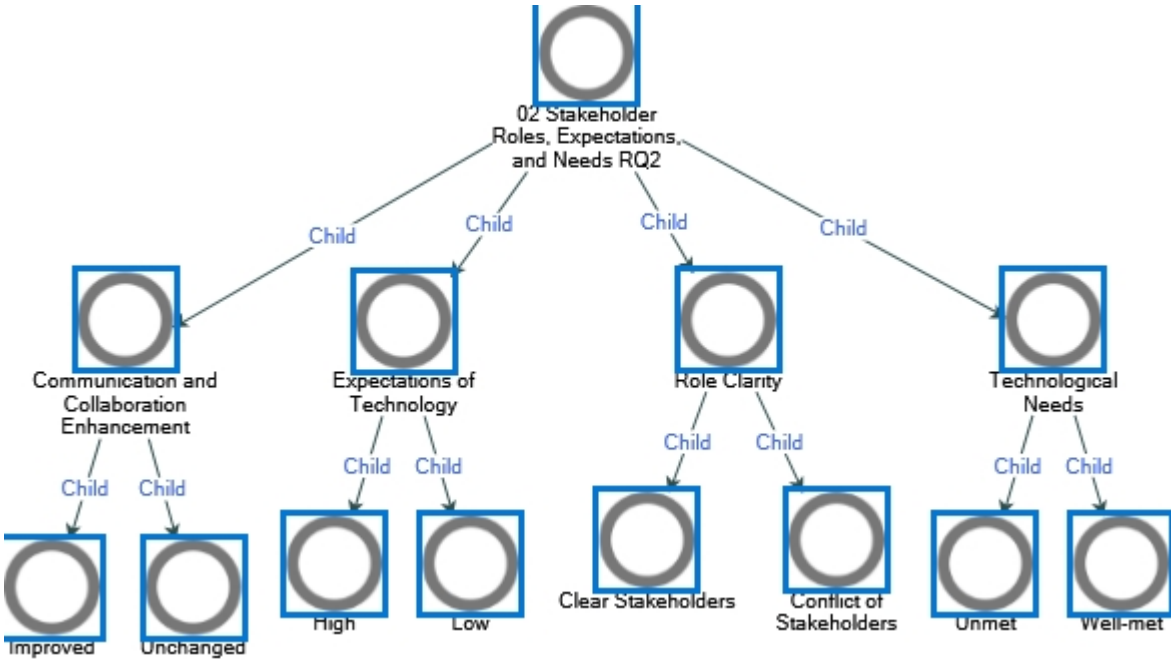

Figure 9 Concept Map: Stakeholders Roles, Expectations and Needs RQ2

H.4 Concept Map 03

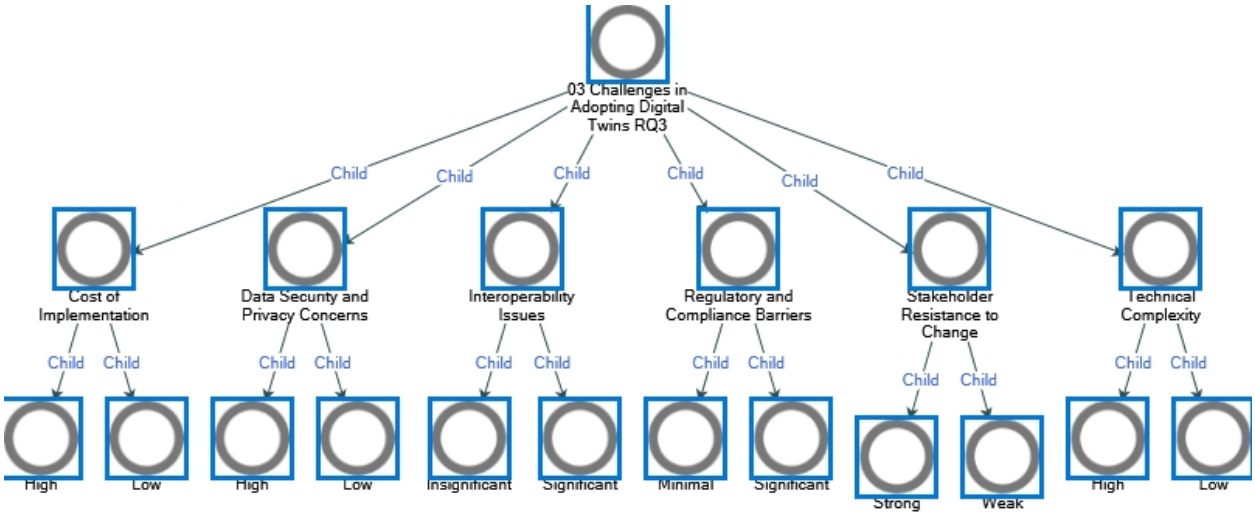

Figure 10 Concept Map: Challenges in Adopting Digital Twins RQ3

H.5 Concept Map 04

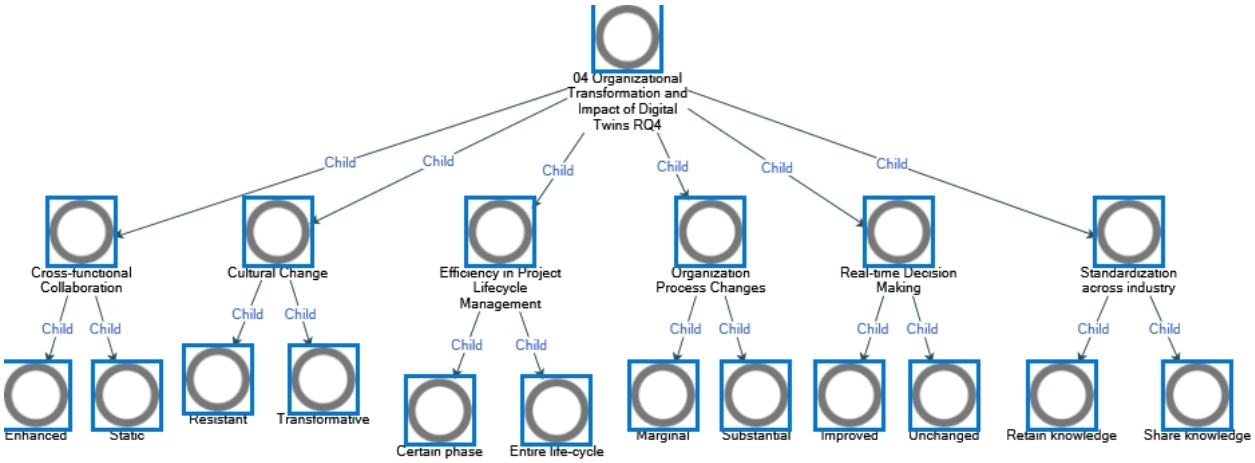

Figure 11 Concept Map: Organizational Transformation and Impact of Digital Twins RQ4

H.6 Concept Map 05

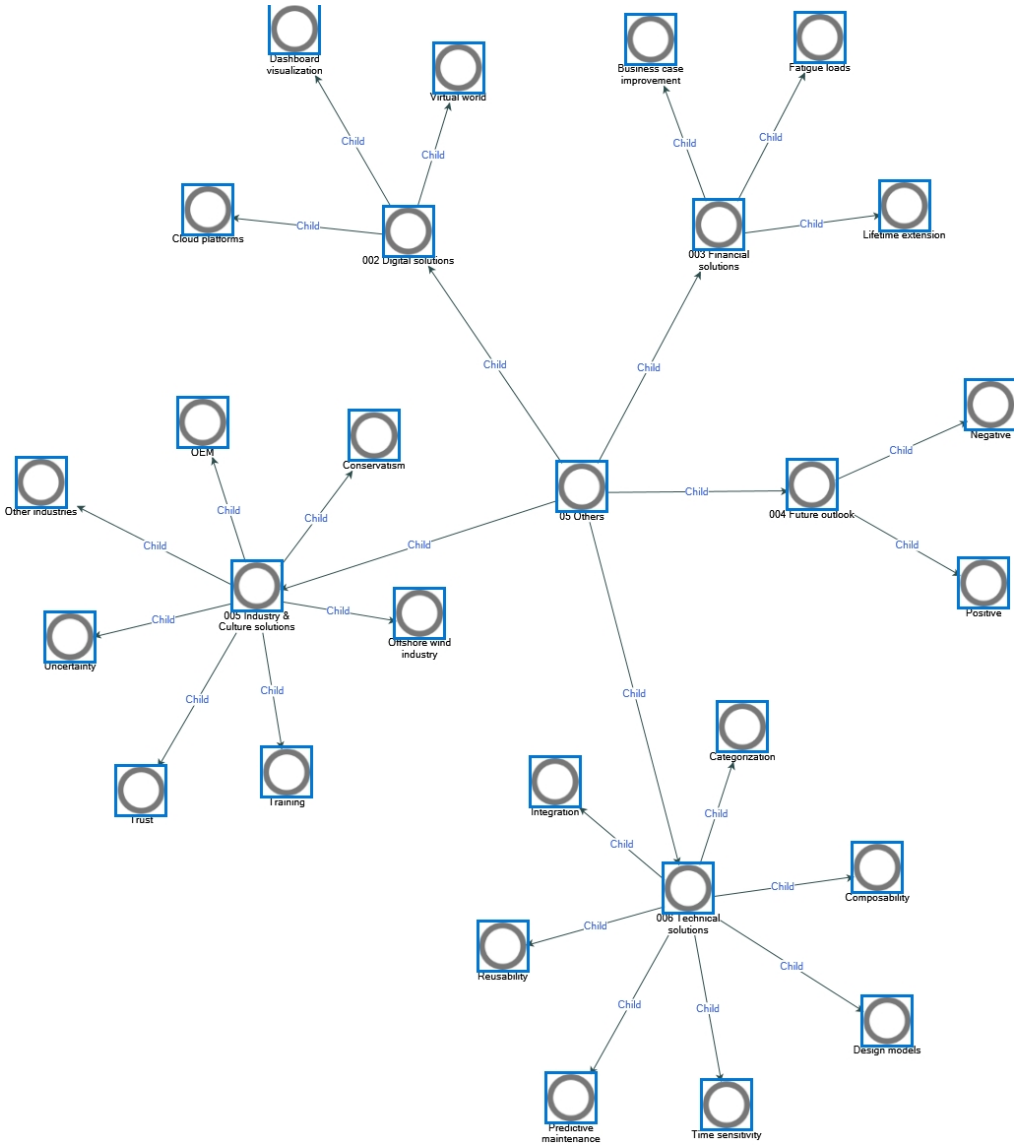

Figure 12 Concept Map: Others

Appendix I: Decomposition Trees of Themes

I.1 Stakeholder Perceptions of Value Creation from Digital Twins RQ1

Figure 13 Decomposition Tree: Stakeholder Perceptions of Value Creation from Digital Twins RQ1

I.2 Stakeholder Roles, Expectations, and Needs RQ2

Figure 14 Decomposition Tree: Stakeholder Roles, Expectations, and Needs RQ2

I.3 Challenges in Adopting Digital Twins RQ3

Figure 15 Decomposition Tree: Challenges in Adopting Digital Twins RQ3

I.4 Organizational Transformation and Impact of Digital Twins RQ4

Figure 16 Decomposition Tree: Organizational Transformation and Impact of Digital Twins RQ4

I.5 Others

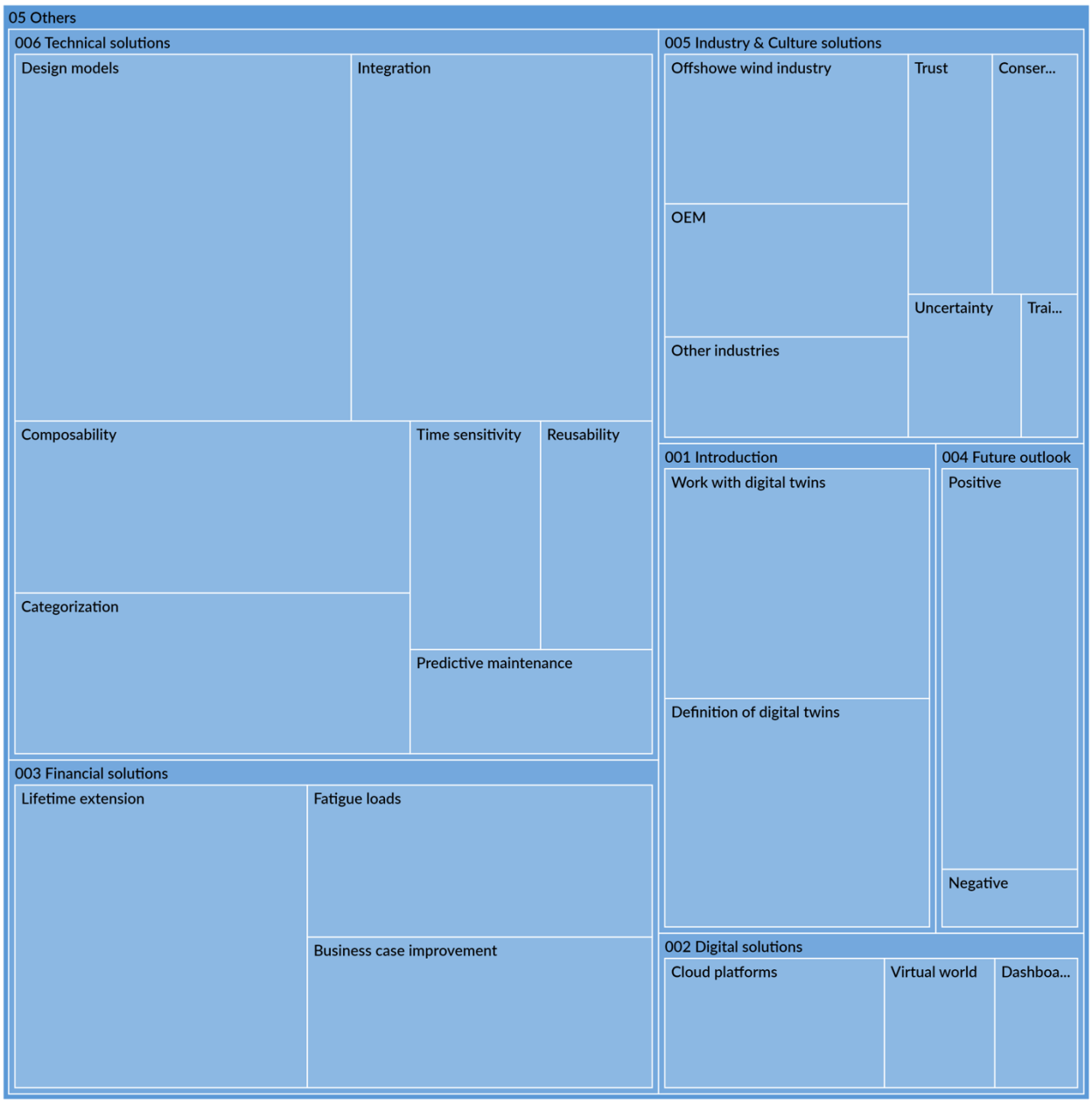

Figure 17 Decomposition Tree: Others

Appendix J: Codebook

00 Consent		**15**	**15**
No		0	0
Yes		15	15
01 Stakeholder Perceptions of Value Creation from Digital Twins RQ1	This theme establishes a foundation for understanding how stakeholders view the technology's benefits and drawbacks, setting the context for deeper analysis.It addresses primary research question: "How do different stakeholders perceive value creation from digital twins in offshore wind?" as well as (RQ1).	15	100
Cost Savings	(Significant vs. Minimal)	10	18
Minimal	Cost-saving effects are not clearly seen or considered marginal by stakeholder	3	4
06 challenges, key suppliers do not know where the money is going		1	1
09 challenges, cost of not training employees is higher		1	1
13 costs, DT for foundations costs are peanuts compared to steel prices or turbine generators		1	1
13 prioritization, on portfolio level we collect demand and trying to fit resources we have		1	1
Significant	Digital twins lead to a clear reduction in costs (e.g., maintenance,	9	14

	downtime, operational expenses).		
01 needs, cost reduction and control of risk and safety		1	1
01 stakeholders, goal is cost reduction		1	1
01 value, costs less to fix a problem early than later		1	1
02 future, within 3 years harvesting major part in lifetime extension and steel consumption in design		1	1
02 challenges, how to increase earnings, reduce costs through optimization		1	1
03 values, not doing anything without financial outlook		1	1
03 values, operational and economic aspects are closely linked, business case meets expectations		1	1
05 use case, unlike gearboxed or blades, structures cannot be replaced		1	1
06 values,how to spend our capex and how to balance opex		1	1
11 needs, O&M to help organization reduce costs		1	1
11 use case, cost optimization of maintenance to put turbines rest for 1 year		1	1
12 challenges, downtime and unavailability are very expensive so its better to do a little more maintenance		1	1
13 cost sharing, construction and development that benefit should share the costs but it is not easy in an organization with budget constraints		1	1
14 new system, we use accelerations in tower instead and is more economical, better lifetime and is much better		1	1
Environmental and Sustainability Impact	(High vs. Low Perceived Benefit)	8	13
High Perceived Benefit	Stakeholders view digital twins as contributing to sustainability goals, such as reducing carbon footprints or improving environmental monitoring.	7	12

01 sustainability, reusing instead of rebuilding is sustainability		1	1
01 sustainability, repurposing		1	1
01 sustainability, saving resources, enhancing sustainability		1	1
01 value, financial, economic value, extend rather than build		1	1
02 needs, cutting costs or increasing earnings and sustainability		1	1
03 values, sustainability through lifetime extensions, thought its not the primary focus		1	1
04 values, sustainability using less material, comes in design changes rather than O&M		1	1
05 values, importance of environmental benefits in addition to the financial benefits		1	1
05 values, predictive maintenance, you can save components early on, saving the environment		1	1
05 values, sustainability produce an asset with less steel		1	1
06 values, also sustainability to save steel for something else		1	1
14 values, our studies shown that scour protection correctly in design models could save up to 20 % of steel used		1	1
Low Perceived Benefit	Limited or no acknowledgment of environmental benefits.	1	1
13 environmental factors, green steel is always more expensive but it fits the company strategy		1	1
Long-term Strategic Value	(Sustainable vs. Unsustainable)	13	25
Sustainable	Digital twins are perceived as providing enduring strategic value, aiding future planning and scalability.	10	20
01 objective, highest level value creation when developing DT		1	1
01 objective, Lowest level easy access to data		1	1
01 stakeholders, funding from value creation		1	1

03 future, never succeed without a strategy		1	1
03 introduction, developments focused on value proposition		1	1
03 introduction, measure reality and ensure to have digital representation		1	1
03 values, information is power, we can influence both stakeholders how to operate		1	1
03 way of working, identify problem, mitigate it, update outlook		1	1
04 benefits, options to explore and encounter problems differently		1	1
04 values, de-risk project to enable incentive for partnering		1	1
05 use case, operational data from production assets, analytics that optimize operations		1	1
06 stakeholders, the board making strategic investment decisions		1	1
08 stakeholders, operators want to see behaviour of the system		1	1
09 strategy, technology are means of accelerating good strategy and supporting business processes		1	1
09 strategy, that is to me a key enabler otherwise IT predicts 1 thing and Engineering other		1	1
11 use case, operation as we want to be able detect failures as early as possible		1	1
11 values, 2 weeks developing DT saves loads of time and costs for downtime		1	1
13 financial perspective, you can put KPIs in place to assess the most beneficial investment		1	1
15 life cycle, for new sites we installed anemometers in the tower and foundation to monitor turbine performance over time		1	1
15 success, we determined there was about 10 years more life		1	1
Unsustainable	Digital twins are seen as limited in long-term value, with concerns about obsolescence or evolving project needs.	5	5
04 integration, struggled to figure out how to bank this, how to get it into business cases		1	1

05 challenges, DT word can be diluted and misunderstood in all sales material		1	1
07 values, customers might pay for lifetime counters for blade bearings across wind farm, some want full service contract others prefer digital twins service		1	1
10 challenges, roadmap in place, not getting too far down the road		1	1
14 costs, is the one part of the structure that you cannot change because is so expensive		1	1
Operational Efficiency	(High vs. Low Impact)	13	29
High Impact	Stakeholders report significant improvements in real-time monitoring, predictive maintenance, or resource optimization.	13	28
01 needs, improving efficiency in daily work		1	1
01 value, work efficiency, all available on screen		1	1
02 use case, improving operations, maintenance, optimization of earnings		1	1
02 value, 10year extension represents a lot of earning		1	1
02 values, lots of built-in advantages in lifetime extension on for example O&M		1	1
03 integration, control operation, ensure smoothest operation possible		1	1
03 way of working, measure performance prmeters, when deviation have closer look		1	1
04 benefits, lots O&M features to optimize		1	1
04 improvement, intervene with operation to improve performance, future more automated		1	1
04 values, decommision after 30, extend by 10, O&M costs go up linearly		1	1
05 values, run wind farm in more optimized way, operation is used on doing the best economic value		1	1

06 integration, if unexpected happen we can quickly assess operations		1	1
06 life cycle, for asset managers, the benefits can be planning preventive maintenance		1	1
06 values, validation is good for economic and operational ability and be in control what you are actually doing		1	1
07 stakeholders, operator benefit too		1	1
10 values, economic or operational part		1	1
10 values, operational phase where more intelligence by your DT to test something prior testing in real environment		1	1
10 values, sustainability has value, but at the end economic part is important		1	1
11 applicability, from the very start how much OPEX turbines might be		1	1
11 needs, optimize by knowing whats going on using DT		1	1
11 use case, optimize maintenance strategy, cannot be there every day		1	1
12 prioritization, DT would allow which turbines to prioritize for fixing issues		1	1
12 role, as asset manager my focus is on operational phase to focus on value adding		1	1
12 values, good feedback for value optimization in terms of operation		1	1
13 values, in the long run more stable operations		1	1
14 needs, we should improve operations focusing on safety and reliability		1	1
15 values, DT analysis revealed that retrofitting the blades can keep the farm ruinning for plus 10 years		1	1
15 values, minimising OPEX costs		1	1
Low Impact	Minimal or no perceived impact on operational performance.	1	1
12 experience, in previous job we talked about DT in maintenance		1	1
Risk & Safety Mitigation	(In Control vs Not In Control)	8	15

In Control	Stakeholders recognize the role of digital twins in reducing operational risks (e.g., equipment failure, safety issues, environmental impacts).	6	12
01 risk and safety, DT help you get maximum while being in control of risk and safety		1	1
01 stakeholders, risk and safety interest		1	1
01 value, continuous monitoring understand safety and risk levels		1	1
01. risk and safety, everything we do is based on safety		1	1
04 prevention inspections, according to standards and owners manual		1	1
06 integration, we ensure the safety is controlled and always in place		1	1
06 needs, guarantee of safety to operate turbines if unexpected events occur		1	1
06 values, be able to assess the risks to the specific case as a whole		1	1
06 values, safety is the primary driver and we need to get rid of conservatism and add risk in a controlled way		1	1
07 stakeholders, utilities ask for validation, we show risk management		1	1
09 operation, demonstrate they work in practice through controlled experiments		1	1
12 needs, safety is the first priority		1	1
Not In Control	Digital twins do not significantly improve risk management or risk-related decision-making.	3	3
01 needs, become in control of risk and safety		1	1
08 values, run what-if type scenarios without proving or doing risky operations on actual assets		1	1

15 values, if we were onshore also safety, but offshore a blade simply falls into the sea		1	1
02 Stakeholder Roles, Expectations, and Needs RQ2	After understanding stakeholder perceptions of value, it is important to identify their roles and expectations in the digital twin ecosystem. This directly relates to your sub-questions about stakeholder roles (SQ2) and their needs (RO2). Understanding the roles and expectations provides insight into why stakeholders perceive certain value or challenges.	14	70
Communication and Collaboration Enhancement	(Improved vs. Unchanged)	9	11
Improved	Digital twins facilitate better communication and collaboration among stakeholders (e.g., shared platforms, real-time updates).	6	7
01 future, ease collaboration among stakeholders		1	1
04 collaboration, universities need to co-develop those standards, is a bad circle to close		1	1
07 future, from OEM perspective we want to offer DT as a service, now we need new revenue streams		1	1
09 needs, suppliers and tech providers should collaborate to provide comprehensive decision making products		1	1

10 needs, stay close to stakeholders to ensure development meets needs		1	1
10 stakeholders, proximity to stakeholder is crucial		1	1
11 collaboration, we also need to team up with other parts of company to develop comprehensive solution		1	1
Unchanged	Digital twins do not noticeably improve stakeholder communication or collaboration.	4	4
02 stakeholders, if you cannot convince investors, you have no project		1	1
04 collaboration, universities are asking for data but utilities are reluctant to share		1	1
06 stakeholders, generation is primary customer and there needs to be good collaboration		1	1
14 challenges, DT should be product of foundations or digital engineering as it is a digital product		1	1
Expectations of Technology	(High vs. Low)	12	25
High	Stakeholders expect digital twins to deliver significant operational or strategic benefits.	11	19
01 challenge, complexity can deter users, simplicity is essential		1	1
02 needs, coding and software development to process data		1	1
03 integration, measurements, complete documentation and human beings on top of that		1	1
03 integration, not just monitoring, complete database of documentation		1	1
03 needs, driven by the old organization that initiated development of DT		1	1
05 integration, you may never reach perfection stage with DT for entire asset		1	1
05 reliability, showcase compliance from the data aggregated from the operation of the wind farm		1	1

	07 future, having AI and machine learning to consume data and aggregate into decisions and results		1	1
	08 digital platform, all could be done on 1 platform		1	1
	08 needs, to verify digital solutions or products we as suppliers are developing		1	1
	08 values, development time, in past it´d be long validation process and testing		1	1
	08 values, increase dependability and decrease time to product		1	1
	09 cybersecurity, DT predictive modelling is contained, data goes in but nothing goes out		1	1
	09 challenges, we need to account for diff turbines in proximity, varying ages and diff revenue rates		1	1
	10 future, DT will become more prominent based on specific use cases		1	1
	11 stakeholders, initially almost nothing from technology, now more and more features		1	1
	12 future, ease of use and access to data, nobody wants to dig through data		1	1
	12 transition, is about from fixed schedules to more data driven predictive approaches		1	1
	14 utilization, we need this tool to handle massive amounts of data		1	1
Low		Expectations are modest, with stakeholders unsure about the tangible benefits.	4	6
	04 initiation, we had data-driven O&M philosophy having lots of data without any use case		1	1
	05 challenges, misleading to believe that we can deliver more than we are doing		1	1
	11 challenges, we showed value, we demonstrated models of DT were providing useful information		1	1
	11 stakeholders, approched for basic functionality		1	1
	12 benefits, i do not need to know details as long as they can show and realize the value they sell		1	1

12 benefits, i do not need to understand the details as long as i understand the principle		1	1
Role Clarity	(Clear Stakeholders vs. Conflict of Interest)	9	19
Clear Stakeholders	Stakeholders have a well-defined role in the implementation or utilization of digital twins.	8	15
01 stakeholders, audits and regulatory bodies		1	1
01 stakeholders, government departments		1	1
01 stakeholders, insurance companies		1	1
01 stakeholders, operations team		1	1
01 stakeholders, people from operations		1	1
02 stakeholders, investors		1	1
04 stakeholders, are really important		1	1
04 stakeholders, environmental groups can be stakeholders		1	1
04 stakeholders, investors would inherently be a little bit pessimistic, they want low risk to ensure high business case certainty		1	1
06 stakeholders, regulators and certifiers		1	1
08 stakeholders, supplier and technology provider		1	1
12 values, also provide great inisghts for investors discussing major replacements towards the end of assets lifecycle		1	1
14 stakeholders, our team foundations dept and asset management who sponsored the development		1	1
15 stakeholders, foundations and wind turbine departments		1	1
15 stakeholders, supplier or tech provider		1	1
Conflict of Stakeholders	Stakeholders express confusion or lack clarity regarding their role in the digital twin ecosystem.	3	4

04 collision, between investors and project developers		1	1
04 stakeholders, conflict between investors and project developers		1	1
05 stakeholders, technology companies who develop and makret DT		1	1
06 stakeholders, operational teams and asset managers, these should not require a lot of staff once operational		1	1
Technological Needs	(Well-met vs. Unmet)	8	15
Unmet	Stakeholders express that digital twins fail to meet their specific requirements (e.g., usability, scalability, relevant data).	7	10
02 needs, it infrastructure to handle data		1	1
04 future, automated failure mode detection from DT		1	1
04 regrets, in many case we regret not having more extensive data		1	1
05 composability, bring components such as cables, substations together to have DT		1	1
05 stakeholders, external companies trying to sell digital twins of wind farms, instead they have DT for certain part of the wind farm		1	1
06 security, energy consumption related to IT and organizing data archives		1	1
08 needs, first simulare controller of DT before deploying it out in the field		1	1
08 understanding, there is no commong perception of what DT is in offshore wind		1	1
09 challenges, tech alone does not solve your problems		1	1
11 needs, DT can not solve everything		1	1
Well-met	Digital twins fulfill stakeholders' needs, such as real-time data visualization, automation, or integration with other systems.	5	5

02 needs, toolbox of advanced tools to solve specific needs		1	1
05 stakeholders, we are partners in work if we thinkg they have interesting product		1	1
06 development, if you develop something you might not develop it for yourself only		1	1
09 values, mixture of verificaiton and validation		1	1
10 needs, part of company´s product realization is not a need		1	1
03 Challenges in Adopting Digital Twins RQ3	Having understood how stakeholders perceive value and their roles, it's important to explore the barriers and challenges they face. This addresses SQ3 and RO3, focusing on obstacles to the adoption and implementation of digital twins. The challenges often provide context for gaps between expectations and outcomes, making this a logical next step.	15	101
Cost of Implementation	(High vs. Low)	10	18
High	The cost of implementing digital twins is seen as a major barrier, especially for those with limited budgets.	9	17
01 challenge, interested but lacks money to invest		1	1
01 needs, challenge related to costs		1	1
03 integration, complete cost loss, no profit nor revenue at this stage		1	1

04 challenges, you cannot prove that you will have problem down the line		1	1
05 challenges, SSI work costs a lot of money, therefore a need to market what they are doing		1	1
08 investment, all these technologies require upfront investment		1	1
09 history, government refused to fund research in previous role		1	1
09 stakeholders, DTs cost money so we need to understand benefits well		1	1
10 challenges, blockers and hurdles in development of DT might entail a lot of costs		1	1
10 values, determine the value as costs can outweight benefits		1	1
13 challenges, nobody wants to take the costs, is like wanting the product but not wanting to pay for it		1	1
13 challenges, you need a customer in place otherwise do not develop		1	1
13 stakeholders, be aware of cost impacts and need to have customer for the product		1	1
13 stakeholders, in the end you need to have a customer who is deploying the technology		1	1
13 stakeholders, you need to have someone paying for the development		1	1
13 use case, costs are ending in the right place which is of course customer side		1	1
14 success, the reason is that monopile especially is expensive to change		1	1
Low	Costs are seen as manageable or outweighed by the benefits.	1	1
06 challenges, to ensure this technology development as a priority		1	1
Data Security and Privacy Concerns	(High vs. Low)	5	9
High	Stakeholders are worried about data privacy and cybersecurity risks associated with	5	9

	digital twin technology.		
02 future, analogous to ChatGPT, absorb lots of data and categorize it, train models for diff purposes		1	1
02 challenges, digital platform to handle cybersecurity		1	1
04 challenges, gaining pipeline access to the sites, data infrastructure and IPR are big barriers		1	1
04 challenges, willingness to share data betweem manufactures and utilities		1	1
05 challenges, cybersecurity is absolutely criticial as DT gives visibility of your asset, but you may also be able to change things with your asset		1	1
10 challenges, both OT and IT security elements are high		1	1
10 challenges, we can get external company so how what DT can do but it must comply with our security requirements we have		1	1
10 challenges, within energy sector providing directly to TSO, where depenency is high on delivering high standard otherwise no electricity		1	1
13 digitization, is becoming more important and naturally increases cybersecurity threaths, but is just how work environments are evolving		1	1
Low	Stakeholders perceive these concerns as minimal or well-managed.	0	0
Interoperability Issues	(Significant vs Insignificant)	7	20
Insignificant	Few or no interoperability challenges reported.	3	7
05 digital platform, helpful but value drives in individual applications from different components		1	1
05 interoperability, value from applications and then connect them		1	1
08 composability, must share a common digital platform and set of rules to enable interoperability		1	1
08 interoperability, framework how we exchange information and how to fdefine attributs		1	1

08 interoperability, one of the success factors in DT		1	1
11 interoperability, knowing dependencies we want more accurate DT in the end		1	1
11 interoperability, outputs of these components to sum up		1	1
Significant	Significant challenges in connecting digital twins with existing technologies or data systems (e.g., data silos, incompatible software).	6	13
02 advantage & disadvantage, everything in one system, but less flexible		1	1
02 interoperability, combine different disciplines to create value		1	1
05 development, build brick by brick towards that vision of full scale offshore wind farm DT		1	1
05 challenges, create a platform that integrates everything is very challenging		1	1
05 interoperability, scattered landscape, ideally everything under one roof but would delay these capabilities available now		1	1
06 challenges, such as interoperability and development complexity		1	1
08 challenges, how to establish a common language		1	1
08 challenges, interoperability and standardization as lot of systems are vendor speicifc		1	1
08 interoperability, previosly you have silor of DTs		1	1
08 values, more standardized interfaces		1	1
09 integration, couple products brough in from outside that label as DT to predict failures		1	1
09 integration, you can not optimize gearbox maintenance in isolation, needs to account for other ongoing maintenance		1	1
14 future, focus of DT is on entire wind farm including cables, but right now we do only support structures on individual turbines		1	1
Regulatory and Compliance Barriers	(Significant vs. Minimal)	9	12

Minimal	Regulatory concerns are not perceived as a significant obstacle.	6	9
01 future, standardization across the industry, avoid competing on risk and safety		1	1
01 stakeholders, regulation of technology		1	1
03 stakeholders, existing rules and regulations do not fully cover what we are doing yet		1	1
04 stakeholders, incentivize regulators to advance the digital twin philosophy		1	1
12 collaboration, government reached out to us to assess lifetime extension		1	1
12 introduction, we needed to demonstrate to government how can our park be running longer and by how many years		1	1
12 stakeholders, government has interest in making best use of the space in north sea		1	1
14 industry, using DTs could lead to updated norms and stanrdards		1	1
15 stakeholders, look towards other project developers for potential partnerships		1	1
Significant	Regulations or compliance issues are seen as major barriers to the deployment of digital twins (e.g., data security, privacy concerns).	3	3
02 future, share experiences, also anonymize data so that it could benefit everyone without releasing secrets		1	1
05 needs, live to the requirements and compliance of your asset		1	1
10 cybersecurity, integrating DTs is a question of complying with regulations and requirements for security both on OT and IT sides		1	1
Stakeholder Resistance to Change	(Strong vs. Weak)	5	12
Strong	Resistance from stakeholders, such as reluctance to	5	11

	adopt new technologies or shift existing processes		
01 challenge, buzzwords and talk but lack understanding		1	1
01 challenge, lack of experience, people do not invest in what they do not understand		1	1
02 challenges, ask the owner what their needs are, but they´re not aware of possibilities		1	1
02 challenges, certain you can help, but difficult for owner to realize it		1	1
03 challenges, humans involved, managing change acrpss entire organization is complicated		1	1
03 challenges, rolling out DT is challenging, it relies on human input		1	1
03 challenges, the biggest challenge is human		1	1
05 challenges, buzzwords used as sales material and availability of data		1	1
05 challenges, DT is so broad and it is a trending word		1	1
10 future, it needs to mature more, with ability to create value		1	1
10 future, technology needs to be defined first		1	1
Weak	Minimal resistance, with stakeholders generally open to adoption and use of digital twins.	1	1
03 stakeholders, we need all certifying bodies on board		1	1
Technical Complexity	(High vs. Low)	11	30
High	Stakeholders cite significant technical challenges (e.g., integration with existing systems, complexity in data processing).	11	27
01 future, offshore wind DT integration		1	1
01 value, ease of use, information in one place		1	1

	02 future, some kind of platform to allow lots of connections		1	1
	02 challenge, bridgin the gaps and ensure no overlaps		1	1
	02 challenges, big gap, many levels to pass from technical engineering part		1	1
	02 uncertainties, never fully replicate real world but we can simulate		1	1
	03 life-cycle, DT consists of multiple data streams		1	1
	05 challenges, easy to build UI to present all kinds of data than to actually make data available and feed it into systems		1	1
	05 challenges, have the whole architecture in IT or OT landscape to bring all data in data lakes and cold storage		1	1
	05 challenges, initially is data collection		1	1
	05 challenges, selling a platform with visualizations but missing data, which is required to deliver by the buyer		1	1
	06 complications, we cannot defend trying trial and eror to see what we can get out of it		1	1
	06 challenges, digital and physical interfaces align		1	1
	06 challenges, how we collect, transport and store large data volumes		1	1
	06 life-cycle, expand scope and increase data flow		1	1
	06 technology, still in early stages especially in offshore wind		1	1
	06 technology, there is still work to be done to make it operational rather than development		1	1
	07 needs, design assumptions are made for turbines, but are needed for wind farms		1	1
	08 development, lots of early efforts should be able to emulate whether these applications is stable enough		1	1
	09 challenges, big challenge is making outputs useful		1	1
	10 challenges, data infrastructure needs to be mapped out before you even start developing		1	1
	10 challenges, first you need to understand how to get data in		1	1
	10 challenges, I was part of development of DT in other company, do not underestimate time, cost and mapping to create the DT to get the data in and make it intelligent		1	1

11 challenges, disturbances are challenging, we need to develop robut DTs against disturbances from outside		1	1
11 use case, we use Microsoft data lake house and azure machine learning and databrick for data exploration and DT development		1	1
14 data infrastructure, it is a challenge and many other operators struggled to develop it		1	1
14 challenges, scale of work required for data infrastructure is a huge challenge and many have failed at it		1	1
Low	Digital twins are perceived as straightforward to implement and use.	2	3
01 integration, offshore wind not far along in integration		1	1
02 future, if you have a technology, you cannot imagine the delay to implement it		1	1
02 probabilities, today you might never experience probability to failure		1	1
04 Organizational Transformation and Impact of Digital Twins RQ4	Once established how stakeholders perceive value and identified key challenges, now we can focus on how digital twins influence organizational transformation (SQ4 and RO4). This theme covers broader organizational impacts, such as process changes, cultural shifts, and collaboration, which are often shaped by the challenges and roles already identified.	15	109
Cross-functional Collaboration	(Enhanced vs. Static)	8	11

Enhanced	Digital twins foster better collaboration between departments (e.g., engineering, operations, finance).	5	7
01 interoperability, ultimate dream about collaboration but also different disciplines		1	1
02 collaboration, coordinate operation and structural team to take initiatives together		1	1
06 collaboration, the generation wants it so much that is easier for us to keep it under budget		1	1
08 integration, we work with DTs in other business areas and work on standardizing how we see diff components		1	1
14 application, first the DT will be used for our team and once tested it will be used towards stakeholders		1	1
14 challenges, we collaborate with digital engineering to bridge the gap between technology and engineering		1	1
14 stakeholders, additionally digital engineering ensuring governance, security and IT compliance for web based hosting		1	1
Static	Collaboration remains siloed, with little change in interdepartmental communication or cooperation.	4	4
03 way of working, proactive, normally we get a call		1	1
06 responsibilities, teams involved in work related to DT leave the project early so there is a need for systematic handover		1	1
09 needs, better collaboration between modelers, turbine manufacturrers and part suppliers, but incentives dont favor this		1	1
11 challenges, team has developers but not necessarily engineering knowledge of the DT		1	1
Cultural Change	(Transformative vs. Resistant)	7	18
Resistant	Organizational culture remains unchanged, or	5	10

	resistance to digital adoption is strong.		
02 challenges, convince organization they need this, barriers in addopting new technologies		1	1
02 challenges, message will not get to the top, siloed departments		1	1
02 standardization, wind industry keeping knowledge in silos		1	1
03 future, small team from bottom-up telling the rest this is the way		1	1
04 challenge, need to address cultural challenge		1	1
04 challenges, cultural change to convince organization that we need monitoring to be proactive		1	1
04 challenges, organizational acceptance is a struggle		1	1
06 challenges, the organizational setup to have the same priorities		1	1
06 responsibilities, DT cut across established pakcages and is important to streamline to project organization		1	1
14 challenges, politics can also be challenging as DT spans across diff departments		1	1
Transformative	The adoption of digital twins fosters a culture of innovation and data-driven decision-making.	4	8
01 technology, not moving backwards		1	1
03 future, transition from top-down strategy		1	1
03 challenges, key decision makers and ambassadors to be around, is crucial to have gatekeepers in large organization		1	1
03 organization, change management people with driving the change		1	1
03 organization, if you dont have gatekeepers, you will never succeed implementing it		1	1
03 strategy, moving the industry forward		1	1
04 benefit, DT can help break silos and barriers		1	1
05 future, it might be less of a buzzword and more people starting to understand the true application		1	1

Efficiency in Project Lifecycle Management	(Optimized vs. Inefficient)	8	18
Certain phase	Digital twins do not significantly improve lifecycle management, or challenges persist in certain stages.	5	9
04 integration, initially design and later operational phase		1	1
06 life-cycle, enable value during engineering, design and construction		1	1
06. life-cycle, deliberate decision to allocate resources		1	1
10 integration, DT is useful in early design phases and is done by OEM, they have most of design capabilities and simulations		1	1
10 life cycle, most vlauable in design and construction phase		1	1
10 stakeholders, design and construction vs operaitonal phase diff stakeholders		1	1
10 values, provide stronger design and construction capabilities in project phase		1	1
11 integration, before we build the park we can have DT to see how it would react		1	1
13 life cycle, deploy it in development phase so you can still shape it		1	1
Entire life-cycle	Stakeholders report that digital twins optimize the lifecycle management of offshore wind projects, from design to decommissioning.	5	9
01 project lifecycle, DT monitoring along the life		1	1
01 project lifecycle, DT part of project from day 1		1	1
01 project lifecycle, not too late to integrate DT in existing wind farm		1	1
04 integration, look at entire lifecycle and next era in offshore wind		1	1
04 life cycle, entire life-cycle		1	1

04 life-cycle, important to have full lifecycle on board for strategy		1	1
05 life-cycle, all stage have own value proposition, cost savings from understanding fatigue are significant		1	1
08 life cycle, apply it during entire project lifetime even before you built the system		1	1
11 use case, many use cases from development to decommissioning		1	1
Organization Process Changes	(Substantial vs. Marginal)	7	12
Marginal	Process changes are minimal or non-existent.	4	4
04 initiation, strategy commencement in 2020 but did not pick up		1	1
06 challenges, priority of one team but not a top priority of other team		1	1
10 standardization, too early to say because the tech is not fully developed		1	1
11 challenges, later you need input from end users to make it part of their daily processes		1	1
Substantial	Digital twins lead to significant process changes, such as new workflows, decision-making processes, or operational practices.	5	8
01 integration, within our organization state-of-the-art		1	1
02 interdisciplinary, DT experts in each discipline		1	1
02 values, tomorrow with this technology and our expertise you can realize this benefit tomorrow		1	1
03 interoperability, not just building API, matter of building organization that operates on certain interface		1	1
03 strategy, you need all parts of the organization onboard with strategy		1	1
04 challenges, fence between phases where materials are just handed to next team without lessons learned		1	1

04 regrets, could have made so much value if we did it in the past		1	1
06 challenges, it might be a struggle to let go of what we develop to the other teams		1	1
Real-time Decision Making	(Improved vs. Unchanged)	7	18
Improved	Digital twins enable faster, data-driven decision-making through real-time insights and predictive capabilities.	7	12
02 challenges, decision-making can change but decisions can be based on technology		1	1
02 values, supporting decision-making is a discipline in itself		1	1
03 needs, the real origin is in enhancing data-driven decision making and digitalization of processes		1	1
04 integration, vehicle to enable data-drioven decision making		1	1
06 stakeholders, to make sure that this technology fits the company as well		1	1
08 interconnected, model of system of interest receives updates		1	1
08 introduction, have model of transmission system, by feeding it real time data get updated behaviour of power system		1	1
08 introduction, monitoring or control system to make necessary decisions		1	1
08 life cycle, interconnect model with real time data coming from realized DT		1	1
08 needs, to support decision making		1	1
09 needs, decision support during operational phase		1	1
13, values this leads to a better decision making		1	1
Unchanged	No noticeable improvement in decision-making processes.	2	6

09 decision making, if decision makers do not understand we always make suboptimal decisions		1	1
09 challenges, model needs to support decisions to be usefuk		1	1
09 challenges, need a business capable making uncertainty based decisions, people need training		1	1
09 challenges, people currently cannot quantify impacts of decisions		1	1
09 technology, DTs can´t make decisions, they do not provide business answers directly		1	1
13 values, as well as data collection you make decision not based on assumptions but on things that worked in the past		1	1
Standardization across industry		14	32
Retain knowledge		5	6
03 standardization, limited resources to achieve common goal for humanity		1	1
04 standardization, can become competitive edge and we are gaining lot from measurements on business cases		1	1
11 standardization, OEM can provide DT to us, but how to use it should remain our knowledge		1	1
11 standardization, the way we operate our business is something we know		1	1
12 standardization, is nice to be a leader because that is how you beat competition, it is valuable		1	1
13 standardization, if the gain is greater do not share, is a strategic decision		1	1
Share knowledge		13	26
01 future, generic format but decide which prmters to compete on		1	1
02 needs, support of standardization		1	1
02 stakeholders, society will focus on getting richer, innovation and local community		1	1
02 stakeholders, society would benefit from having sustainable production of energy		1	1
02 standardization, real benefit comes from sharing		1	1
03 standardization, fully in favor		1	1

	04 change industry, we need to be transparent with the data		1	1
	04 standardization, needs to happen across industry, someone needs to take initiative on data sharing		1	1
	04 standardization, open to share everything but can be difficult		1	1
	06 future, a team can get devoured by its own development if there is nobody to spar with		1	1
	06 future, is always good to hear ideas from someone outside of your own bubble		1	1
	06 standardadization, it would benefit us to have some opennes on this		1	1
	07 standardization, DTs are still evolving and important is how to scale this technology		1	1
	08 standardization, we should standardize DT models		1	1
	09 standardization, modern turbines and real data with suppliers and customer participate		1	1
	10 standardization, is not to be shared only DT across industry, is more about entire industry standardization		1	1
	12 standardization, on the other hand people rotate in offshore wind and the word spreads around		1	1
	12 standardization, there is so much to gain from whole industry using this technology better, also societal benefit and sharing is a good thing		1	1
	12 standardization, you gain more if you share the knowledge		1	1
	13 standardization, could be beneficial if you are investing in the same area		1	1
	13 standardization, it depends maybe find partnerships for data sharings and offers mutual benefits		1	1
	14 futures, we shared data packages with companies and students to explore if this is the right way to go		1	1
	14 standardization, sharing our insights and data would challenge the industry to evlve and help us to profitable market		1	1
	14 standardization, we are developing data sharing platform to allow accessible data to whole industry		1	1
	14 standardization, we won´t gain much by keeping this knowledge to ourselves		1	1
	15 standardization, share it at least with customers		1	1

05 Others		15	253
001 Introduction		15	30
Definition of digital twins		15	15
01 The most used digital twin in the world is Google Maps. A digital twin is typically a digital replica of something physical, like a building, or even a process. Google Maps, for example, is populated with information like addresses, reviews, and opening hours. In the context of integrity management, it could be documents, drawings, or other information. The real-time aspect is also critical—just like Google Maps tells you how long it will take to drive from A to B, a digital twin can provide real-time data through sensors. The main purpose is to make life easier by having all information in one place, rather than scattered across different platforms.		1	1
02 Yeah, I've seen many formulations, and I think you also provided a fundamental one, but I maybe prefer another formulation. A digital twin is a virtual representation of an object or system designed to accurately reflect a physical object. It spans the object's lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help make decisions. So, I like that definition a lot.		1	1
03 When we define a digital twin, for us, a digital twin is a prediction—a forecast—of something happening in the future, and it's something that we use to assess the risk of our decisions.		1	1
04 It's very important that we have a model, and you could say a calibrated model with the given environment and so on—this is what I consider the digital twin. I really like your focus on the entire lifecycle; that's quite accurate to me.		1	1
05 For me, a digital twin in its perfected form is a digital version of the physical assets offshore, where you can see what has been done on the asset, what it looks like today, and predict what it will need and look like in the future		1	1
06 My understanding of digital twin is that it's been a buzzword over the past five to ten years, covering many functionalities. In our context, particularly in foundations or structural analysis, I see it mainly as the collection and use of real-life data to back up our design assumptions made during the engineering phase, before a project is built. This data can be used during the operational phase to troubleshoot, extend the project's lifetime, or improve design methodologies in future iterations of the digital twin		1	1
07 now we could spend the next hour talking about what it is. For me, in the basic sense, a digital twin is about visiting the data formation. I think of it as a number of models that describe the behavior and state		1	1

	of the turbine. But when you see it, you might think of 3D and VR, which aren't the focus here. For me, it's about taking models, typically design models that are certified, and deploying them at scale for mass consumption			
	08 what I would say is a digital twin is basically a model representing something physical out there. It doesn't necessarily need to be physical either, but it's representing a subject of interest, a model representing the behavior and processes of a system of interest		1	1
	09 To me, there's a physical object out there in the world, and the digital twin represents the current state of that object. It can also predict forward, modeling future evolution of the state based on environmental effects, operational conditions, etc.		1	1
	10 It's essentially a complete mirror of your assets. But the term is also used for simpler models, like basic 3D models or simpler algorithms. So, in general, the term "digital twin" is used very broadly, which leads to confusion in the industry about what it means. This often results in different parties talking in slightly different "languages" when discussing technology.		1	1
	11 So digital twin? I would say it's a type of mathematical description of the system that we are under—it's under our consideration. So basically, we expect to give the input to our system, and at the same time, the same input to the digital twin, and we are getting the same output from both of them. It's not necessarily nowadays just a kind of mathematical description. It could also be a visual description, a geographical description—it could be anything		1	1
	12 But from the Structural Health Department and the Foundations Department, I've heard about it. My understanding is that it's a model of the wind turbine in the computer, kind of trying to replicate the real thing. You feed it with data and it can replicate the actual turbine and also forecast what happens if certain scenarios play out.		1	1
	13 I would say it's basically a virtual wind farm. In that sense, it's having a virtual environment where you can try things without needing to do that on the operational wind farm. You can see how that works. It's basically a sandbox, I would call it. That would be my take on it		1	1
	14 so many use digital twins as a buzzword, and people have different perceptions of this buzzword. From my understanding, a digital twin is a digital representation of the real world and its behavior. So that means in my understanding it's not enough with just a computer model, a		1	1

design computer model of some turbine, or if it was an offshore jacket or whatever it is			
15 I see two types of digital twins: the real-time digital twin and the retrospective digital twin. The retrospective digital twin is quite computationally heavy but simple in concept. It takes measurements from throughout the lifetime—say 20 years—and looks back at what has happened to the turbine. We gather all input data from anemometers, wind, waves, etc., and input it into a simulation tool like HAWC2, which can simulate both turbine and wave interactions. This allows us to calculate historical vertical loads and extreme loads and compare them to the original design loads, letting us know if conditions have been harsher or more favorable than expected, which aids in lifetime extension assessments. The other kind, which is what most people refer to as a digital twin, is a real-time model that shows whether the turbine is experiencing more fatigue loads or higher extreme loads than anticipated.		1	1
Work with digital twins		15	15
Direct		9	9
Indirect		6	6
002 Digital solutions		8	15
Cloud platforms		6	8
02 integration, data from sensors sent to cloud solutions		1	1
02 integration, have structured database full of information and build applications		1	1
07 digital platform output, basically a database in the cloud		1	1
11 digital platforms, there are lots of platforms out there, we use Microsoft to run DT and store data		1	1
12 challenges, you measure a lot of data through sensors and send them to database, but i worry what happens in between and we would miss a hole in the tower		1	1
13 needs, it is not immediate impact, advantage is data gathering and better database means better decisions and operations		1	1
14 backfilling, we ensure redundancy of data is low and backfiling of data so we can retrieve it in case of a loss		1	1
14 compliance, of course we ensure everything lands in database		1	1

Dashboard visualization		2	3
08 digital platform ,how to manage different versioning of information, communication infrastructure		1	1
14 consistency, work with engineers often results in varied responses, dashboard is to ensure consistency		1	1
14 outputs, are extensive and we build web-based dashboard that visualizes our DT for foundations		1	1
Virtual world		3	4
02 main purpose, create virtual world to predict performance		1	1
10 integration, on our side we have models but are actually VR models		1	1
10 life cycle, VR tech is used for training, but to me VR is not a DT		1	1
11 integration, room in a form of DT, sort of a visual map		1	1
003 Financial solutions		11	48
Business case improvement		8	13
04 needs, improve business case instead of 30 years to have 40 years		1	1
04 stakeholders, business case development		1	1
04 use case, see it as a leverage in business cases, understand life cycle of projects		1	1
04 use case, to gain a bit on the business cases		1	1
05 future, development is based on healthy business cases that companies need		1	1
06 needs, identify opportunities to make business cases viable		1	1
08 future, investigation if worth to invest in DT to optimize business case		1	1
09 values, balancing income, repair costs and other factors		1	1
10 values, truly business case behind DT, improve safety, operational ability or ability to optimize assets		1	1
12 values, business case supports, lifetime extension and costs optimization		1	1
12 values, you need to prepare business cases, and give time with DT to prepare ahead is a huge benefit		1	1
14 values, lifetime extensions could offer strong business cases		1	1

14 values, of course if there is a permission to operate then it might be a good business case		1	1
Fatigue loads		4	13
05 communication, SSI claims to have DT for wind farm, but its specifically for assessing fatigue loads on foundations		1	1
05 integration, we have DT for assessing fatigue loads on foundations		1	1
05 misunderstanding, instead of DT for wind farm you only have DT for cables		1	1
05 misunderstanding, SSI claims to have DT for wind farm, but it is rather foundaiton has an ability to collect data on fatigue loads		1	1
05 misunderstanding, we have DT only for foundations and not for other components		1	1
05 scope, SSI covers foundations, looking at fatigue loads, is not a wind farm digital twin		1	1
05 understanding, SSI is one component (foundations) of DT		1	1
06 integration, operational changes and how these affect residual life of the structure		1	1
14 values, controlling operational safety to leverage data´s full potential to optimize from fatigue management to operational strategies		1	1
14 values, ensure structures are performing well and identify issues early		1	1
14 values, it provides real time structural health insights for all turbines		1	1
14 values, so we account for fatigue damages to the structure all over the monopile and tower		1	1
15 integration, it includes fatigue and other aspects and we use historical data as input to our simulation tool		1	1
Lifetime extension		7	22
02 introduction, roadmap to reach goals, like lifetime extension		1	1
02 needs, primary need is lifetime extension		1	1
02 use case, network of possibilities, start lifetime extension		1	1
03 needs, lifetime extension and decision making based on data		1	1

03 needs, goal of lifetime extensions, it is coincidence that it is financing this		1	1
04 integration, initial idea led to lifetime extension		1	1
04 values, optimizing structures to save CAPEX or to extend the lifetime for 15 more years		1	1
10 values, optimization of production or lifetime extension		1	1
12 introduction, SSI team mentioned they hava data and models to show how much lifetime of turbine is remaining and show if a storm hapens how much lifetime was lost		1	1
12 needs, lifetime value optimization		1	1
12 needs, make sure we do not run out of structural lifetime and DT is a good tool for getting alarms which turbines need extra attention		1	1
12 role, as 1 of the few teams we try to optimize value throughout the lifetime		1	1
12 stakeholders, lifetime extension is shared interest with government and us		1	1
12 stakeholders, regulators are opened to discussion for lifetime extension		1	1
12 stakeholders, they did not agree on fixed numbers for lifetime extensions w the government but base it on numbers with safety margin		1	1
12 stakeholders, we show them scientific data, while ensuring safety by showing how much lifetime is left in the structures		1	1
14 values, failure prevention extends asset lifetime		1	1
14 values, foundation will hold just buy other components and can operate		1	1
14 values, instead of 25 years can live 200 years as we did not account for loads in the design phase		1	1
14 values, we already showed we can extend structure lifespan significantly and is just beginnings		1	1
15 needs, second we ensure longest possible lifetime for the site		1	1
15 values, extended lifetime but im only talking about offshore turbines		1	1
004 Future outlook		8	16

Negative		2	2
06 industry, is struggling with business cases as well as get FID		1	1
09 standardization, one company building everything in DT will not happen		1	1
Positive		8	14
04 future, dream about continuous monitoring of the DT		1	1
04 future, monitoring fish populations around structures		1	1
04 needs, we needs proof cases for DT to be fully accepted		1	1
05 future, DT will not fade out because it is the sum of its components related to analytics and so on		1	1
05 future, more perfected DT, you could control your assets and give instructions for operation		1	1
06 benefits, first benefits, using knowledge to improve future projects or products		1	1
07 future, be competitive and provide value		1	1
09 future, individual models for every single component updated with real data		1	1
09 future, self-diagnosis and makes repair decisions		1	1
09 future, we need to avoid questioning these systems when they are performing better than humans		1	1
10 future, early design of a component or a VR model		1	1
12 future, dashboards to show what is running but also fast forward and see model predict for the next half year		1	1
12 future, not just the current situation through DT but also predictions for the future		1	1
15 future, in few years we will build precise models based on actual data and measurements to simulate how turbine should behave and detect deviations		1	1
005 Industry & Culture solutions		10	39
Conservatism		4	5
06 industry, conservative approach, should be reduced		1	1
07 values, not fully mature understanding value to customers yet		1	1

08 future, i do not think we are there in the wind industry yet		1	1
14 industry, current design standards use conservative factors due to uncertainties		1	1
14 needs, identify and quantify how conservative we are in the design and how much lifetime we have compared to how much we designed		1	1
OEM		4	8
Benefits with OEM		2	2
11 collaboration, between suppliers, operators and developers, OEM could provide DT of their components when developing		1	1
15 cooperation, OEM could anonymize the information so we can not use it against htem but use it for DT purposes		1	1
Challenges with OEM		3	6
09 challenges, OEM serve as a layer between part manufacturers and end users		1	1
10 integration, most of DT work is handled by OEM, their integrate DT into their design processes		1	1
15 challenges, biggest concern is we have detail information about foundations because we design them but we do not have detailed designs for blade components		1	1
15 challenges, OEM hand it to approver and tell us it was accepted		1	1
15 challenges, problem is getting detailed information on turbines design, assembly and control		1	1
15 challenges, we got too little information from OEM about their controllers and detailed designs		1	1
Offshowe wind industry		4	9
08 future, we are in the awakening phase in wind industry related to DT		1	1
08 future, wind industry is complex, there are different classes of DT and some parts of industry have different interests		1	1
08 challenges, extremely difficult for one company, should be industry effort		1	1
08 industry, also oil and gas, but in wind we have not identified possible benefits we can get from DT in wind production		1	1

10 future, industyr must align on what DT actually is - component or a full wind farm		1	1
10 standardization, in wind we agreed on certain standards for safety, design and quality		1	1
10 standardization, overarching boundaries involves different IP rights that need to be adhered to, we can share best practices across industry		1	1
11 industry, it is a boom and stakholders see it around and want it as well		1	1
13 industry, 2 years ago the industry was about growth and capex but it is not the case anymore		1	1
Other industries		3	6
07 standardization, is different in offshore wind than military, is more about practical applications and scaling engineering models		1	1
08 future, good way forward, look at other industries		1	1
08 industry, certain industries are quite mature in DT, like military or power systems		1	1
08 industry, in transmission you train operator in real life but also DT		1	1
08 industry, you replicate real life situations with control room and same systems		1	1
10 application, DT for marine construction in energy sector		1	1
Training		2	2
10 integration, confusion with people refering to training modules that emulate scenarios as DT		1	1
11 use case, O&M you can use DT for training new employees		1	1
Trust		4	5
07 values, reliance and confidence in your product		1	1
09 values, once you trust DTs, there is massive economic advantage		1	1
11 challges, trust from stakeholders, once see benefit they believe to trust		1	1
11 stakeholders, after gained trust want more features		1	1
12 trust, the models must be trustworthy		1	1
Uncertainty		2	4

09 strategy, good strategy recognizes reality, reality is we are operating in highly uncertain environment		1	1
09 trust, you need to learn understand uncertainty		1	1
09 uncertainty, all the key factors we care about are probabilistic, we need to average our futures		1	1
13 replication, from finance perspective it would be easier if you could replicate successful project consistently but thing change over time		1	1
006 Technical solutions		14	105
Categorization		2	15
08 introduction, many levels of DT, model you build is fit for purpose that is intended for		1	1
14 costs, tower might be expensive, blades are off-the-shelf items and drivetrain and nacelle are things you can just buy		1	1
14 integration, we touched upon layer 1 and 2 in our projects		1	1
14 levels of DT, 3rd step is to calculate loads and there is lot of uncertainty		1	1
14 levels of DT, 4th layer is to quantify the uncertainty of your DT, to quantify what is the uncertainty of the DT		1	1
14 levels of DT, all physical parameters have distribution but we usually use mean and especially in design		1	1
14 levels of DT, correlate your model to physical parameters is interersting because it can represent real world physical behaviour		1	1
14 levels of DT, first is investigations on computer model if is updated as precisely as it can be		1	1
14 levels of DT, level 2 continued and we make conservative assumption in computer model		1	1
14 levels of DT, step 2 when measured vaues, physical behaviours and computer model you can tune your computer against these values		1	1
14 levels of DT, step number 2 is to go out and monitor, you place sensors and capture physical behaviours		1	1
14 levels of DT, there are one to five levels of DT		1	1
14 levels of DT, with a lot of data we can base predictions on machine learning		1	1

14 levels of DT, with that you can begin 5th layer to make predictions about the future		1	1
14 previously, most of condition monitoring systems involved measuring structures with low-frequency response		1	1
Composability		6	16
07 composability, you do not deploy a DT for the whole turbine immediately, you start with components and build up		1	1
07 integration, start with blade bearing, which is interesting component		1	1
07 responsibility, lies with the component owner		1	1
07 technology, is like a laboratory on scale, but can not test on every component		1	1
08 composability, military have high level architecture to compose simulation models to make one bigger simulation model		1	1
08 composability, model of system could look like and add a new component		1	1
08 challenges, risk is to have many DTs that are not integrated		1	1
09 composability, integration with business processes and across diff components of turbines		1	1
09 challenges, you can not optimize for one component or one turbine		1	1
11 composability, we wanted DT for entire turbine particularly nacelle part, not ffeasible, tried external company but not happy		1	1
11 challenges, we cannot develop a complete DT, it must be done component by component and then integrate		1	1
11 strategy, in our team is to define DT for each component and aggregate them together		1	1
11 use case, after development you can have DT to see how they fit together		1	1
11 use case, we have a component - reactor, we use data to create DT of that component		1	1
12 challenges, so many components that interact, there is a vibration for blades but instead they were bearings		1	1
14 composability, to have full-fledged DT it would be nice ot have the blades, drivetrain, gearbox and cables as well		1	1

Design models		5	29
07 cooperation, operators have access to data, but do not have design models		1	1
07 digital platform, engineers responsible for digital models upload their models and they can schedule how frequently these models run		1	1
07 human error, we have stringent standards for design model ownership		1	1
07 integration, if the model for blade bearing too slow for real time data, we might need to optimize it for operaitonal use		1	1
07 integration, we prefer to develop and validate models in technology phase where risks and costs are lower, use them later in product development		1	1
07 introduction, feed the model with same data, inputs and come to conlucion on lifetime consumption or even hotspots		1	1
07 introduction, instead of traditional engineering approach to run a single design, i run the model on thousands of turbines in parallel to get output at scale		1	1
07 needs, much more than DT, they only serve to ensure that models are validated to level we need		1	1
07 ownership of model is component based within the organization		1	1
07 stakeholders, as technology matures, i´d begin request models from suppliers		1	1
07 technology, DT supports both long term technology development 6-8 years and product development validating design assumptions		1	1
07 technology, when scaling all models have assumptions		1	1
07 trust, DT is about authorirative modeling that I trust, and to trust it must be validated at scale		1	1
07 utilization, the model owner can deploy their models, see cost estimates, storage requirements etc...		1	1
08 future, common model or terminology		1	1
08 initiative, org pushing DT and their models to be easily exchangeable between systems		1	1
08 introductin, DT scale from generil model to interconnected model		1	1
08 introduction, more detailed models able to simulare behaviour of multiple aspects		1	1

08 introduction, simple model is generic representing types of inputs		1	1
08 introduction, to be interconnected, system of interest would adjust behaviour of the model		1	1
08 needs, if designin forecast model, it would be nie to have a DT to see the behaviour		1	1
08 stakeholdrs, people who need to design and expedite their designs using DTs		1	1
09 future, analytics and modeling are combines and if we operate 80 % capacity i am willing to call it a DT		1	1
09 introduction, engineering models withou real object do not add value		1	1
09 introduction, it is abou inverse modeling to understand behaviour in certain decisios		1	1
09 needs, there is no standardized test bench on the market to establish accuracy		1	1
09 technology, it is how those models integrate with logistics and business decision making		1	1
10 industry, DT can mean many diff things, high-fidelity model with lots of data is high end DT		1	1
14 introduction, DT can also be just a model of something you built		1	1
Integration		12	26
02 integration, measurement systems in place		1	1
02 integration, measurement systems, need for methods and coding software		0	0
02 knowledge, recognize relationships between design variables		1	1
03 integration, all this information is fed into DT		1	1
04 integration, scratching the surface because we have no full response from measurements		1	1
05 use case, monitoring corrosion, turbines have sensors to understand their condition, visual applications using augmented reality		1	1
06 existing technology, we already have temperature monitoring on cables, is matter of integrating these		1	1
06 integration, during design we make assumptions about downtine, might impact design life		1	1

06 integration, sensor system that provides data and when commissioned showing us what is happening		1	1
09 integration, components such as nacelle, gearboxes and generators		1	1
10 integration, currently is not part of the product, but can be requested		1	1
10 integration, wind turbine referring to nacelle, blades and all turbine components but not the foundation		1	1
11 integration, transformer based on physical descriptions can be a DT		1	1
11 use case, we run DT and real life in parallel, afterwards comparing the outputs		1	1
12 integration, not sure if the technology is at work but the devices are out there		1	1
12 integration, we developed projects and we capture data we need		1	1
13 integration, it makes prediction of certain events much easier and improves business case		1	1
14 integration, but with 200 turbines we mean only foundation - monopile and tower		1	1
14 integration, data infrastructure we have a VOSS design toll where we run models and we calculate damages for each turbine once a day		1	1
14 integration, it allows us to see where damages occur and identify anomalies compared to expected results		1	1
14 integration, virtual sensing where we installed sensors and are getting that data in		1	1
14 integration, we also work on implementing automated quality assessments of data inthe cloud by calculating various parameters based on 10 minute interval		1	1
14 integration, we design the monopile and buy the tower		1	1
14 integration, we have almost 200 turbines where we have sensors located in each one of them		1	1
14 opportunities, we are in the first in the world to install on all turbines in a wind farm, it gives us an edge		1	1
14 use-case, we have 139 turbines and each second we receive 36 000 data points via internet to cloud located in Azure		1	1
15 integration, first full simulation of what happened over past 20 years and evlauated if turbines needed refurbishing or we can extend lifetime		1	1

Predictive maintenance		4	6
07 background, we do a lot of diagnostics and predictive maintenance that are model-driven		1	1
07 values, from customer perspective better models could enhance predictive maintenance		1	1
07 values, predicting performance closer to limits is good for sales and after-sales services		1	1
08 values, predictive maintenance forecasting based on weather		1	1
11 use case, main one is early failure detection or predicting failures		1	1
15 needs, there are 2, first is we can prevent major incidents detecting when conditions exceed design levels		1	1
Reusability		2	6
08 planning, if planning im not interested in maintenance but let me reuse existing model and extend capabilities		1	1
08 reusability, in one project in wind we tried to reuse some principles of DT from other areas		1	1
08 reusability, it does not mean the DT itself is reusable		1	1
08 reusability, models of DT to be reusable		1	1
14 reusability, all the theory we are using can be also applied to other components		1	1
14 reusability, it might differ a little bit but you can predict how each component is performing and detec when a change is needed		1	1
Time sensitivity		4	7
07 operation, DT does not need to be time-critical, it should be handled by the turbine´s onboard system		1	1
07 operation, nothing dramatic should happen on a blade bearing over a week		1	1
07 use case, for real-time conditions like frequency changes indicating a crack, needs to be handled by turbine in real time		1	1
07 values, generally DT creates value if it provides a reaction time you would not otherwise have		1	1
09 values, time based optimization, schedule interventions before failure across turbines		1	1

12 use case, ideal scenario is for DT to input real time data and run models ahead by few years and forecast something is likely to fail		1	1
14 needs, ensuring safety of assets in real time is crucial		1	1

Table 8 Codebook (own work)

Appendix K: Interview Transcripts

K.1 Interview #1

Name: Participant 1

Title: Stakeholder & Community Manager

Company: Internal

Date: 22-08-2024

Time: 09:55 – 10:30

Samuel Ziak 0:04
All right. Nice to have you here. During this interview, we will explore the integration of digital twin technology within the offshore wind industry. Do you agree that notes can be taken, and I could introduce direct quotes in my master thesis, and that the conversation can be transcribed?

Interviewee 0:29
Yes, as long as I know that it's confidential, of course.

Samuel Ziak 0:32
Indeed, yes, we can also sign a confidentiality or nondisclosure agreement.

Interviewee 0:33
Yes, yes.

Samuel Ziak 0:38
Alright then, let's proceed to the questionnaire involving digital twins. The questions were attached to the email before the meeting, which is taking place on Microsoft Teams. First, let's begin with an introduction and background. Can you briefly describe your role and responsibilities within the company?

Interviewee 1:01
Yes, yes. I am hired as a consultant, as a strategic advisor. My role is to develop a strategy for the support structure integrity team. Developing a digital twin is one of the areas I focus on, along with organizational development—getting the right people on board who are needed to deliver on this.

Samuel Ziak 1:42
When you mentioned you work with digital twins, what is your understanding of the term "digital twins"? Can you elaborate a bit?

Interviewee 1:45
Yes, yes. I think it's a term that many people find confusing. I like to use something very simple: Google Maps. The most used digital twin in the world is Google Maps. A digital twin is typically a digital replica of something physical, like a building, or even a process. Google Maps, for example, is populated with information like addresses, reviews, and opening hours. In the context of integrity management, it could be documents, drawings, or other information. The

real-time aspect is also critical—just like Google Maps tells you how long it will take to drive from A to B, a digital twin can provide real-time data through sensors. The main purpose is to make life easier by having all information in one place, rather than scattered across different platforms. That's my understanding of a digital twin.

Samuel Ziak 3:55
On that note, before I proceed to the next question, I found in theory that there's some confusion between authors considering digital twins as part of a product lifecycle management system versus just a standalone product. It's fascinating. But moving on, do you directly or indirectly work with digital twins? Can you highlight something specific you've worked on?

Interviewee 4:30
Yes, I developed what could be considered the world's first digital twin for real-time structural integrity management in my previous job. When I say "developed," I led the initiative, getting funding, assembling the team, and overseeing development.

Samuel Ziak 4:45
OK.

Interviewee 4:51
Here at the company, I'm the lead for the front end of the digital twin we're developing for support structure integrity. I work with a design company to ensure the front end is easy and intuitive to use—like the Google Maps of our system.

Samuel Ziak 5:31
That's a great statement. Now, let's transition to the next section. Could you describe how digital twin technology is planned, currently or in the future, within your projects or in your company? What's your vision?

Interviewee 5:53
I'm not sure what you mean by "planned."

Samuel Ziak 5:56
How do you believe digital twin technology is currently or will be integrated into your projects? How is it evolving?

Interviewee 6:05
I think, at a high level, you should always start with value creation when developing or purchasing a digital twin. You need to assess your needs—if you don't have significant needs, you don't require a full-blown digital twin. So, start by mapping your needs and what value you want to achieve. Then you can develop or purchase a digital twin that fits those needs.

Samuel Ziak 7:18
At this point, what's the status of digital twins within offshore wind farms?

Interviewee 7:26
Yes. Yes.

Samuel Ziak 7:31
Is there a standardized version that companies use? Any insights you can share?

Interviewee 7:40
In offshore wind, digital twins are not that far along in terms of integration. The oil and gas industry is much further ahead because of the complexity and number of components involved. In offshore wind, there are fewer components, so the need isn't as urgent. However, this can vary depending on the discipline you're focusing on. Based on my two years of experience in offshore wind, I don't think the industry is very advanced in its use of digital twins.

Samuel Ziak 8:41
OK, that answers the question perfectly. For the purpose of this research, I've identified different stages of the project lifecycle—design, construction, operation, management, maintenance, performance, environmental monitoring, and innovation. Do you think digital twins should be integrated across the entire lifecycle, or just specific stages?

Interviewee 9:17
It goes back to your needs and the value you want to get out of it. In my opinion, a digital twin should be part of the project from day one. It should be the backbone of the project.

Samuel Ziak 9:36
Yes.

Interviewee 9:36
But that doesn't mean it's too late to create a digital twin for an existing structure that's been around for 10-20 years. However, for future projects, I believe it should be the backbone from the start.

Samuel Ziak 9:58
So, you would cover it all the way to the end?

Interviewee 10:02
Yes, of course. You use the digital twin to learn throughout the project's lifecycle. If you only monitor or update the twin for a short period, you won't get the full value. For example, if you monitor corrosion but stop 10 years before the end of the project's life, you'll miss valuable insights. So, in my opinion, a digital twin should be there from the start to the very end of the project.

Samuel Ziak 10:52
OK, cool. That's a valuable takeaway. Do you think companies, whether your own or others, have specific objectives they want to achieve by implementing digital twins in their projects or portfolios?

Interviewee 11:19
Yes, but it depends on who you talk to. If someone says they don't see the need, it might be because they don't understand the full potential of value creation. At the lowest level of complexity, the objective is to have easy access to information and an overview of all your data.

That's the basic level—a digital replica of the physical world with all documents and drawings in one place.

Samuel Ziak 12:01
That brings me to my final question for this section—interoperability. With all this data and different systems like SAP or enterprise planning, is it challenging for digital twins to aggregate data and improve interoperability? Could you elaborate on this?

Interviewee 12:29
Yes, of course. The ultimate dream is not just about collaboration between different software types but also between different disciplines. There's no "mother of all digital twins"—each discipline has its domain-specific twin. For example, Google Maps is for roads, but you wouldn't use it for an oil and gas platform or an offshore wind park. The vision is a full-blown digital twin where all disciplines and systems communicate. That's the dream, though I haven't seen it fully realized yet. The challenge is making it simple and intuitive. The point of a digital twin is to have all information in one place, so it's better to have it connected than to use multiple systems to get the information you need.

Samuel Ziak 13:33
Yes.

Interviewee 13:40
To achieve this, you'll likely need APIs or similar solutions.

Samuel Ziak 13:46
And making it intuitive is key because the more complex it is, the less likely users will want to engage with it.

Interviewee 13:52
Exactly. Complexity can deter users, so simplicity is essential.

Samuel Ziak 14:05
Now, transitioning to stakeholder roles and collaboration—what are the key stakeholders involved in the implementation of digital twins from your point of view? What roles do they fulfill?

Interviewee 14:17
Typically, to do anything, you need money or the will to invest, driven by needs and value creation. Stakeholders are usually those who have a challenge they want to solve, like the people responsible for operations.

Samuel Ziak 14:22
Yes.

Interviewee 14:25
Yes, typically, to do anything, you need funding, right?

Interviewee 14:35
And that funding often comes from stakeholders who see a need or a potential for value creation.

Interviewee 14:43
So, typically, stakeholders are those who have a challenge they want to solve. For example, it could be the individuals responsible for operations.

Interviewee 14:59
However, it could also be someone like a visionary CEO who wants the company to become more data-driven.

Samuel Ziak 15:10
Umm.

Interviewee 15:11
So, in my experience, it's often the operations team that drives these initiatives because they are looking to optimize or solve specific challenges.

Samuel Ziak 15:20
Umm.

Interviewee 15:26
It's typically driven by the goal of reducing costs, essentially.

Samuel Ziak 15:31
So, based on what you're saying, at this point in time, the key stakeholders are likely investors or those responsible for risk and safety.

Interviewee 15:40
Yes, exactly. Those who are responsible for risk and safety in operations are often the most interested because they can see the benefits of having real-time information about the structure.

Samuel Ziak 15:46
Umm.

Samuel Ziak 15:55
What about external stakeholders? Can you think of any that might be relevant?

Interviewee 16:02
Yes, it's primarily internal within each company. But at a higher level, you could consider external stakeholders, such as government departments responsible for asset safety in a country.

Samuel Ziak 16:25
Yes.

Interviewee 16:30
For example, in Norway, there's an organization responsible for both oil and gas and offshore

wind. It would be ideal for them to have real-time information available during audits to ensure operators are in control of their assets.

Samuel Ziak 16:49
Yes.

Interviewee 16:49
Typically, during audits, operators might show up with multiple reports to demonstrate control. But having a dashboard with real-time information would be a dream for these regulatory bodies.

Samuel Ziak 16:58
Yeah, yeah, yeah.

Interviewee 17:07
It would be ideal to just show up and have everything displayed on a dashboard, with all indicators green.

Interviewee 17:16
Another external stakeholder could be insurance companies.

Samuel Ziak 17:21
Uh-huh.

Interviewee 17:21
For them, having access to this real-time information would be invaluable. It would allow them to assess the health of a park or platform more accurately, instead of relying on traditional assessments that might not be as transparent.

Samuel Ziak 17:40
Yeah.

Interviewee 17:40
So, if we consider external, high-level stakeholders, those would be two key examples.

Samuel Ziak 17:46
OK. In terms of regulation, is there any complexity or challenge with state authorities or other regulators? Are they open to the technology, or is it still somewhat uncertain?

Interviewee 17:55
Yes, it's still somewhat uncertain. There’s definitely work to be done to move the industry forward.

Interviewee 18:07
The current codes and standards aren’t fully aligned with what digital twins can offer. There’s still a lot of progress to be made, but we’re moving in the right direction.

Interviewee 18:17
For example, cars now have sensors that tell you the tire pressure—this kind of digitalization is becoming more common. I once heard at a conference that digitalization is not about 'do or don't'; it's about 'do or die.' We're not going to move backwards when it comes to this technology.

Samuel Ziak 18:39
Umm.

Samuel Ziak 18:45
That leads to my final question regarding stakeholders: among wind farm developers or project developers in the offshore wind sector, who do you think is leading the way in adopting digital twin technology?

Interviewee 19:17
That's a tough question. If you ask them, I'm sure they would all claim to be leaders.

Samuel Ziak 19:25
OK.

Interviewee 19:25
Honestly, I'm not deeply aware of what others are doing. But within our organization, we believe that what we are doing is state-of-the-art and unique, particularly in the area of support structure integrity.

Samuel Ziak 19:40
Yes, yes.

Interviewee 19:42
Of course, there might be others who stand out in different disciplines, but I don't have the insight to give you a detailed answer.

Samuel Ziak 19:49
That's fine. Thank you. That wraps up this part of our discussion. Now, let's move on to the next section, where we'll talk about needs and values, starting with needs only.

Interviewee 20:00
And.

Samuel Ziak 20:01
It's important to focus on needs first, and then we'll discuss value in relation to digital twins.

Interviewee 20:08
Yes.

Samuel Ziak 20:09
As a stakeholder, what do you expect a digital twin can or will solve for you?

Interviewee 20:21
Yeah. It's not difficult for me to imagine because I've spent eight years selling these technologies to stakeholders. I know exactly what their typical needs are.

Interviewee 20:31
Usually, it starts with a challenge, often related to cost. The question then becomes, how can we reduce these costs?

Samuel Ziak 20:40
Mm-hmm.

Interviewee 20:44
What can we do to reduce costs, or what can we do...?

Samuel Ziak 20:46
OK.

Interviewee 20:48
We have a situation where we don't feel that we are in control of our risk and safety. How can we become in control of our risk and safety? So, that's typically the challenge—the need to feel in control. A digital twin brings more certainty about what is happening in real life, which helps you get that control.

Samuel Ziak 21:22
Umm.

Interviewee 21:22
You know why? It's because design models are based on a lot of assumptions. It's like asking you how long you think it will take to drive from here to there. You might guess an hour, but Google Maps can give you a precise answer.

Samuel Ziak 21:37
But you don't know? Yeah.

Interviewee 21:38
No, no, no. Google Maps will tell you it only takes 20 minutes. The same principle can be applied to any parameter in a digital twin.

Samuel Ziak 21:41
Yeah.

Interviewee 21:45
So, the needs are typically cost reduction and being in control of risk and safety.

Samuel Ziak 21:55
OK, so these are the two that you would highlight or cherry-pick as the most important?

Interviewee 21:58
Yeah, those two. And if I had to pick a third, it would be improving efficiency in daily work and operations.

Samuel Ziak 22:34
To proceed, there's a table that lists relevant needs for your role, categorized as strategic optimization, decision-making, operational efficiency, risk management, and sustainability. Which of these is the most important to you as a stakeholder?

Interviewee 23:09
To me, optimization and efficiency are almost the same, so that's a huge parameter.

Samuel Ziak 23:15
OK.

Interviewee 23:21
What was the fourth one you mentioned?

Samuel Ziak 23:23
Risk and safety.

Interviewee 23:25
Yes, yes. So, I would say optimization, risk and safety.

Samuel Ziak 23:37
Can you elaborate a bit more on risk and safety and sustainability from the stakeholder perspective with regard to digital twins?

Interviewee 23:41
Yes. Everything we do is based on safety, even if not everyone realizes it. For example, when we say the lifetime of a structure is 25 or 40 years, that's based on safety and risk levels. It's crucial to be in control of that, especially when unexpected events like a ship impact or damage occur. You need to quickly understand your risk and safety levels. Digital twins allow you to monitor and control these aspects in real time, giving you a more precise understanding of reality. Typically, this could show that you have more lifetime left in a structure than you thought, which can lead to lifetime extensions. Reusing instead of rebuilding is sustainability by definition, and that's exactly what a digital twin can help with.

Samuel Ziak 24:56
Mm-hmm.

Interviewee 24:56
Digital twins help you get the absolute maximum out of your structures while always being in control of risk and safety.

Samuel Ziak 25:31
So, to summarize, if you integrate digital twins into an offshore wind farm, you might predict a 20-year lifespan. But as you accumulate data over that period, you could find that there are no abnormalities, which might allow for an extension of five to ten years. That would be a great example of sustainability.

Interviewee 25:43
Yes, exactly.

Samuel Ziak 25:52
Perfect.

Interviewee 25:54
For example, I've worked on projects where an oil and gas platform operated for 30 years, and instead of building something new, they repurposed the existing structure.

Samuel Ziak 26:06
Yes.

Interviewee 26:12
We proved that it could be extended by another 30 years, so instead of building a whole new platform, they reused the existing one for something else. That's called repurposing.

Samuel Ziak 26:16
What are some use cases for utilizing this approach?

Interviewee 26:27
That gas platform jacket structure in the water was repurposed as a substation for a floating offshore wind farm.

Samuel Ziak 26:32
Yeah, cool. OK.

Interviewee 26:40
It could also be used for hydrogen storage, for example. Many oil and gas platforms standing today have already exceeded their design lifetime, but if digital twins can show they can last much longer, they can be repurposed, saving resources and enhancing sustainability.

Samuel Ziak 27:02
Yes.

Interviewee 27:16
That's sustainability because you don't have to build new things.

Samuel Ziak 27:32
Alright, let's bridge into the next section about values. How do you perceive the value added by

digital twins? Could it be economic, operational, sustainable, or strategic? Choose one and elaborate.

Interviewee 27:35
Yes, it's all of them, but if I had to choose one, it would be financial—economic value.

Samuel Ziak 27:44
Economic, yes.

Interviewee 27:56
I've touched on this already. If you can extend the lifetime of a structure, it's much more economical than building something new.

Samuel Ziak 28:10
Also sustainable. That's another aspect.

Interviewee 28:12
Exactly. Another thing is, when something critical happens—like a ship impact or an earthquake—it can cost a lot and take a long time to regain control of your risk and safety if you're not monitoring it. Without continuous monitoring, it becomes guesswork, requiring inspections and so on. But with continuous monitoring, you can quickly understand your safety and risk levels. It always costs less to fix a problem early than later.

Samuel Ziak 28:53
Yes.

Interviewee 28:55
So, from that aspect, it's very beneficial. Also, you become much more efficient in your work. You don't have to look through 20 different reports to find information; it's all available on the screen in front of you. Imagine being responsible for 200 wind turbines—having all that information available at a glance is a huge advantage.

Samuel Ziak 29:42
Yeah.

Interviewee 29:42
Without that, you'd have to open 200 reports or one big report and sift through it to find what you need. This efficiency is what makes working with digital twins far better than the traditional way of working as an engineer.

Samuel Ziak 30:04
So, to sum up, it seems like operations, sustainability, and other aspects all come together to create value.

Interviewee 30:20
Yes, they are all connected in one way or another.

Samuel Ziak 30:26
And that complexity can be overwhelming when developing this technology.

Interviewee 30:38
Maybe, but I don't think that's the main challenge.

Samuel Ziak 30:51
What do you think the challenges are with digital twins?

Interviewee 31:04
I think the biggest challenge is that many people don't have much experience with digital twins, so getting people on board and understanding the value can be complex. People don't want to invest in something they don't understand, and I get that.

Samuel Ziak 31:28
Yeah.

Interviewee 31:29
If you don't understand it, you might just say, "I'm not interested." That's one challenge.

Samuel Ziak 31:34
Hmm.

Interviewee 31:36
Another challenge is that someone might be interested, but they don't have the money. They have to convince someone higher up who might not understand the challenge because they don't face it directly. Often, the person with the challenge wants the digital twin because they know what it can solve, but they need funding from someone who doesn't see the same need.

Samuel Ziak 31:58
Yes.

Interviewee 32:01
So, I think a big challenge with digital twins is that there's a lot of buzzwords and talk, but not everyone truly understands it yet. The understanding will come with time, just like with Google Maps or Facebook—it might take 5-10 years, but eventually, everyone will get it. The typical challenge now is getting funding for such initiatives.

Samuel Ziak 32:59
What's your projection? We're in 2024 now. How long do you think it will take for digital twins to become widely recognized and adopted?

Interviewee 33:19
I think 5 to 10 years.

Samuel Ziak 33:25
OK.

Interviewee 33:26
Of course, it's industry-dependent. In offshore wind, it will take years. Oil and gas are more mature, so they're further along, but offshore wind will take 5 to 10 years before everyone has it and it's a must-have.

Samuel Ziak 33:34
Let's stick to offshore wind then.

Interviewee 33:38
Yes, for offshore wind, I think it will take 5 to 10 years. By then, if you don't have it, you won't be able to compete. In oil and gas, everyone already has it to some degree, but with different levels of complexity.

Samuel Ziak 34:01
When you say oil and gas, do you mean they have digital twins with IoT sensors in substations or for drilling, or something else?

Interviewee 34:05
Yes. When most people think of a digital twin, they think of a digital replica of the physical object, with all the structures, documents, and drawings. Everyone has that. Some also have sensors, etc.

Samuel Ziak 34:23
Fair enough. I think we've reached the final part, which is the concluding question about the future perspective.

Interviewee 34:57
Yes.

Samuel Ziak 34:58
You mentioned how long it might take for digital twins to fully integrate into the offshore wind market. Is there anything else you'd like to share about the future of digital twins in offshore wind or any other ideas you have? If not, that's fine too.

Interviewee 35:08
Yes, I think digital twins have many purposes. In the future, they could ease collaboration between companies, insurance companies, and operators because all the information would be in one place. Instead of sending someone five reports, you could just talk around the screen, making it easier to understand. Just as with cars or other technologies, the world is moving forward. I'm sure that within 10 years, everyone will have it, and if you don't, it will be hard to compete.

Samuel Ziak 36:05
While we're on the topic, do you wish for standardization within the offshore wind market, or do you prefer that it remains competitive, with each company developing its own technology?

Interviewee 36:22
That's a great question. I'm for standardization across the industry—it's key and important. Then

you can discuss which aspects to compete on and which not to. In my humble opinion, risk and safety should not be areas of competition. You can compete on other things, but not on the well-being of people.

Samuel Ziak 36:47
Yeah.

Interviewee 36:59
I would definitely say we shouldn't compete on risk and safety. Having a generic format would be helpful for everyone, and then companies can decide which parameters to compete on and which are critical but still important.

Samuel Ziak 37:07
Absolutely. To consider. Alright, with this, I'd like to conclude the interview. Thank you for your time and insights. Your contribution makes a difference, and I will keep the transcription until the handover of the thesis, which will be in November. After that, it will be deleted. The company name and your name will also be anonymized. Thank you very much.

Interviewee 37:49
Perfect. Good. Thank you so much.

Samuel Ziak
[Transcription stopped]

K.2 Interview #2

Name: Participant 2

Title: Expert Advisor

Company: Internal

Date: 22-08-2024

Time: 13:00 – 13:45

Samuel Ziak 0:04
All right. So, welcome to the interview about the stakeholder perception of digital twins, particularly tailored to offshore wind farms. Before we proceed, I would like to inform you or ask for your consent. During this transcription, there will be no recording, so there's no need to record us, only the transcription will be kept. I would also like to ask if you give consent for notes to be taken, to introduce direct quotes in my master's thesis, and if the transcription is OK. Is that OK with you?

Interviewee 0:41
Yeah, that's of course OK. So, as long as we can read it before it's published, that should be no problem. So, of course, yes.

Samuel Ziak 0:52
And just to inform you, if you mention the company, it will be anonymized. Your name will be anonymized as well, along with your responses.

Interviewee 1:04
Excellent.

Samuel Ziak 1:05
So confidentiality will be set in place.

Interviewee 1:08
Good.

Samuel Ziak 1:09
Yes. So, let's jump straight into the questionnaire. To begin with, could you please describe your role and responsibilities within the company?

Interviewee 1:20
Yeah, well, I am an external consultant for [Company A]. I work as an expert advisor, and my role is, yeah, preparing the development of new methods for wind turbines. So, it's in the range of our area of preparing technical roadmaps, method statement reports, and along the same lines, preparing or making products that actually build on these methods. So, preparing products that can be applied to, yeah, in the future, on a whole lot of data from our many different turbines and wind farms.

Samuel Ziak 2:40
Umm, so, in terms of your background, if I can sum up, you sound like someone who is an expert in the field of developing products for offshore wind technology. Could you also elaborate on your background? What's your experience from the past?

Interviewee 2:58
Umm, yeah, I was in the oil and gas business for 30-plus years, and, well, yeah, I developed digital twins for that sector. So, yeah, about 1.5 years ago, I got an offer. I became an external consultant, and right now, I'm hired on contract for [Company A].

Samuel Ziak 3:39
That's exciting. To elaborate a bit further on what you said, you mentioned that during your previous career path, you were in oil and gas and developed a digital twin. Can you elaborate on your understanding of the digital twin? Then, maybe narrow it down from oil and gas to offshore wind?

Interviewee 4:01
Yeah, I've seen many formulations, and I think you also provided a fundamental one, but I maybe prefer another formulation. A digital twin is a virtual representation of an object or system designed to accurately reflect a physical object. It spans the object's lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help make decisions. So, I like that definition a lot.

Samuel Ziak 4:37
Umm.

Interviewee 4:38
I don't think there's a big difference, but yeah, take learnings from measurements and update and improve prediction models for better predictions. For example, with many purposes, but mainly for lifetime extension.

Samuel Ziak 4:58
So, assuming that your work is directly impacted or you work directly with digital twins, because, I mean, you are an expert and you developed and worked with them before you even joined the offshore wind industry.

Interviewee 5:09
Yeah, yeah. Yeah, exactly.

Samuel Ziak 5:12
Yes. Perfect. So, let's jump to the second section of the interview, which is the actual integration of the digital twins. Can you describe or explain some experiences that you've had or plan to have in integrating digital twins into the products or life cycles? Just describe what your experience from the past or currently is.

Interviewee 5:36
Umm.

Samuel Ziak 5:43
I will leave it up to you. It's an open question.

Interviewee 5:45
Yeah. OK, good. Well, in continuation of the first question, of course, that's what I did for oil and gas as well. It's a matter of finding this roadmap for getting to a point where you can start harvesting the benefits and values from the digital twin. So, for now, the plan is a three-year plan. I have developed a three-year plan to reach some goals. Within the three-year plan, the digital twin measurements will still focus on increasing lifetime extension. So, I made a roadmap and planned for activities to be performed.

Samuel Ziak 6:47
Does that mean that the digital twin you mentioned is for a project that already exists, or is it for projects that are just now being initiated and will be in operation going forward?

Interviewee 7:00
Yeah. Yeah. See, [Company A] already has a project where they use part of the technology, and so they started putting in measurement systems and installing them on offshore wind parks. Now, they need methods and coding software developed that can process all of this data and unlock its potential.

Interviewee 8:00
Before you can start post-processing data, you need to gather data from sensors. So, [Company A] has installed a lot of sensors on the park, and now the data from these sensors is being sent to big cloud solutions where they can do the first part of processing the data. But the real benefit, well, that's what I made a plan for. So, that's the plan for the next three years.

Samuel Ziak 8:44
Yeah, the roadmap that you mentioned.

Interviewee 8:46
Yeah, to develop the methods so that you can really start and have an impact.

Samuel Ziak 8:54
Now you've sparked my curiosity. When you say that [Company A] already created the measurement sensors, is there a universal sort of platform? I'm asking about interoperability. If we take out the data that needs to be generated and post-processed, do we aggregate the data within only one cloud platform, or are there multiple ones that you use, for example?

Interviewee 9:31
Yeah, that's also part of the development. First, you need the IT infrastructure just to be able to handle all of this data. You need a digital platform first for handling all of the data, and that's a big issue, including cybersecurity and all the challenges there.

Interviewee 9:59
Then there's the first part of pre-processing the data to get the first part of the value from it. But beyond that, the idea is that this data should not only be used for lifetime extension but also for improving operations, maintenance, optimization of earnings, and so forth.

Samuel Ziak 10:24
Yes.

Interviewee 10:28
So, yeah, it will be... I'm not sure if I understand the question correctly, but it will be a kind of platform facility that, in the future, will allow for lots of connections and utilization of the data. Combining it with other databases and other data will also be key. The more you can combine different disciplines, the more benefit you can create and value you can get from all of this information. So, yeah. I don't know how deep I should go into the description because...

Samuel Ziak 11:19
No, that's okay. So, first, you need to have some sort of digital infrastructure.

Interviewee 11:22
Umm.

Samuel Ziak 11:25
So, we have a physical wind turbine that exists, and we install a lot of sensors—or there are already a lot of sensors, of course—because we need to generate the data. Then we gather the data, and we need to process and post-process it.

Interviewee 11:31
Yeah.

Samuel Ziak 11:38
But in order to do that, we need some digital infrastructure. We have a digital platform where we aggregate all this data, but it's still taken from multiple touchpoints or connections.

Interviewee 11:41
Yes.

Samuel Ziak 11:52
And now, when we are at these touchpoints or connections, how do we actually connect them?

Samuel Ziak 11:58
Do we use application programming interfaces (APIs)? Or are there other methods? Maybe just a final word in this section about how we actually get it to the final consumer.

Interviewee 12:07
Yeah, yeah. The idea is that, yes, it should be a standardized procedure, standardized data format, API, and so on, so that you have a structured database full of information. Then you can build different applications that take data from this database and analyze it for specific purposes. One of the purposes, and the one where I started, is lifetime extension, but there will be other disciplines as well. Please separate this from other benefits like optimization of operations and maintenance. At the end of it all, training models, weather forecasting, etc., explore how to get the power on the grid when it's really needed so you can optimize the full power from the wind farms. It's a network of possibilities, and while we start with lifetime extension, the idea is that once it runs for that, you can, for example, optimize based on further information, like the

current power price. If the price is 0 Danish kroner per kWh, they might want to shut down turbines that have the biggest fatigue lives to connect earnings with fatigue and operational maintenance control.

Samuel Ziak 14:35
There are a lot of connected benefits.

Interviewee 14:37
Yeah.

Samuel Ziak 14:39
So, to sum up again, the digital twin is not a single concept because there are many factors at play.

Interviewee 14:49
Yeah. Yeah. The interesting thing is that I work a lot with this, but depending on the need, I have a toolbox of advanced tools to solve specific needs.

Samuel Ziak 15:17
You've touched upon standardization, and I'd like to ask more about the toolbox or tools that you or others use when working with digital twins. Is there currently a standardized toolbox or any standardization methods for digital twin implementation in offshore wind farms?

Interviewee 15:46
No. If we take it one layer deeper, you'll see that the digital twin is not just one thing. The reason it's so successful is that it combines many different disciplines.

Samuel Ziak 16:13
Yes.

Interviewee 16:14
And there are experts in each discipline.

Interviewee 16:18
You have experts in wave dynamics, elastic or dynamic regulation, and many other areas.

Samuel Ziak 16:25
Yeah.

Interviewee 16:26
So, you have lots of disciplines—reliability, risk and safety, structural dynamics, etc.

Samuel Ziak 16:31
Umm.

Interviewee 16:33
And these are all experts. The real challenge is bridging the gaps between these disciplines and

ensuring that there are no important overlaps missed. I think that's a challenge in the industry—you have many experts working in isolation.

Samuel Ziak 17:08
My question now, which was also asked to other interviewees, is this: Digital twins can be considered just one aspect of a product, but that would be an oversimplification. Some authors in the literature have tried to define a framework that applies to the entire product lifecycle, from design to construction to innovation and beyond. In your experience, do you agree that digital twins should be considered throughout the entire product lifecycle? Or is there a single stage you would prioritize, such as getting the digital twin up and running early in the design stage?

Interviewee 18:00
Hmm.

Samuel Ziak 18:00
Maybe at a later stage?

Interviewee 18:06
Yeah, that's a big question because the end goal is that we've gained so much data and experience that, based on this, we can benefit from it right from the start, before designing a new wind turbine. The idea is that we will have new knowledge of the relationships between design variables—some we can measure, some we cannot. It's comparable to structural discipline today, which is based on thousands of years of experience. Following these standards, you have a well-calibrated design. But today, we need to be much more efficient, and we cannot wait another thousand years to get closer to the real world. We're dealing with probabilities, and some of these probabilities are closely related to safety. These probabilities of failure are so small that you might never experience them, and that's where a well-calibrated digital twin comes into play.

Samuel Ziak 19:55
Mm-hmm.

Interviewee 19:56
So that's just one of the many purposes of a digital twin.

Samuel Ziak 20:09
Yeah, yeah, yeah.

Interviewee 20:09
Creation of the real world—on top of this, of course, we'll never fully replicate the real world. That's where we quantify uncertainties in the model. But once we have the model and the model uncertainties, we can simulate the world. We may need up to 20 million years of simulations to assess these very, very small probabilities, which form the basis for the code from standards. That's one of the purposes of the digital twin: to create a virtual world in which we can predict performance, not just for 20 years. Because if you want to maintain something for 20 years, you have high uncertainties. You don't know what those uncertainties are, so you don't know how much maintenance is needed.

Samuel Ziak 21:06
Yeah.

Samuel Ziak 21:11
This is really valuable content from someone who works with the technology and provides a lot of insight.

Samuel Ziak 21:30
But you've answered everything perfectly. Thank you for this part. Now, still within the same context, I'd like to discuss stakeholders and their roles. Who would you consider the key stakeholders involved in the implementation of digital twins?

Interviewee 21:40
Yep. Hmm, very good question.

Interviewee 22:04
Yeah, yeah. It really depends on your position or viewpoint. I would say the main stakeholder, of course, should be the investors.

Samuel Ziak 22:35
Of course, because it's a young technology as well, right? And you need...

Interviewee 22:38
It's a young technology, and the investors should be convinced based on the business case.

Samuel Ziak 22:51
Absolutely.

Interviewee 22:51
If you cannot convince the investors, then you have no project. But apart from that, the owner—I'm not sure if the owner and the investor could be the same.

Samuel Ziak 23:04
You could say the project developer, but they could be the same.

Interviewee 23:08
And that's what would be very interesting from these questions. I would think that the owner's interest is that once he builds a new farm, he will need tools to optimize the design and save a lot of steel.

Samuel Ziak 23:15
Yeah.

Interviewee 23:28
For example, before he designs it—that's money.

Samuel Ziak 23:30
Yeah.

Interviewee 23:31
The other thing is that once it is up and running, he also wants to reduce the cost of maintaining and operating the system.

Interviewee 23:57
And maybe, I don't know, if we miss one—because it could be from the perspective of society as a whole, they would benefit from having a sustainable production of energy. So our whole society, whether it's Denmark or elsewhere, could benefit. Starting from the top, and this is why I say it's dependent on the viewpoint. People involved in environmental groups, of course, will focus on sustainability, pollution, and things like that.

Samuel Ziak 24:49
Yeah.

Interviewee 24:50
The government, the state—Denmark, for instance—will focus on the society getting richer, on innovation, and on the local community.

Samuel Ziak 24:57
It's...

Interviewee 25:03
But maybe the question should be answered from my closest connection point. The owner would say they get most of the benefit and earnings from their wind park.

Samuel Ziak 25:13
Yeah, for sure. We already reasoned why. Since the technology is in its early stages, it’s yet to be fully integrated across the industry, I guess.

Interviewee 25:43
Yeah, but of course, this is also why we want you to look into this. The purpose of your study is to tell us what the needs of each stakeholder are and then, based on these, maybe highlight the ones that support us. But yeah, we want to do something good for our main stakeholder, and that’s why it's important that we know exactly what their primary needs and other needs are.

Samuel Ziak 26:54
Exactly, exciting. So, you’ve mentioned the needs. Let’s proceed to the next chapter.

Interviewee 27:01
Yeah.

Samuel Ziak 27:01
Now we will discuss the needs and values. But first of all, we will speak only about the needs.

Interviewee 27:04
Yeah.

Samuel Ziak 27:06
So remember, first only needs. If you put yourself into the shoes of a stakeholder, what do you expect that a digital twin can or will bring to you? What need can it or will it solve for you?

Interviewee 27:29
Yeah. Umm... I would see it at one level.

Interviewee 27:38
I would say what we're hired to do is lifetime extension, so let the main purpose be that.

Samuel Ziak 27:55
Because that would translate to many other factors that could be affected.

Interviewee 28:09
Yeah.

Samuel Ziak 28:10
So this is a major step or a major tracking point, right?

Interviewee 28:16
I'm hired to develop for extending the lifetime of platforms, and then we try to enlighten the owner that this is what we do. Based on the table with possible needs, it's difficult to answer.

Interviewee 30:00
But this is difficult, and you'll improve on that and be much more systematic about it. But let's take what you have, and, um, yeah. Let's assume that the categories are as they are. Then yes, lifetime extension could be categorized under operational efficiencies. But it's also about cutting costs or increasing earnings, and about sustainability, of course.

Samuel Ziak 30:46
Yeah, they are closely related, right?

Interviewee 30:47
Decommissioning.

Samuel Ziak 30:49
It wasn't easy for me to put them into brackets, but it was more just so you could choose whichever need. You mentioned lifetime extension primarily, but then other needs would be filled out or affected by it.

Interviewee 30:49
Yeah, yeah. Ohh, yeah. So originally, I'm hired for achieving lifetime extension. And actually, it's upfront lifetime extension. The idea is that we've already given a benefit to the owner because we have told them that in their present business case, they assume 20 years. That's what

the whole account and earning is built on, but tomorrow, with this—or if they take our report and install this equipment—they can get the benefit tomorrow, literally. They can change the business case and get another 10 years. They can put it into the account. So lifetime extension is itself, and there are lots of built-on advantages. One is that the business case and the company's accounts can be adjusted today, and in the future, you can get cost optimization on O&M. And at the same time, you start monitoring the performance, so you can see if there are any changes or reasons for taking further actions from there.

Samuel Ziak 33:14
I see. Yeah, yeah, absolutely. Yeah, that makes a lot of sense because, yeah...

Interviewee 33:18
And, and, and once we get to full implementation, it will be a totally new, developed tool for making decisions. Supporting decision-making is a discipline in itself. The decision-making is based on a cost formulation where all costs can be implemented. So if things change, you can activate this decision-making, and it will guide you on the decision to be made based on that.

Samuel Ziak 34:04
Yep. So there are a lot of factors affected, right? It's not just a simple way of picking one because they affect each other. There's a link between them.

Interviewee 34:14
No, no. Yeah. Also, it supports standardization so that others will also be able to make it more optimal, yeah.

Samuel Ziak 34:33
No, but that's perfect. I think we've answered the question of which needs to address.

Interviewee 34:37
Yeah, good, good, good.

Samuel Ziak 34:39
Now I would like to switch to the opposite side where we speak about the value. And so, of course, they are not different from each other, but maybe how do you perceive the value of a digital twin apart from what we've already mentioned? Is there anything else that comes to mind?

Interviewee 34:44
And, umm...

Samuel Ziak 34:58
Maybe something apart from what we've already mentioned, like lifetime extension or the improved support of business cases? Is there anything else that you would cherry-pick?

Interviewee 35:14
Yes.

Samuel Ziak 35:16
It could be a major value, a major takeaway.

Interviewee 35:26
I think, uh, yeah.

Samuel Ziak 35:30
It could be a specific example. It could be anything that you would like to see as an end-user, right?

Interviewee 35:37
Yeah. As I see it, I think... and of course, that... you will get a higher value out of what you already have. So, like, a 10-year extension of the lifetime, that represents a lot of earning. And so I think earning is the main thing. But it could also be...

Samuel Ziak 36:17
It's not an easy question. I am aware.

Interviewee 36:19
Yeah, yeah. I think because for me, it's difficult to separate the, ohh...

Samuel Ziak 36:27
Just try to put yourself completely into the shoes of someone with no knowledge of this and who would like a digital twin to deliver value. What would that value be? Would it be having a dedicated application where you can see a lot of different data? Would it be something in a different format? Could it be an economic aspect where you increase your return on the initial investment? That's a lot to consider, so you can put yourself in the shoes of any party, any stakeholder.

Interviewee 36:59
Yeah, I think the most important thing is the last thing you said. In my words—and there could be many words for it—it's just increasing your earnings. That is the main issue. How could you increase your earnings? You could increase them on many levels: extending the lifetime, reducing costs through optimization, and so on. So, it's in line with that. I think those are the most important things.

Samuel Ziak 37:40
Yeah.

Interviewee 37:41
But then maybe also things that reduce costs. I guess also that you are able to monitor and, as part of communication and coordination in a company, because I think you get lots of earnings just by coordinating and aligning all disciplines. For example, the operation team could be separate from the structural team, and the structural team could take some initiatives, like extending a tower, without knowing that the operation team has problems with the blades or the gear. So, if you extend the lifetime of the tower, then you might have to replace the gear or the blades. Here, you have the possibility of compiling this data and having much more information to make better decisions, reducing costs.

Samuel Ziak 38:58
Yeah, absolutely, absolutely.

Interviewee 39:01
Umm.

Samuel Ziak 39:01
So now, mindful of the time, I will proceed to the final section or sections, which are challenges and maybe your future perceptions. But I will first begin with the challenges. We've already addressed some early on in the interview. If you remember, it was the interoperability, the digital infrastructure, and the digital platform—you need some sort of a platform to operate and aggregate the data. Do you yourself perceive any particularities with what I've mentioned, such as infrastructure platforms or interoperability with taking all the data in and making it consumable or relevant for an organization or the end consumer?

Interviewee 39:30
Yeah. Yeah, I think—I don't know if it fits here or where it fits—but I think a typical immediate challenge is that you are certain you could help the owner, but it's difficult for the owner to realize it. So, umm, I think the benefit of the filtering should, in a way, be presented or run on a much broader scope, on a much higher level in the company, because it is extremely... hey, a conversion process to convince the organization that they really need this. So, there are lots of challenges and barriers within the company itself in adopting new technologies.

Samuel Ziak 40:51
And especially, I would assume, in larger companies where change is usually more difficult to implement and integrate into. Correct me if I'm wrong.

Interviewee 40:59
Yeah. Yeah. And also, there's a big gap, and maybe many levels to pass from the very technical, technical engineering part. They should have a certain gift, what do you call it? And tell them, tell them to actually communicate the advantages up to a higher level. There are so many levels to pass where they have filters, and the message typically will not get to the top. Then, priorities are not set, and there are also issues sometimes with silos, where people...

Samuel Ziak 41:17
Knowledge. Capability. It's...

Interviewee 41:47
...are responsible for different disciplines. Like, for example, IT. I'm not saying this company has this challenge, but it could be that IT is their own, like their own kingdom.

Samuel Ziak 42:03
OK, umm...

Interviewee 42:05
Yeah. And it's difficult to make any changes. That's why it's good to have everything in one big system—that's an advantage. But the disadvantage is that it's much, much less flexible and operational. So, there are a lot of challenges and barriers.

Samuel Ziak 42:36
Brilliant. I love your input on this because it's extremely valuable and probably challenging and problematic for corporations or for any sort of technology to integrate it from, let's say, a concept or an idea and then actually convince the stakeholders. And also, synchronize the siloed departments that usually work unless you have a bimodal IT, which, OK...

Interviewee 43:01
Yeah.

Samuel Ziak 43:01
...but still, if your organization is large enough, it's a bit more difficult to actually operate it.

Interviewee 43:07
Yeah.

Samuel Ziak 43:07
That was a brilliant perspective and, yeah, yeah, yeah.

Interviewee 43:10
Because...

Interviewee 43:10
Because...

Samuel Ziak 43:12
Go on, go on. If you have more—I don't know if you have a meeting, but we can just extend by a few minutes if that's fine.

Interviewee 43:12
And then... yeah, I think so. The contrast...

Samuel Ziak 43:20
I only have one last question for you, and that would be about the future perspective, and then we can close. So, I don't have much more on my desk.

Interviewee 43:28
Yeah. Good. Good. I'm just—just one more thing, but that's part of convincing. Yeah. And of course, if there are many parts that have to be convinced, it's a... yeah, I think that's all on the same.

Samuel Ziak 43:44
Yeah. So, my last two questions are: how do you see the role of digital twins continuing, and what would be your timeline?

Interviewee 43:50
Well, one more thing is that typically, you can try to ask the owner or the stakeholder what their needs are, but if they're not aware of the possibilities, it can be difficult for them to identify some

needs. So, because there could be needs that they haven't realized because they don't know the potential. So, I think maybe that's also a point.

Samuel Ziak 44:21
For sure, for sure. I learn as I go, and that's why you are among my first stakeholders to be interviewed as well. But just my final question for you: let's say that right now you are working on this technology in a company—what's your expectation for the technology? What's your timeline? Maybe 2, 4, 6 years? How long do you think it will take to become more of a standard within users, companies, or the industry?

Interviewee 44:31
Yeah.

Samuel Ziak 44:50
Do you have something that you would expect or have you formed an opinion about it?

Interviewee 44:55
Hmm. Yeah, that's an extremely good question because, for example, this structural reliability analysis with the clear benefits of being able to actually quantify safety and then optimize things—the idea or the methods for that were developed in the 1980s. When I finished university in 1989, I thought I had to go out and use this because everybody should be looking for this. And now we are today, and it's not even... it's not even taken into... yeah, it's not even applied now. So, the big answer is that usually, if you have a technology, you cannot imagine how long the delay can be in implementing it. But I think the plan for that right now is three years. So, within three years, they will start harvesting the major part.

Samuel Ziak 46:15
Cool.

Interviewee 46:23
But from then on, that is maybe—or that is the—I don't want to say a limited scope, but that's lifetime extension. So, that's fatigue of the towers and optimization of steel consumption in design.

Samuel Ziak 46:39
And that's what you were initially hired for, if I understand correctly.

Interviewee 46:43
Yes, exactly.

Samuel Ziak 46:44
So that falls under your scope of work within the organization that you work for.

Interviewee 46:49
Yeah.

Samuel Ziak 46:50
Cool. That's brilliant.

Interviewee 46:51
But on top of this, we foresee that maybe there will be another three years in harvesting the benefits from the full implementation.

Samuel Ziak 46:58
Of course.

Interviewee 47:06
Yeah, this cost optimization formulation, taking other parts into account, would take, yeah, another three years maybe.

Samuel Ziak 47:17
Because it's not gonna die just there when you finish the task, right? If successful, it's not gonna just stop at that point in time. It's gonna be maybe even more pervasive, and people are gonna be more aware as well, so fingers crossed this works out.

Interviewee 47:31
We are just taking the first benefits, and in order to get the full benefit of optimizing production and similar things, it will take longer.

Samuel Ziak 47:36
Absolutely. And my final question—not to burden you any more—that's one of my own. And that is: right now, you are hired in a company that you developed this technology for. Would you like—if this comes to play and develops further so the technology becomes more accepted—would you like it to become an industry standard, or would you prefer to keep it only within the selected organization? On one hand, if we are speaking about safety and risk, maybe it's good to spread it across the industry, but at the same time, if you develop this technology, it gives you a competitive edge, right?

Interviewee 48:14
Yeah. Yeah.

Samuel Ziak 48:25
So maybe share your thoughts about this.

Interviewee 48:25
Yeah, yeah, definitely. I have. Because, like, the wind industry is famous for keeping things in silos and keeping the knowledge to themselves, especially in the wind industry. But the real benefit comes from sharing. For example, one big idea is that we will, by using machine learning and artificial intelligence—the idea is that the main point here is the data. The more data, the better; the more data you have to learn from. So, in order to get more data, you need a big worldwide database of all data. So imagine—and also the theories of transferring information for different purposes, for different disciplines—into one main tool where you can take limited data from a specific structure and gain from a big database of information. So the idea is that, if you could combine data from the oil and gas industry, from all the Norwegian platforms, all the

Mexican platforms, all the American platforms—all the platforms in the world—into one big database, train it, extract the information and knowledge, update our models, combine it with sensor measurements from all wind parks in the whole world, maybe even combine it with measurements from VSOs like big container ships, measurements on airplanes, and measurements on bridges, for example, or on high-rise buildings... The idea is that there will be some main general relations that can... like, for example, if you go to the doctor today, you open your mouth, and he sees your red throat, and then he can make a diagnosis just by looking at the redness. How did he get this experience? Again, it's from 2000 years of absorbing knowledge from all patients in the whole world, building a database of knowledge. So when a specific patient turns up, he can make a very quick diagnosis from very simple information.

Samuel Ziak 51:41
But is this something that you've mentioned? For example, for oil and gas, does something like this exist—a platform or repository that aggregates all the data? For example, for the Norwegian oil substations or drills, etc.? Is there something that you know about? I like the idea, but it might be a bit too difficult to execute.

Interviewee 52:02
Yeah. Well, it is one of my favorite ideas, and it's pretty wild. It's probably not going to happen in my time, but definitely, it should be possible. We tried in Norway—I've told some of the Norwegian parties that they should look into this, and they can see the benefit, of course. But if all the different companies released data to each other and shared experiences, there are standards that could anonymize the data so that it could benefit everyone without releasing secrets from different parts of the industry. So, it is a favorite idea of mine. That's why we should share data, which ties into your question of why we should share. The reason is that I need more data than I have myself, and in that sense, I would benefit from all the others.

Samuel Ziak 53:14
Yeah. Yep.

Interviewee 53:29
And solving all of this is very analogous to ChatGPT. You absorb all the data in the whole world, try to categorize it, and train different kinds of models for different kinds of purposes with all the data in the world. That is actually possible today.

Samuel Ziak 53:59
Yeah.

Interviewee 54:01
So, why not go in the same direction? You can do that, but you just have to convince others. You can use data without... yeah, probably, yeah.

Samuel Ziak 54:17
Exciting. No, that's brilliant. I love the chat we've had, and with this, that was definitely a future perspective on the technology. In the meantime, I stopped sharing the screen because, with these final words, I'd like to thank you for your time and the insights you've provided. They are extremely valuable to the research, and I appreciate your participation. Thank you.

Interviewee 54:43
OK.

Samuel Ziak 54:44
And with this, I'll stop the transcription.

Samuel Ziak
[Transcription stopped]

K.3 Interview #3

Name: Participant 3

Title: Technical authority

Company: Internal

Date: 22-08-2024

Time: 14:00 – 14:30

Samuel Ziak 0:03
All right.
So welcome to the interview about the integration of digital twins into the offshore wind industry.
And before we begin, I would like to ask if you give consent that notes can be taken, that I could introduce direct quotes in the master thesis, and that the conversation can be transcribed.

Interviewee 0:22
Go.

Samuel Ziak 0:23
Yes.
So to start, could you provide or describe your role and responsibility within the organization or company that you work for?

Interviewee 0:35
Very simply, I'm the technical authority within support structure integrity.
That means that I'm responsible for developing the products required to conduct measurement campaigns.
I'm responsible for securing the overarching technology, its roadmap, and strategy, with a special focus on how we secure lifetime extension on our spending assets. How do we secure that?
Do we work smartly in the future, meaning that we would...
Yeah.
And we will not do anything in our developments that are not focused on the value proposition.
So we're not doing anything because it's a fun thing for an engineer to do—turning every stone and doing a desk study.
Everything we do has a higher purpose and is something we would like to certify to realize true value.
So in essence, I'm responsible for everything that covers from sensor to screen to application and ensuring that it's certifiable in the end.

Samuel Ziak 1:54
Beautiful.
OK. That's brilliant, because now, of course, there are many definitions of the technology called digital twins, and I found through the literature that some authors classify it as the entire product lifecycle, whereas others classify it as just a product.

Interviewee 2:07
Hmm.

Samuel Ziak 2:14
But it can be defined as almost anything.

Interviewee 2:15
Yeah. So, here, it's a matter of technology and what's the purpose.
The purpose for us is to be able to do data-driven decision-making, both in the short term and long term. When we define a digital twin, for us, a digital twin is a prediction—a forecast—of something happening in the future, and it's something that we use to assess the risk of our decisions. That's the "fluffy" side of it.

Samuel Ziak 2:28
Mm-hmm. Yeah, yeah.

Interviewee 2:53
But in essence, what we try to do is actually to ensure that we measure reality and then have a digital representation of that with all the underlying physical models, etc.
But in the end, you measure something here, and you'd like to get the same result when you do your prediction. So, for us, this is a prediction of the future.

Samuel Ziak 3:12
So…
Yeah, yeah, yeah.
And that means, switching into the second section now, that digital twin technology is for sure going to be part of your…

Interviewee 3:20
Yeah.

Samuel Ziak 3:27
...but it is part of your work right now and will be part of your work in the future as well, probably.

Interviewee 3:31
Hmm.

Samuel Ziak 3:34
Is there any particular highlight that you would mention in terms of digital twin implementation and integration?

Interviewee 3:40
Yes.
Yeah, so it's actually a really good question because for me, repairing something in a digital sense, that's something we do all the time.

Samuel Ziak 3:41
Is there something that you've experienced?

Interviewee 3:55
We do calculations, and everybody is working in the same way when we do predictions.
And what we are trying to introduce is actually the direct coupling between reality, prediction, and how we present that prediction—the more accurate, the more updated the prediction of the future.
So, for me, the essence here is actually how we work with information. We should not work with information in an Excel sheet or in MATLAB code or anything like that.

Samuel Ziak 4:25
Umm.

Interviewee 4:33
That's something you can use when you are going into the deepest details, but to get the overview of all the threats to your operations, that's something you should just have streamlined. You measure different performance parameters, and when something deviates from what we originally expected, then we take a closer look.

Samuel Ziak 4:54
Yes.

Interviewee 4:57
But that's a proactive way of working.
Normally, we just get a phone call from the site saying, "Hey, something is burning out here," and then we have to do something.
The intention here is actually to use this methodology—digital twins—to become proactive in real time. Do an assessment fairly quickly.
All the underlying technologies required to solve the engineering task, that's just the traditional way of working, but we need to have all the information aligned for us when we need to…
Yeah.
Identify the problem, mitigate it, and in the end, update the outlook for the future.

Samuel Ziak 5:41
Umm, now coming back, you can see that there is a table, but I'm not sure if that's much relevant because it refers to either an entire lifecycle or just a product.

Interviewee 5:46
Umm.
Umm.

Samuel Ziak 5:51
So, in my experience, mostly digital twins are ideally applied across the entire lifecycle, each phase.
Do you agree? Disagree? Just quickly, one sentence, one word as you prefer, but…

Interviewee 6:05
I agree. A digital twin will be over the entire lifecycle. And here it's important to understand that a digital twin like ours consists of multiple data streams.

Samuel Ziak 6:10
Yeah.

Interviewee 6:18
Many believe that we are just monitoring our structures.
No, we're not just monitoring our structures. We also have a complete database of all documentation, so if we need to change a bolt out there, we have the lifecycle of that bolt documented.
We bought it from them, this crew installed it, the last time we went out there to check it was on this and this date. Let's document the document control, and then we have the inspection part of it, because that's where you have the observation part.
So we actually cover everything in the digital twin when we are going into the details.
We have real-time measurements, complete documentation of what's actually out there, and then on top of that, we also have human beings looking at the structure and saying, "Oh, that painting is still surviving this harsh environment," and reporting it back to us.
All of that information is fed into the digital twin for us to make the right decisions in the future.

Samuel Ziak 7:23
Brilliant.
And now the question to conclude this section: the actual interoperability of these systems that you take.

Interviewee 7:28
Umm.

Samuel Ziak 7:31
So, let's say you have a database or an ERP system.

Interviewee 7:31
Hmm.

Samuel Ziak 7:34
You can have whatsoever. There are lots of sensors on an offshore wind turbine.

Interviewee 7:38
Yeah. Hmm.

Samuel Ziak 7:40
How do you integrate and ensure that the interoperability works well?
Is that through an API connection? Is that through...?
Maybe share a few thoughts, a few words on that.

Interviewee 7:50
So here, it's really essential to say that theoretically, the technical roadmap is there, but to make

this work—what you're pointing at here is actually the most advanced stuff—because it's not just a matter of building an API. Here, it's a matter of building an organization that will operate a certain interface.
It could be an API, but I don't have an API when I receive a PDF file from the site with a huge inspection campaign saying, "I have been out there and checked this bolt and flange detail."

Samuel Ziak 8:18
Mm-hmm.

Samuel Ziak 11:34
Yes.

Interviewee 11:34
Everything that happens until that point in time is a complete cost loss for us because we don't have any profit or revenue at this stage.

Samuel Ziak 11:44
Generation.
Yeah, yeah.

Interviewee 11:52
The only thing we can control is the operation. That's our part of the business. We need to ensure the smoothest operation possible. When I say "smooth," I mean optimizing everything we do out there.

Samuel Ziak 12:16
Yes.

Interviewee 12:16
For example, I have a case here. Some of my colleagues wanted to go up and install equipment on a turbine. They needed to travel through the hub or take a ship to an accommodation platform, then go to the wind turbine and back again. Afterward, they needed to stay overnight and return the next day.

Samuel Ziak 12:39
Yeah.

Interviewee 12:42
I asked them, "Have you asked someone from operations if there are any pictures of that installation?" If we had a digital representation of the geometry and how it's built, we could have used that instead of making the trip. That's something we're envisioning for the future.

Samuel Ziak 13:11
Yeah, brilliant. Would you say there are external stakeholders that could complicate things? For example, regulators or investors?

Interviewee 13:23
Yes, absolutely. To benefit from the digital twin, especially in predicting the future, we need all the certifying bodies on board. Otherwise, it will just be another proof of concept that isn't certifiable.

Samuel Ziak 13:43
Are there any current standards or regulations you follow?

Interviewee 14:02
We have plenty of regulations, but they follow traditional standards. When optimizing our predictions, the existing rules and regulations don't fully cover what we're doing yet.

Samuel Ziak 14:08
OK.

Interviewee 14:20
That's why we're preparing and moving the industry forward with this strategy. If you're familiar with that...

Samuel Ziak 14:29
Yeah, another interview touched on it briefly. But let's keep on track and proceed to the next question.

Interviewee 14:33
Sure.

Samuel Ziak 14:39
Now, let's discuss the needs and values. First, we'll talk about the needs. What are your needs as a stakeholder that you expect a digital twin could solve? You mentioned an example with the team going to the offshore wind turbine.

Interviewee 14:58
Yes.

Samuel Ziak 15:01
Is there any other need as a stakeholder that you think a digital twin could solve?

Interviewee 15:07
Actually, the example I gave pretty much covers everything. It's about making operations more efficient and informed by data.

Samuel Ziak 15:10
So, the needs you mentioned can be summed up in the example you gave. But if you had to prioritize, what would be the most important need?

Interviewee 15:27
It's hard to single out just one need because everything is interconnected. But if I had to pick, I

would say the lifetime extension is critical because it's closely tied to our current work. However, it all stems from data-driven decision-making and making our operations more digitalized.

Samuel Ziak 15:41
So, primarily, the focus is on lifetime extension, given the nature of your work at the moment, correct?

Interviewee 15:50
Yes, we are supporting the lifetime extension journey. But it's important to note that this initiative didn't start with the goal of lifetime extension. It just happens to be a coincidence that it's financing this. The real origin is in enhancing data-driven decision-making and digitalizing our processes.

Samuel Ziak 16:06
Is this initiative driven by the organization, or did you and your team propose it?

Interviewee 16:19
It was driven by the old organization that initiated it.

Samuel Ziak 16:31
OK, and that organization is no longer in place?

Interviewee 16:32
Correct. We now have a new organization and a new structure for how we should operate.

Samuel Ziak 16:37
I see. And the new organization is still figuring out how to proceed with this?

Interviewee 16:45
Yes, that's right. This was the original intention, but with any technology that impacts all parts of an organization, you need everyone on board with the strategy. When the organization changes, it becomes more challenging to implement.

Samuel Ziak 17:23
Yeah.

Interviewee 17:33
A year ago, we had the ideal setup to do things right. Now, with many changes among our stakeholders, we need to figure out how to move forward. But the key decision-makers and ambassadors for this project are still around, which is why we can continue working on it. It's crucial to have gatekeepers when you implement a process in a large organization.

Samuel Ziak 18:10
Hmm.

Interviewee 18:13
If you don't have gatekeepers and people passionate about the project, you will never succeed in implementing it.

Samuel Ziak 18:25
What do you mean by "gatekeepers" in this context? Could you elaborate briefly?

Interviewee 18:33
When dealing with change management, you need people with an entrepreneurial mindset—those who are passionate about driving the change.

Samuel Ziak 18:37
Internally or externally, or does it matter?

Interviewee 18:46
Internally. It's crucial internally.

Samuel Ziak 18:47
OK, perfect. I understand now. To be mindful of the time, let's move on from the needs, which we've summed up, to discuss the values.

Interviewee 18:51
Yes.

Samuel Ziak 18:59
I have outlined four major values that could be classified as economic, operational, systemic, and strategic. All of them will be affected, of course.

Interviewee 19:12
Yes.

Samuel Ziak 19:12
But how do you perceive the value added by the digital twin from your point of view?

Interviewee 19:19
First of all, we're not doing anything without a financial outlook. So, the economic aspect is key.

Samuel Ziak 19:30
Primary, yeah.

Interviewee 19:31
Yes, absolutely. But operational and economic aspects are closely linked. That's where we ensure our business case meets expectations.

Samuel Ziak 19:44
Yeah, I understand.

Interviewee 20:09
We have really expensive infrastructure out there—not just from a monetary perspective, but also from a sustainability perspective. There are a lot of natural resources involved. Should we operate these assets for 20 years, knowing that with a bit more effort, we could extend their life to 30 years? Not doing so would impact sustainability. So, this is, by definition, also a sustainability issue, though it's not the primary focus.

Samuel Ziak 21:16
Yeah, it's a side effect—an important one, but still a side effect.

Interviewee 21:18
Yes, it's an important side effect, but not the main focus.

Samuel Ziak 21:22
Still nice to have, but I get that it's not the main focus. Perfect. Now, transitioning...

Interviewee 21:26
Uh, yeah.

Samuel Ziak 21:27
Yeah, yeah.

Interviewee 21:28
From a statistical perspective, information is power. That's why we're doing this. When we get the information from our data cells, it gives us the power to influence both external partners and internal partners on how we should operate.

Samuel Ziak 21:40
And you'll like the last two segments of the question I'll ask. I hope there's time to answer them. First, we've touched on challenges, like the interoperability of data. You may have different software systems to aggregate it, etc.

Interviewee 22:02
Hmm. Yes.

Samuel Ziak 22:15
Do you think these challenges could affect the development of this technology? Or have you experienced any obstacles in your current or previous roles? For example, cybersecurity implementation, or any other issues?

Interviewee 22:28
I'd actually like to be quoted on this: when dealing with such a project, the biggest challenge isn't technical—it's human. All the humans involved, that's the real challenge. Managing change across an entire organization is the most complicated journey.

Samuel Ziak 23:00
I see.

Interviewee 23:11
For example, rolling out a digital twin as a digital representation of your operation is challenging because it relies on human input. That's the tricky part.

Samuel Ziak 23:34
I see. But from a technological point of view, do you see challenges in connecting departments, like IT and operations?

Interviewee 23:45
Yes, everything boils down to strategy. As I mentioned, you'll never succeed without a cross-discipline strategy. Right now, we're in a bottom-up situation, where a small team is developing this and then telling the rest, "This could be a feasible way to do something."

Samuel Ziak 24:18
Yes.

Interviewee 24:19
But that's not a healthy way of working. Someone needs to step up and say, "Hey, we could do this smarter." Then there's a transition from bottom-up to top-down strategy.

Samuel Ziak 24:21
Yeah, to be the flag-bearer.

Interviewee 24:37
Exactly. But that's just the nature of change management. I've seen it in many situations.

Samuel Ziak 24:44
Brilliant. Now, to conclude with the cherry on top, you mentioned that information is power.

Interviewee 24:52
Hmm.

Samuel Ziak 24:53
My final question: do you believe that the information gathered from digital twins in offshore wind should be shared across different companies or developers in the market?

Interviewee 25:05
I'm fully in favor of realizing that, yes.

Samuel Ziak 25:07
But should it remain within the company to give a competitive edge, or be shared?

Interviewee 25:16
No, we should be as transparent as possible. Of course, we're mindful of commercial interests, but to truly make progress, we need to be fast and free within one generation. We should avoid financial battles between stakeholders because we have limited resources to achieve a common goal for humanity. This may sound philosophical, but I believe we should share technologies

across companies. The real competition should be on the risk profiles of individual companies, not on the technology.

Samuel Ziak 26:03
Yeah.

Interviewee 26:16
That's the business case—we shouldn't fight over technology; we should compete on risk management.

Samuel Ziak 26:24
Brilliant. I think that's a perfect ending to the interview. Thank you very much for your time and insights.

Interviewee 26:28
You're welcome.

Samuel Ziak 26:30
As I mentioned initially, everything will be anonymized.

Interviewee 26:37
Yeah, yeah, yeah. I'm fine with that. Even when anonymized, people might know who said it.

Samuel Ziak
[Transcription stopped]

K.4 Interview #4

Name: Participant 4

Title: Platform Director

Company: Internal

Date: 23-08-2024

Time: 10:00 – 10:40

Samuel Ziak 0:03
Excellent.

Interviewee 0:04
Yeah.

Samuel Ziak 0:05
So, welcome to today's interview. My name is Samuel, and this interview is about digital twins in offshore wind turbines, particularly focusing on stakeholder perceptions.

Interviewee 0:07
Thank you.

Samuel Ziak 0:19
Before we begin, I would like to ask if you give consent to transcribe the meeting and for notes to be taken and utilized in my final thesis. The transcription will be kept until submission, after which everything will be deleted.

Interviewee 0:37
Yes, I consent to that.

Samuel Ziak 0:39
And for your information, the company name, your name, and your responses will be anonymized, so there's no need to worry.

Interviewee 0:47
OK, that's fine.

Samuel Ziak 0:49
Great.

Interviewee 0:50
Fine with me.

Samuel Ziak 0:51
So, to kick things off, there are different sections of the questionnaire prepared beforehand. To

begin, could you briefly describe your role and responsibilities within the company you work for?

Interviewee 1:01
Yes, I'm a Platform Director within the offshore development team. My role is to ensure we have a competitive set of technology for our future projects. I connect the projects with the concepts we have and try to push the boundaries of where we need to be in the coming years to close gaps.

Samuel Ziak 1:33
Umm.

Interviewee 1:33
In that regard, I have the Concept Directors I can go to and say, I need to push technology development in this direction to close this gap, ensuring we have that product in place, and so on. Then, I can play it into the platforms we have available for the projects.

Samuel Ziak 1:55
So, to understand correctly, you are a step before the actual platform development takes place?

Interviewee 2:03
Yes, my role also involves developing the platforms, but it's true that I also need to be upfront of that.

Samuel Ziak 2:07
OK. Umm.

Interviewee 2:14
So the platform is developed.

Samuel Ziak 2:14
So, in the design phase and in the sort of pre-development phase?

Interviewee 2:17
Yeah, it's pre-design, yes. It's before the projects are even won or being bid on.

Samuel Ziak 2:24
OK, OK. So completely initial, even before, OK.

Interviewee 2:27
Yeah, very initial—building the business case up to something that is waterproof.

Samuel Ziak 2:37
Cool. So now to transition a bit into the topic. If I ask you, what is your understanding of the term digital twin?

Interviewee 2:44
Yeah.

Samuel Ziak 2:45
That's the core concept we're speaking about here.

Interviewee 2:46
Yeah, and actually, the description you have there is, in my mind, quite accurate. It's very important that we have a model, and you could say a calibrated model with the given environment and so on—this is what I consider the digital twin. I really like your focus on the entire lifecycle; that's quite accurate to me.

Samuel Ziak 3:14
So, would you say it's more of a lifecycle to you or more of a product? Because that's very generic, right? A product can deal with anything, whereas a digital twin is sort of an aggregation.

Interviewee 3:21
Yeah, I'm also seeing it as a lifecycle, and it's really important to have the full lifecycle on board for the strategy.

Samuel Ziak 3:33
Yeah. We'll get to that in a second. Can we assume that digital twins are somewhat part of your work?

Interviewee 3:36
Yes.

Samuel Ziak 3:40
Is this something you focus on, or could you elaborate on that?

Interviewee 3:43
If I should answer directly or indirectly, I would probably say indirectly. In the past, I was primarily in near foundations, which was in direct contact with digital twins, but now it's more in a business case environment. For me, it's more indirect; I'm using the technology to gain a bit on the business cases, and for that reason, I would call it indirect.

Samuel Ziak 4:13
So, assuming what you say, can we state that this technology is useful to you?

Interviewee 4:21
Yes, it is. But I'm not using it directly; I'm more seeing it as leverage in the business cases—something that can improve the business cases and the understanding of the lifecycle of the projects, so to speak.

Samuel Ziak 4:26
Of course, of course. Now transitioning into the second section of the interview, which focuses more on digital twin integration within your current organization.

Interviewee 4:49
Yeah.

Samuel Ziak 4:49
As you mentioned, you had experience with digital twins before, and you're probably indirectly involved with them as part of your business cases or maybe looking into the future as well.

Interviewee 4:54
Yeah, yes.

Samuel Ziak 5:03
How do you see them evolving from when you worked with them in the past to now, or perhaps in the future? Could this technology help companies or the industry to move forward? Is there anything else you'd like to highlight?

Interviewee 5:14
Yeah, I definitely see a huge potential in digital twin philosophy—the philosophy around digital twins. Perhaps "digital twin" becomes a little bit fluffy, but I would say more the data-driven design and data-driven decision-making, where I think the digital twin is the enabler for that because the digital twin will be the vehicle that allows data-driven decision-making. That's really, really important. I think that would be the next era in our offshore wind—to have this, and it's again very important to look at the entire lifecycle. From design, we can gain a lot, but I think on the operational side, those questions come later as well. But in all of these categories, there will be meaningful topics to address when it comes to data-driven decision-making.

Samuel Ziak 6:23
Absolutely. Just to follow up on that, we'll skip the question here because it's about which part of the lifecycle you think plays a value, but we already predicted that.

Interviewee 6:31
Yeah, it's the entire lifecycle. I cannot think of any place where it doesn't make sense to have it.

Samuel Ziak 6:40
Yes, absolutely. I fully agree. Proceeding to maybe what sort of benefits do you feel the company tries to achieve by implementing this—maybe cherry-pick as well?

Interviewee 6:53
Yeah, yeah. I think we have different phases. Actually, I was one of the people, together with Michael, who implemented the whole philosophy at [Company Name]. In the very early stages, I struggled to figure out how to bank this—what the benefit would be to get it into the business cases. My idea was that the easiest way forward would be with a lifetime extension potential, defining a lifetime extension—saying what happens if we design our structures for a shorter lifetime than expected because of the monitoring, for example, and then trying to see what leverage we can get out of the monitoring. We gradually saw many other spinoff benefits with implementing a data-driven decision-making or digital twin approach. You could say it's not even a true and genuine digital twin yet; it's still scratching the surface because we haven't got the full response from the measurements and the environment pushing our structures down to an integrated model.

When it comes to lifetime extension, that's quite obvious. But we also have lots of O&M features to optimize. We have this whole risk-based inspection planning that can be suddenly picked up in a different way. So, if you encounter a problem on-site, we can discuss whether we need to do anything about it or if we can pack it because of the lower utilization of the structure, and so on. Suddenly, we have a big opening of different options to explore, and we can also encounter problems differently. You can sense that a structure is failing somewhere and pick up those problems at earlier stages.
There's one great story—not from [Company Name] but from [Another Company]—where they lost a rotor at an offshore wind farm. They looked back at their measurements and could see that just a few hours before the rotor dropped, there was a rise in one of the peaks in the frequencies. Something odd was going on, and it turned out there was a crack inside the shaft, which is impossible to monitor directly. But now, they're monitoring that peak. They can shut down the turbine if they see this growing peak. That's a super interesting way to solve a huge and difficult problem by collecting data and making decisions at the right time. That's just one out of many examples of where you can use data in a more proactive way.

Samuel Ziak 10:59
And then prevention, especially investing in this. Just to follow up with two questions: When did this initiative begin with your colleague, when you started to think about digital twins?

Interviewee 11:01
Yeah, exactly. Preventive maintenance, yeah. In 2020, we really started having these strategies. We had a digital strategy at [Company Name], but it didn't pick up on the digital twin philosophy until a little bit later. We had a data-driven O&M philosophy, which was the starting point, but we realized we were doing a lot of measurements on our structures without using the data for anything. Then we thought, OK, how can we actually use this? We hired Michael, who came from oil and gas with a lot of experience with digital twins for oil structures. We picked up on his learnings, and now he's moving ahead with it.

Samuel Ziak 12:30
That's why we are here as well today.

Interviewee 12:31
Yeah, so there's been a lot of development in this area.

Samuel Ziak 12:34
So, that brings me to my second question in this section before we move into specific stakeholders: the challenges of interoperability. As you mentioned, there's a lot of data from different structures of the digital twin, but that raises the question of how you actually utilize all this data. How do you store it? How do you manage it?

Interviewee 12:59
Yeah.

Samuel Ziak 13:00
Is that an issue? Is it something you've experienced?

Interviewee 13:02
Yes, it is. There's been a need to address some cultural changes as well. For example—

Samuel Ziak 13:20
When you say cultural, do you mean organizational, in a way—organizational culture?

Interviewee 13:23
Yes, organizational culture. For example, one barrier that has surfaced is why we are picking up high-frequency measurements—why we are collecting more data than initially needed. We have a monitoring system running with a certain sample rate, and we're saying we need as much as we can on the sample rates. But why? Because we don't know what problems we might monitor in Year 5, for example. We need a data storage that allows us to have a higher sample rate. The response would be, "But that costs $100 a month to do." OK, but what are the savings in Year 5? You cannot prove that you'll have problems, so you have this cycle of arguments—do we need to prove that we need this higher sample rate? What do you believe you can pick up? That's linked to the perception that you need to know all your failure modes before setting up a monitoring system, and that's the wrong way to perceive it. It's wiser to say that we're monitoring to clarify what failure modes we might have in the coming years. That has been a difficult cultural change—to accept that we might be over-monitoring a bit but believe that we can capture things that don't exist yet.

Samuel Ziak 14:55
Again, coming back to the point of prevention, but as to sum up, it's more difficult to convince the organization or the interested parties that prevention is worth it and will save money eventually.

Interviewee 15:18
Yes, I've seen so many cases where a problem occurred, and after 20 years in the business, I've seen many issues like crowded connections that fail and other problems solved with data that existed to some degree. We often regret not having a higher sample rate or not installing a strain gauge because it could have made so much value. But we also have this monitoring system on one side—can that be used to calibrate our understanding of the problem? In many cases, we regret not having more extensive data.

Samuel Ziak 16:29
So technologically, it seems viable to execute and get the technology done.

Interviewee 16:32
Yeah.

Samuel Ziak 16:33
However, organizational acceptance is more of a struggle.

Interviewee 16:38
Yes, even when it comes to very small budgets for CapEx, like why are we adding a monitoring system? We can save that money. It's a bit of an old-fashioned delivery model—not just at [Company Name], but at many companies. They have a Phase 1 for product development, Phase 2 for project execution, and Phase 3 for operation. Between these, there's often poor

understanding of how to take a holistic view of the whole project. There's no overarching project delivery model that covers everything. There's a fence between phases where materials are just handed over without the next team consulting the previous one for lessons learned. This model doesn't incentivize investing more money in the first phase because savings could be realized in the third phase. Digital twins can help break down these silos and barriers; it's also a cultural change that comes with it.

Samuel Ziak 19:05
For sure.

Interviewee 19:05
I don't know if that became a little bit too much, but—

Samuel Ziak 19:08
It doesn't matter. You share your thoughts as you feel. For me, it's helpful, no matter what experiences or use cases you have.

Interviewee 19:11
Yeah.

Samuel Ziak 19:15
For me, it's brilliant. Now, transitioning towards more of the organizational aspect and the actual stakeholders of digital twins, in your experience—it can be current or future.

Interviewee 19:17
Yeah.

Samuel Ziak 19:27
I've also prepared a table to help. Which stakeholders do you believe could be the most valuable, maybe within your experience or your exposure?

Interviewee 19:34
Yeah.

Samuel Ziak 19:43
Could that be the developers?

Interviewee 19:44
Yeah.

Samuel Ziak 19:45
Could that be the investors? It could be. The regulators as well—I'll leave it up to you.

Interviewee 19:52
Yes, I think project developers would be really important. Michael and I have tried to formulate strategies that also go towards the regulators, but it's more about moving the industry forward. What Michael and I realized is that if we really want to advance the digital twin philosophy and

challenge the safety factors, we need the full industry to accept this. It also needs to be incorporated into guidelines and standards.
I think that's a circle that needs to be closed somehow. Universities are asking for data, but they are using data from back in 2009 because utilities are reluctant to release new data due to confidentiality and other concerns.

Samuel Ziak 20:41
Umm, yes.

Interviewee 21:00
We need standards and guidelines to change in order to push the limits of what we're doing. The universities need to co-develop those standards. Right now, it's a bad circle, and to close that circle, someone needs to step up and address the industry's needs, including data sharing. We need to close the circle in a good way, and that makes me think that regulators, universities, and so on will be key stakeholders for us.
Developers of models and similar areas are important. Suppliers and technology providers, I think, are perhaps secondary.

Samuel Ziak 21:58
Well, you can see.

Interviewee 21:58
Environmental groups might also be secondary stakeholders, I don't know.

Samuel Ziak 22:01
Yeah, you can say that because probably the suppliers and the technology providers would likely be in-house development within the owner organization.

Interviewee 22:07
Yeah, and I think as long as the direction is set, that will also come naturally, more or less.

Samuel Ziak 22:16
Yeah, like a side benefit in a way. Cool, cool. Do you perceive that there might be any or are there any issues between certain groups, like project developers and investors? Do you think there's some sort of friction at the moment?

Interviewee 22:31
Yeah, a little bit, especially when it comes to risk or the perception of risk. For example, we just talked about lifetime extension—the philosophy behind lifetime extension is to be optimistic about the future, to say, "OK, we have a monitoring system because we believe everything we do is conservative, and any conservatism will be taken out." But I've also seen cases where the assumptions made in the design phase weren't conservative, and suddenly something changed, like a coating failure making the structure more exposed to corrosion.
There's definitely a difficulty between investors and project developers. If I want to be optimistic, investors would inherently be a little bit pessimistic—they look at the risks and say they want low risk, they want safety, and so they prefer a conservative approach to ensure high business case certainty.

Samuel Ziak 23:57
Of course.

Interviewee 23:57
So that's a big conflict between those two groups.

Samuel Ziak 24:03
Could you say that this is because digital twin technology is still relatively in its early phase?

Interviewee 24:09
Yes, and we need more proof cases for digital twins to be fully accepted. We need proof of concepts; we need universities to go out and disseminate results—go out and say, "Look at this, we have now modeled 15 wind farms, and it's overly conservative in these load cases." Then the question is, do we change the load cases into a more optimal setup, or do we maintain the conservative approach and bank on it for lifetime extension? There will be a boundary between optimizing our structures to save CapEx and the opportunity to extend the lifetime for, say, 15 more years. I think it's more valuable to aim for the latter.

Samuel Ziak 25:38
I see. Really cool. I like the discussion and the insights you've shared. To be mindful of time, we have only three sections left, and two are quite similar.

Interviewee 25:54
Yeah.

Samuel Ziak 25:56
Now we will discuss needs and values. First, let's speak only about the needs.

Interviewee 25:58
Yeah.

Samuel Ziak 26:01
Put yourself in the perspective of a stakeholder, and share with me your needs. What do you expect that the digital twin can or will solve for you as a need?

Interviewee 26:16
If I take my stakeholder view, I would be in the business case development phase. I would say, what can I gain from the digital twin for my business case? The digital twin can ensure that I have the lifetime extension potential in my project. I can put into my business case that it's designed for 30 years but can be used for 40 years, which means I can extend the lifetime for free in my business case. That's worth quite a lot.

Samuel Ziak 27:04
So it would improve all your metrics and KPIs?

Interviewee 27:04
Yes. The IRR and NPV will improve significantly from the lifetime extension of 10 years.

Imagine you have a high CapEx and the return on investment balances out after nine years of operation—then the structure goes on for free, so to speak.

Samuel Ziak 27:16
Yeah.

Interviewee 27:38
If you have a prerequisite that you are decommissioning your structures after 30 years, then this last 10 years comes for free. Of course, the O&M costs go up—we're currently assuming O&M increases linearly, but that's how it is.

Samuel Ziak 27:47
Umm.

Interviewee 27:55
I think the O&M cost optimization on the OEM side is also quite important. It's not something I currently incorporate into the business cases, but it's something we should consider. How can we improve that?

Samuel Ziak 28:12
So you mean during the standard lifetime or during the extension lifetime of O&M?

Interviewee 28:20
Both. Because I think we would see benefits with inspections, for example. How many inspections do we carry out for our structures? You have statutory inspections from guidelines or standards, but you also have inspections dictated by the owner's manual, which ideally links to failure modes. I wonder if those failure modes exist. We might be looking at specific failure modes that don't exist, but missing out on failure modes that do exist. We need the digital twin to bridge that gap.
I'm nearly tempted to hope that in the future, we get automated failure mode detection from digital twins. It's tricky, but if you imagine a fully monitored structure, you can see everything is fine—it's like monitoring the heart rhythm of a person in a hospital. You have a diagram that comes up, and suddenly something is wrong with it.

Samuel Ziak 29:34
Yes.

Interviewee 29:39
Then you spark an alert that goes into an office, and people will say, "OK, there's something wrong with this person's heart rhythm; let's check it out." In the end, you'd find out, "OK, you missed a failure mode on your structure." This is something I really dream about—having these opportunities will come with digital twins. I'm 100% positive.

Samuel Ziak 30:10
Although it's important to know there is still room for human error—even though someone tracks and keeps an eye on overall performance, a decision still needs to be made by someone.

Interviewee 30:21
Yeah, yeah, yeah.

Samuel Ziak 30:35
I see.

Interviewee 30:36
I think you could nearly imagine artificial intelligence rolling in and helping with that one, but that would—

Samuel Ziak 30:46
But let's say it doesn't look like someone monitors every part of the turbine. How do we aggregate all this information? Would that need some digital infrastructure?

Interviewee 31:02
Yeah.

Samuel Ziak 31:03
Would there be a development of a digital platform or maybe something that the user sees as well?

Interviewee 31:08
Yeah, and that's already in the making. For example, having a green light means you don't have to interact, and suddenly it turns yellow, signaling that you need to look at this. Just having that kind of visual system, where you fly a helicopter and can immediately see a spot that goes wrong, guides the teams to look at that spot and say, "There's an alert here, let's check why." We've already done things like that on a very immature level. We can see, for instance, a wind park where the lifetime consumption on one of the foundations goes up, and upon checking, we found that a damper wasn't adjusted correctly. You can intervene with the operation of the turbine to improve foundation performance. That's extremely interesting, and in the future, it could be much more automated.

Samuel Ziak 32:42
Yeah, but now we are also transitioning softly into the next part of the interview, which is value. That was a clear example of the value—preventing future mishaps or accidents. To keep some direction, is there any other value you would highlight as a stakeholder?

Interviewee 32:46
Yeah, definitely. The two top categories—economic and operational—will be the main drivers. I was speculating a bit on risk mitigation. Changing the risk profile of a project can be a tremendous value for us. If you have a given project and can de-risk it, that can be a big incentive for partnering. It could fall into economic as well, but it's a really important value.

Samuel Ziak 34:18
OK, so you could say decreasing the risk or uncertainty on the overall project execution and operation.

Interviewee 34:24
Yes, exactly. On sustainability, one of the big levers is using less material. That's interesting, and it comes more with design changes rather than O&M. But O&M would, of course, have an impact—less visits to the structure for maintenance have a good sustainability profile.

Samuel Ziak 35:07
Umm.

Interviewee 35:08
I'm also thinking that in the future, there will be more advanced ways of monitoring sustainability as well. It could be in nature-inclusive designs, like monitoring fish populations around structures.

Samuel Ziak 35:23
The important thing for me here with sustainability is that it's a side effect, not the primary driver for developing this technology.

Interviewee 35:32
No, it's not the primary driver, not yet at least.

Samuel Ziak 35:36
That's why it's included—just to give a reference as well.

Interviewee 35:39
Yeah, definitely. Economic and operational are the main drivers.

Samuel Ziak 35:46
Exciting. That brings us to the last bit of the interview, which is challenges and future perspectives.

Interviewee 35:53
Yeah.

Samuel Ziak 35:57
I'll just ask one final question that I've asked so far to participants—the challenges. As I've mentioned, it could be interoperability, or any other challenges from your perspective.

Interviewee 36:04
Yeah, I think the main challenge is the willingness to share data, for example, between turbine manufacturers and utilities. The openness between those organizations is one of the main challenges.

Samuel Ziak 36:22
Hmm.

Interviewee 36:27
There's also a challenge with data infrastructure. You mentioned cybersecurity, and I think we

have also struggled a lot with gaining pipeline access to the sites. Cybersecurity, intellectual property rights, and so on are big barriers.

Samuel Ziak 36:55
That was my final question—whether you would prefer that the company or the developer of the technology keep it within its own organization, or whether the industry should be more standardized and open.

Interviewee 36:58
Yeah, it's a super difficult question. I think I would be inclined to share everything and be open to it, but I can also see why it's difficult. It can quickly become a competitive edge for us. There's no doubt that we're gaining a lot from the measurements and tests we're doing—it's a big lever in our business cases. I can easily understand the top management's decision to keep this as a competitive edge, but if we want to really change offshore wind and gain the last mile of improvement, we need to be more transparent with the data.
This needs to happen across the full industry, because we need to change the standards and engineering mindset. That can only start if someone takes the initiative on data sharing, and then others might follow. But I would be careful to believe that easily.

Samuel Ziak 38:42
Definitely.

Interviewee 38:42
But I think it's necessary somehow.

Samuel Ziak 38:45
Exciting. That actually brings the interview to an end. Unless there's anything else you'd like to share, please feel free.

Interviewee 38:54
No, I think this captures quite well the thoughts I have. You're welcome to reach out if you need more details or if anything I said doesn't make sense—just let me know.

Samuel Ziak 39:03
Thank you. Being part of the system design helps me now quite a lot because they focus on all these technical parameters.

Interviewee 39:17
Yeah.

Samuel Ziak 39:18
So that's helpful. Otherwise, I'd like to thank you for your time and the interview today.

Interviewee 39:25
Yeah, yeah.

Samuel Ziak 39:26
It was extremely insightful to talk to you, and it brings a lot of value. If you're interested, I can keep you informed.

Interviewee 39:29
Yeah, I hope so.

Samuel Ziak 39:35
The handover will be in November, so I can share the results with you as well.

Interviewee 39:37
Yeah, please do. That would be fine.

Samuel Ziak stopped transcription

K.5 Interview #5

Name: Participant 5

Title: Product Director

Company: Internal

Date: 23-08-2024

Time: 11:00 – 11:30

Samuel Ziak 0:03
OK, very cool. So, welcome to today's interview involving digital twins in offshore wind, particularly focusing on stakeholder perception.
Before we begin, I'd like to ask if you consent to the following: the processing of the data for the master thesis, the data to be disclosed to my coordinator and the examiner, and the disclosure to CBS in Copenhagen. The data will be anonymized and published in anonymous form, representing your company and not relating to yourself. Is that acceptable?

Interviewee 0:50
Yeah, that's all good. I'm not sure what type of questions you'll ask, but I can give my view on it. It won't necessarily be an official company view, as there are many individuals with different perspectives. I hope that's understood as part of this.

Samuel Ziak 0:59
That's perfect.

Interviewee 1:09
So, I'll give my view on the digital twin topic.

Samuel Ziak 1:10
Great, that's perfect. I just needed to ask for your consent explicitly.

Interviewee 1:17
Yep, all good.

Samuel Ziak 1:20
Perfect. Let's proceed. For introduction, there are six sections, more or less. Can you briefly describe your role and responsibilities within the company you work for?

Interviewee 1:31
Yes, I'm a Product Director in offshore wind generation, heading the product development team. I'm responsible for exploring new technologies, software, and hardware that can help improve our offshore wind farm operations.

Samuel Ziak 1:50
OK, exciting. That brings us to the burning question: What is your understanding of digital twins, or what's your current knowledge of it?

Interviewee 2:02
For me, a digital twin in its perfected form is a digital version of the physical assets offshore, where you can see what has been done on the asset, what it looks like today, and predict what it will need and look like in the future.

Samuel Ziak 2:31
In terms of scale, if I asked you to rank it from 1 to 10, where would you place this technology on a priority or excitement list?

Interviewee 2:54
I think the digital twin in its complete form has elements that rank on the lower scale and elements that rank on the higher scale. For example, the component that SSI is working on ranks higher—assessing the remaining useful life of assets is highly valuable and important.

Samuel Ziak 3:09
OK.

Interviewee 3:09
That's just one element of a digital twin. There are also solutions similar to Google Street View for assets, where you can explore virtually, and how CAD drawings are made available in as-built documentation. So, digital twin applications vary widely in their value and importance.

Samuel Ziak 3:58
Fair enough.

Interviewee 4:06
Certainly, there are components that rank on the higher end in terms of value and impact.

Samuel Ziak 4:15
That's a brilliant distinction. Early on, the focus of the SSI team is mostly on lifetime extension. But I was also...

Interviewee 4:26
With SSI, they often communicate having a wind farm digital twin, which is a nice message from a communication perspective. But in reality, it's just one element—specifically assessing fatigue loads on foundations. It's important to remember this when talking about the full digital twin concept.

Samuel Ziak 4:54
Yes.

Interviewee 4:58
We do have a digital twin for assessing fatigue loads on foundations, but it's not the whole wind farm digital twin as it's sometimes presented. It's crucial to keep that in mind.

Samuel Ziak 5:17
And this is the nature of these interviews, right? To find and try to identify the reasons or perceptions of stakeholders and how they promote it.

Interviewee 5:20
Yeah.

Samuel Ziak 5:27
Because I step in as an independent student or researcher, and it's my job. I love that you highlighted this already.

Interviewee 5:31
Yeah.

Samuel Ziak 5:36
OK, but I would like to share with you my perception. From the literature, I found that a digital twin can span the entire product lifecycle or focus on a single product. Based on what we've discussed, it seems like you see it more as a lifecycle approach, with different components and values.

Interviewee 6:07
Yeah, and that's where you get value from each component. You may never reach the perfection stage with a true digital twin of your entire asset that covers everything from cables to turbine parts. If you had all these components combined, you'd have a comprehensive wind farm digital twin.

Samuel Ziak 6:43
Of course, which is difficult, right? To achieve a full, detailed replica.

Interviewee 6:52
Yeah. The roadmap needs to involve focusing on specific elements of digital twins, like what we're doing with SSI. Build brick by brick toward that vision. Trying to get everything in one go is overwhelming. Better to focus on high-value components first.

Samuel Ziak 7:31
It's a philosophy you can apply to major tasks or goals in life.

Interviewee 7:35
Yeah, exactly.

Samuel Ziak 7:41
To be mindful of time, are digital twins directly or indirectly part of your work?

Interviewee 7:43
Yes, certainly. In SSI, it's part of our product portfolio. We work with Michael and Jacob, focusing on fatigue loads. We also have sensors for monitoring corrosion, relating to foundations. Turbines have sensors for analytics to better understand their condition, another

digital twin component. There are also visual applications using augmented reality, smart glasses, etc.

Samuel Ziak 8:04
Yes.

Interviewee 8:35
We're not working much with the engineering side of things like having RDSP set up, but it's about understanding how the asset is built and the components it includes.

Samuel Ziak 9:07
For clarification, what does RDSP mean?

Interviewee 9:12
RDSP is a standard ID encoding for turbines. Every component in a turbine has a unique identifier through a node system, and that's the RDSP.

Samuel Ziak 9:23
OK, just for me to be aware of the context.

Interviewee 9:35
Yeah.

Samuel Ziak 9:45
You've described how the technology is applied in various projects and at different stages, emphasizing the entire lifecycle.

Interviewee 10:02
Yes, all stages have their value proposition. Understanding components that cannot be replaced and their remaining lifetime is crucial, which is why SSI is important. The cost savings from understanding fatigue loads and optimizing designs is significant.

Samuel Ziak 10:36
I see.

Interviewee 10:48
Knowing the remaining useful life of structures is a big use case because once structures consume their fatigue loads, they need to be decommissioned. Unlike gearboxes or blades, these structures cannot be replaced. Another significant use case is operational data from production assets—analytics that optimize operations. While it's often marketed as advanced analytics or predictive maintenance, it's a form of digital twin to me.

Samuel Ziak 12:02
Good.

Interviewee 12:07
You want to predict what's going to happen to your asset and make the right decisions based on that.

Samuel Ziak 12:13
I agree, as it falls under the umbrella of aggregated digital twin technologies. There's a lot of discrepancy in literature about what constitutes a digital twin, but in the end, it's about what works for the organization or industry.

Interviewee 12:27
Yeah.

Samuel Ziak 12:42
You've mentioned the foundation or monopile as one structure, then sensors in the wind blade, etc. Is there a challenge of interoperability, with data stored in different formats or databases? Is there a need for a digital platform to work with all this data?

Interviewee 13:30
I think a platform is helpful as a user interface, and companies do market digital platforms. However, I see the value drivers as the individual applications, not the platform itself. The platform would connect knowledge about fatigue loads with blade data, allowing more sophisticated analysis. But in my view, start with value from specific applications and then connect them at a platform level as a second step.

Samuel Ziak 14:46
OK.

Interviewee 15:04
Initially, these could be standalone applications accessed through a common environment. Connecting them should come later. It's not easy, given they're provided by different suppliers, and the data's nature varies. Creating a platform that integrates everything sounds great but is likely very challenging.

Samuel Ziak 15:54
Especially at the current stage of technology.

Interviewee 15:59
Yeah, and if a universal platform vision holds back development of specific applications like SSI's, it's better to let them progress independently.

Samuel Ziak 16:50
So the portfolio should contain different development products, each independent. Later, you might aggregate them under one platform.

Interviewee 17:15
Yes, looking at reality today, we have SSI data in data lakes, VTG data separately, analytic models with separate interfaces, cable data separately, etc. It's a scattered landscape. Ideally,

everything would be under one roof, but creating something so complex would delay having these capabilities available now.

Samuel Ziak 19:20
Understandable. Brilliant. I love it.

Samuel Ziak 19:22
I love it.
I love the contribution. Continuing a bit further, what we haven't spoken about is the stakeholders.

Interviewee 19:24
Umm.

Samuel Ziak 19:30
So right now, can one assume that you could be considered...?
I've aggregated a few basic points, but could you, as Hoganas, be understood as an investor in the technology at this point in time?
Do you feel like there is some...?

Interviewee 19:47
I mean, I may be. I'm representing the operators of the assets, so that's where I come from.

Samuel Ziak 19:54
OK.

Interviewee 19:56
So, if we talk about third parties—since I sit on the development budget—yes, I could be an investor in new technology.

Samuel Ziak 19:58
I apologize.
OK.

Interviewee 20:06
So, presenting as an operator and investor would be where I stand.

Samuel Ziak 20:12
Do you think that there is some sort of dynamic that causes friction right now between these stakeholders that you perceive from your point of view?
So, it can be...

Interviewee 20:26
Yeah.
First, maybe I should clarify, depending on what you mean by investors.
(Company) does not have a philosophy of being a shareholder in innovators.
So, in that sense, my department is not investing in innovative digital twin companies.

We're not investors in that sense.
We are partners in their work.
If we think that they have an interesting product, we may collaborate with them to demonstrate their solution, etc.
But we're not investors in the sense of taking a share of the company.
So, I would then put myself as the operator rather than the investor, to make that clear.

Samuel Ziak 21:08
Cool.

Interviewee 21:11
Then your question was if there were conflicting interests between those.

Samuel Ziak 21:14
Is there any friction?
Yeah, yes.
If not, that's fine as well.
It's more than...

Interviewee 21:21
No, I don't think there is—like, nothing that pops up for me.

Samuel Ziak 21:24
Great. To be mindful again of the time because I don't want to go over because I'm aware you are busy. We proceed to the bit about the needs and values and then future challenges and outlooks.

Interviewee 21:37
Right.

Samuel Ziak 21:41
So now we'll discuss the needs and needs only.

Interviewee 21:41
Hmm.

Samuel Ziak 21:44
And if I may, I took the liberty to aggregate some specific needs, but put yourself into the shoes of a stakeholder.

Interviewee 21:50
Umm.

Samuel Ziak 21:55
What would be the needs that you would like to achieve, which we already touched upon with the lifetime extension?

Interviewee 21:56
Hmm. Umm.

Samuel Ziak 22:02
But is there anything else that you want to achieve or that the digital twin can do for you?

Interviewee 22:14
Umm, yes, what I think is not mentioned here—or maybe it's covered—is the coordination in relation to other disciplines and stakeholders, especially the compliance side of operating an offshore wind farm.
You need to evidence that you're in compliance with a number of things: grid compliance, safety compliance, environmental regulations, and so on.
And the data that you collect from your wind farm is the evidence you need to use for those stakeholders.
You need to be able to show that certain systems are running with a certain reliability.

Samuel Ziak 22:55
Yeah.

Interviewee 23:00
Just to take one example: your aviation lights on the wind farm are critical. You need to show that they are working with, you know, 99 point something percent availability.
So that's an important need where the digital twin, so to say, would help you show those stakeholders that they live up to the requirements for your asset.

Samuel Ziak 23:28
Absolutely.
That's brilliant. Brilliant idea to include and elaborate on, and now to swap over to the other side.

Interviewee 23:34
Umm.

Samuel Ziak 23:36
That would be the value where I can say it a bit shorter. I just divided them by economic, operational, sustainability, and strategic.

Interviewee 23:37
Umm. Hmm.

Samuel Ziak 23:45
Apart from the lifetime extension value, which is primarily provided by the SSI team, is there any other value that you would like to highlight from the delivery of the digital twin?
Of course, the regulation that the data would help you to convince and supplement whatever is needed on the table, but yeah...

Interviewee 24:10
Yeah.
I think if you primarily have looked at SSI and the lifetime extension as economic value, then the

digital twin has a sustainability value that is very important.
When you run a green asset for 10 more years, or if you build it with less steel—steel requires a lot of CO2 when it's produced—that will have a huge impact on your environment.
And if you look at other digital twin applications, like predictive maintenance, if you can predict in advance components that are having issues and fix them early on, you are saving a lot on the environment.
You may not need to replace a full component and all the environmental cost of producing that; you may not need larger vessels to come and help you replace that; you can use your normal vessels, etc.
So, the environmental benefits of digital twins are, I think, a very important addition to the financial benefits.

Samuel Ziak 25:37
That's why I would say, as a final mark, that they are sort of additional but not the primary one.

Interviewee 25:45
Yeah.
And for me...

Samuel Ziak 25:46
It's interesting.

Interviewee 25:47
For me, operational benefits—I'm not sure what it means in this interview—but operational benefits are translated into economic benefits.
When you can do better planning of your operational setup, when you can run your wind farms in a more optimized way and have more production, the end result of operation is focused on doing it with the best economic value for the assets.

Samuel Ziak 25:55
Yes. OK.

Interviewee 26:17
So, in that sense, any operational benefit would be driven by the economic upside coming from that.

Samuel Ziak 26:24
Yeah, they go hand in hand for sure.

Interviewee 26:27
Yeah.

Samuel Ziak 26:28
And to conclude the interview, I'm curious to hear what would be the challenges that...
Sort of, how does your organization... I've stated the question:
How does your organization address the challenges related to... I asked about interoperability already, so let's skip that one.

Interviewee 26:48
Yeah. Umm.

Samuel Ziak 26:49
But is there any other challenge that prevents you from actually going for the digital twin, or any other point of view that you might be willing to share in this context?

Interviewee 27:05
Yeah, I think you already mentioned some of them in your examples there.
So, a big challenge initially is data collection—to just get the...
If I call it the reactive digital twin, like SSI, where you collect data and assess—or "reactive" may be the wrong word—but first you need to get the data in, and that's a big challenge.
Do you have the broadband technology for data streaming available, and the whole architecture in your IT/OT landscape to bring all that data into data lakes and cold storage?
It's a vast amount of data that we're talking about, so that's one challenge.
Then I think if you have that more perfected digital twin in the future—a digital twin that, for example, could also control your assets—you could use your digital twin to actually give instructions on what the operation will look like and change things in your turbine.
Then, the cybersecurity aspect of it becomes absolutely critical because if your digital twin is hacked, and that digital twin is not only giving you visibility of your asset but also giving you the ability to...

Samuel Ziak 28:17
Umm.

Interviewee 28:29
...change and do things with your asset from the digital twin, then you need to be very, very sure that it is a secure setup. And then I think...

Samuel Ziak 28:35
Umm.

Interviewee 28:43
One other challenge, if I can call it that—it's not a technical challenge—but the word "digital twin" is so broad, and the definition is so broad, that it's a trending word.
You know, a lot of companies are using it in their sales materials, and internal departments are saying, "We do the digital twin for the wind farm."
As I mentioned with SSI, whereas outside, it means that the word digital twin can be diluted a bit and misunderstood in all that sales material.
And the problem for someone like me, who works with it more, is that stakeholders further up in the company may believe we're doing more things than we actually are doing.
Or maybe they believe when they get sales pitches from companies who say they do fancy things, believing that this will solve many of their problems—which is not true when you actually look into the true content of what the company delivers.
So then I kind of need to be the person who comes with, how to say, maybe a negative message around it.
If an external company has sold in a digital twin to top management, saying, "This will solve all your problems," and then actually, when I look into what's behind the surface, it's mostly fancy

slides and not anything that truly...
You know, will deliver what it promises.
So, that's maybe more in my job sometimes; it's a challenge with some of these buzzwords.
And of course, the last part of that is coming back to the availability of data, but that's the true challenge.
If someone comes, if a third party comes to our top management and presents a really fancy platform with all kinds of visualizations and things, and then says, "This is what our platform can give you,"
But what they need in order for that platform to work is all the data that is extremely difficult for us to gather and provide them so that the platform can run.
And that's maybe something that it's not always understood by those people who are then being, you know, sold by the idea to have something so fancy.
So, that's maybe where there would be a disconnect between, "Yes, it's easy to build nice user interfaces that can present all kinds of data.
It's more difficult to actually make the data available and feed it into such systems."

Samuel Ziak 31:41
I have two remarks that I would like to end with, and one is just curiosity and the second one is related to the terminology of digital twin that you've provided.

Interviewee 31:44
Yeah.
Yeah.

Samuel Ziak 31:53
First, briefly, if I just understand correctly, the SSI team and the foundations—are they internally hired to develop this technology?
This doesn't have to be part of the transcript, but it's just for me to understand.
Are they external consultants trying to pitch this idea and sell it to (Company) in a way that they became internal for a moment, or are they early internal workers on the technology?

Interviewee 32:18
I would consider them to be internal, and the digital twin work by the SSI is anchored internally in (Company).

Samuel Ziak 32:20
Just because you've mentioned that...

Interviewee 32:31
It's done internally through a department in (Company).

Samuel Ziak 32:31
OK.

Interviewee 32:34
Some of the colleagues working on the digital twin are external consultants helping to enable that, so it's not...

Samuel Ziak 32:42
That's what the confusion was. Yeah, that's what...

Interviewee 32:44
Yeah, so it's not about externals coming and selling something to (Company) in that sense. What's important to understand is that the internal development of SSI costs a lot of money, and therefore, the internal SSI team also needs to internally market what they're doing.

Samuel Ziak 33:04
Umm.

Interviewee 33:12
That's not only them—all departments across (Company) make very engaged posts and try to make visibility around the successes they're having and how they essentially are delivering good value for the investments that (Company) does in their teams internally.
So that's what I meant when I talked about that.
You know, also the SSI team does that, which I fully understand, but that's where, you know, SSI is one component of digital twin.
I've seen some posts where they say the wind farm now has a digital twin, and what they're actually saying is that the foundation has an ability to collect data on the fatigue loads.

Samuel Ziak 33:51
Yeah.

Interviewee 34:00
It's not the same to say that the wind farm has a digital twin.

Samuel Ziak 34:03
And that's where my role comes into play because I've been promoted—or not promoted, but I've been mentioned—that we developed these twins.
So, my understanding was that we are developing the solution for the entire wind farm, whereas now after conducting the first set of interviews, it comes to light that it's actually a bit more narrow in scope.

Interviewee 34:26
It's a very... yeah.
And that's something that needs to be very clear—the SSI only looks at the foundations, and they focus on looking at fatigue loads and the design life of the foundations and how they can optimize that using digital twin technology.
That's their scope. That's not a wind farm digital twin.
A wind farm consists of components, cables, substations, etc.

Samuel Ziak 34:50
Yeah.

Interviewee 34:56
So you can only talk, in my view, about a wind farm digital twin if you begin to bring all of that together.

And that's where it can confuse people when it's sold like that.
If they don't understand what it's about, I've had some examples when the SSI team has made communications where they have communicated SSI as a wind farm digital twin, and then other stakeholders in (Company) have called me...

Samuel Ziak 35:16
At the moment.

Interviewee 35:31
...saying, "Oh, we already have all this," and then it's like, no, what they're actually saying is that they have it for the foundations.
We don't have it for all these other applications, so it has resulted in some of that confusion or misunderstanding of what the SSI digital twin is.
But that's not me being critical about the SSI because SSI is doing great work, and their component of the digital twin is extremely important and delivers a lot of value.
So, I just want to highlight that confusion can come from how you talk about digital twins.
The same goes for all these external companies that I met with over the last five years who talked about having a digital twin for the wind farm, but actually, they have a digital twin for a certain part of the wind farm—a certain application—not kind of one all-encompassing digital twin.

Samuel Ziak 36:04
This is brilliantly modeled.
And in your point of view, are these companies more like tech companies, or is it like a utility company—big, big—they can be a competitor or whatsoever? Just a brief— you don't have to elaborate.

Interviewee 36:37
The companies that develop and market digital twins are technology companies, that's what I see.

Samuel Ziak 36:44
OK.

Interviewee 36:45
It's not the utilities; it's typically a combination of software and engineering companies that make that rumble or things like that.
Yeah, I mean, no one would come and say, "I have a car for you," and they actually only have a wheel, right? That would be seen immediately.

Samuel Ziak 36:50
Absolutely. Absolutely.

Interviewee 37:07
But if you come and say, "I have a digital twin for the wind farm," but you actually have a digital twin for the cable of the wind farm, then that analogy applies here.

Samuel Ziak 37:16
For sure. And for my end, I only wanted—the second part that I've mentioned was that—this is exactly what comes or is derived from my theoretical research so far.
I'm looking at the theory and information systems that label these buzzwords, and people get a lot of confusion because they aggregate a lot of different technologies, and organizations are not ready to adapt them, etc.

Interviewee 37:28
Hmm.

Samuel Ziak 37:41
And then the technology either fades away, dies out in a way, or people just lose interest because it gets too complicated.

Interviewee 37:41
Yeah.

Samuel Ziak 37:48
And the sum...

Interviewee 37:50
Yeah, I don't think—
I mean, there's no chance the digital twin will fade out because the digital twin is the sum of its components related to analytics and so on. All of that...
No, it's so well established and so well founded on healthy, good business cases that companies need.
The digital twin will continue to be there whether it will be less of a buzzword and more of people starting to understand the true application—that's maybe something that will happen over time.

Samuel Ziak 38:31
Sure.

Interviewee 38:31
It's the same with all this talk about generative AI—that has been the latest trend in that sense. Suddenly, a lot of people just like to put that word into whatever PowerPoint slides they do and think, "Are we doing generative AI in your company or in our operations?"—which is too broad of a statement that you need to look into. What are we actually talking about here?

Samuel Ziak 39:01
What's under the surface?

Interviewee 39:03
Yeah.

Samuel Ziak 39:03
Brilliant.

I know we are over time, and I apologize for that, but I would like to thank you very much for the insights today. It's been extremely valuable.

Interviewee 39:06
Yep, no problem.

Samuel Ziak stopped transcription

K.6 Interview #6

Name: Participant 6

Title: Head of Foundations

Company: Internal

Date: 27-08-2024

Time: 09:00 – 09:30

Samuel Ziak: 0:04
OK, here it is.
Good morning, and it's nice to have you here.
This interview is about digital twins and stakeholders' perception of their value.
Before we begin, I would like to ask if you consent to me, as a student, transcribing the interview, taking notes, and using these notes in my master's thesis.

Interviewee: 0:30
Yes.

Samuel Ziak: 0:32
Great. Just to clarify, these notes and everything transcribed will be used until December 2024, after which they will be deleted. Your company, affiliation, or any personal or career-related information you share will be anonymized in the thesis.

Interviewee: 0:48
Yeah.

Samuel Ziak: 0:50
So, to start, I've prepared a questionnaire that is divided into six sections. The first question is: Can you briefly describe your role and responsibilities within the company?

Interviewee: 1:03
Yes, I head the foundations area in product delivery and engineering. I'm responsible for foundation solutions, ensuring we have qualified people and the right tools to support these deliveries. This includes both project developments, product development, and execution, as well as support during the operational phase and decommissioning.

Samuel Ziak: 1:36
OK, that leads me to two questions. First, what is your understanding of the digital twin? Is it part of your team's product?

Interviewee: 1:47
Yes. My understanding of digital twin is that it's been a buzzword over the past five to ten years, covering many functionalities. In our context, particularly in foundations or structural analysis, I see it mainly as the collection and use of real-life data to back up our design assumptions made during the engineering phase, before a project is built. This data can be used during the

operational phase to troubleshoot, extend the project's lifetime, or improve design methodologies in future iterations of the digital twin.

Samuel Ziak: 3:02
Absolutely, that aligns with my research. I've defined it as a virtual replica, but literature points out there's often confusion, particularly distinguishing between the product lifecycle and the product itself. Based on your definition, it seems like you consider it more part of the lifecycle, correct?

Interviewee: 3:35
Yes, I believe that's the first tangible benefit—relating to the lifecycle of a specific project or component. The spinoff, of course, is using this knowledge to improve future projects or products.

Samuel Ziak: 3:52
I see. So, we can assume that digital twins are directly or indirectly part of your work.

Interviewee: 4:06
They are indirectly a part of my work since I'm in line management. I don't work with them personally every day, but they are part of the deliverables in the department.

Samuel Ziak: 4:15
Brilliant. That brings me to the second part. As you can see in the table, it describes different stages of the lifecycle. You don't need to write anything here, but if I can ask: Can you share how digital twin technology is planned or currently integrated within the projects you've worked on?

Interviewee: 4:51
Right now, it's planned and integrated mainly for the operational stage. For example, in a project, we set up a sensor system that provides data when the wind farm is commissioned, allowing us to continuously monitor what's happening. If something unexpected occurs, we can quickly assess whether it's a severe issue or if operations can continue as planned. Towards the end of the project's life, we can also conduct assessments to determine how much residual life remains and decide whether the wind farm can operate longer than initially designed.

Samuel Ziak: 5:51
Do you think there's a particular stage in the project lifecycle where the digital twin is most valuable, such as in troubleshooting or extending the lifespan?

Interviewee: 5:56
Yes, but it depends on who you ask. For enabling offshore wind as an industry, I see value in having conclusions and knowledge from digital twin technology available at the front end during engineering, design, and construction phases. This allows deliberate decisions on where to allocate resources. For example, if we know we can extend a project's life, we can decide whether to design for the full lifespan or for a shorter period and optimize costs accordingly. For asset managers, the focus might be more on everyday tangible benefits, such as understanding site performance and planning preventive maintenance.

Samuel Ziak: 7:19
That's a brilliant point because the goal of the thesis is to understand each stakeholder's primary needs at various phases. Your response also answers the next question about the specific objectives your organization hopes to achieve by implementing digital twins.

Interviewee: 8:39
Yes. For example, during design, we make assumptions about downtime. If turbines are idling, that's not ideal for the structure. If we have longer periods of idling than expected, we can model the impact on design life. Similarly, if we consider controller upgrades or operational changes to optimize the wind farm, we need to understand how these decisions affect the residual life of the structure.

Samuel Ziak: 9:49
Do you see potential challenges with interoperability? For instance, if you're focusing on the structure, but also have data from blades or other components, could aggregating this data pose challenges?

Interviewee: 10:22
Yes, there are many challenges. There's significant development potential in how we collect, transport, store, and preprocess large data volumes. Collecting data without requiring sensitive hardware on each turbine is one concern, along with ensuring IT security, which is a high priority. Another issue is managing the volume of data—determining the right granularity for storage, understanding the energy consumption related to IT use, and organizing data archives that remain usable as personnel change. There's a lot to figure out in terms of process design.

Samuel Ziak: 12:41
It sounds like there are still challenges in designing the process around it.

Interviewee: 12:44
Yes, and also in developing the final front-end interface that employees will use. The technology is still in the early stages, especially in the offshore wind market.

Samuel Ziak: 13:08
So, we can say that digital twin technology is relatively early in its development, at least in your industry.

Interviewee: 13:08
Yes, it hasn't yet become a commodity. There's still work to be done to make it operational rather than in development.

Samuel Ziak: 13:25
We might revisit this later in the interview. Moving on to the third section—regarding stakeholders involved in the implementation—you can see examples like project developers and operators. From your perspective as a stakeholder, how do you perceive other stakeholders in relation to digital twins?

Interviewee: 13:57
Yes, there's the new build project team who need to integrate this as a standard part of their

organization. It's crucial to have clear responsibilities defined, as digital twins cut across established packages, and it's important to streamline this into the project organization. For example, linking digital twin responsibilities to a foundation package makes sense, but these teams often leave the site early, well before commissioning, so we need a systematic handover process to make this as seamless as the rest of the project scope.

Samuel Ziak: 15:54
That's a good point. Expanding digital twins beyond just structures, like including substations or cables, adds complexity, doesn't it?

Interviewee: 16:16
Yes, expanding the scope increases data flow and sampling needs, which in turn raises the demand for post-processing and oversight. You can either start sampling data and figure out its use later, or you can plan what to monitor from the start.

Samuel Ziak: 16:55
Do you think that once a digital twin model for the structure is developed, it could be replicated or implemented in other parts of the wind farm, not just the turbine?

Interviewee: 17:02
Yes, we're already doing similar things, like temperature monitoring on cables. There are various bits and pieces of digital twin technology already in use across different components, so it's a matter of integrating these.

Samuel Ziak: 17:44
That was my initial understanding too, but after conducting these interviews, I found that the scope can be narrower or broader, depending on integration.

Interviewee: 18:06
Exactly, and broader integration does introduce challenges, such as interoperability and development complexity.

Samuel Ziak: 18:12
Right. Let's move forward. But before we do, are there other stakeholders you would highlight?

Interviewee: 18:19
Yes, other stakeholders include the board, especially for making strategic investment decisions. Certifiers and national authorities will also need to accept digital twin methodologies for these decisions. Operational teams and asset managers will be the daily users, and we'll need to think about back-office engineering needs, which shouldn't require a large staff once fully operational. If we need extensive oversight, we risk negating the savings from digital twins.

Samuel Ziak: 20:26
That's a potential future challenge, right?

Interviewee: 20:27
Yes, exactly.

Samuel Ziak: 20:31
Great. Now let's discuss needs and values. As a stakeholder, what are your specific needs that you expect digital twins to address?

Interviewee: 20:41
One need is to identify opportunities that make business cases viable and optimize potential improvements. There's a conservative approach in the industry; although thousands of turbines have been built with no structural failures, which is statistically surprising, this conservatism could be reduced. Digital twins could help us manage this more effectively.

Samuel Ziak: 22:35
Perfect.

Interviewee: 22:36
Another need is knowing it's safe to operate turbines even when unexpected events occur, such as minor structural damage or extended downtime. We don't want to be overly cautious and lose money if it's unnecessary. We want to ensure that we make safe, but not overly conservative, decisions.

Samuel Ziak: 23:28
Good examples. I've also provided a table for inspiration, and I can see you've already highlighted some needs like supporting business cases and potentially optimizing costs. Great insights.

Samuel Ziak: 23:48
I love it and now switching into the different point of view a little bit and focusing on the values which this table is just a summary.

Interviewee: 23:53
Hmm.

Samuel Ziak: 23:57
So it says economical, operational, sustainability, and strategic—it just a spoiler alert.

Interviewee: 24:01
Yep.

Samuel Ziak: 24:05
Usually, people, people, they, they affect each other interchangeably, right? So if you develop this technology, you will get a benefit of all of them. Umm, it's more just to have some reference in grouping for myself and but now asking you how do you perceive the value added by digital twin and which would be the primary one if we can ask.

Interviewee: 24:13
Hmm. Yeah. Yeah. Ohm. Yeah. Again, to me I I'm it's also because let's say the the the. Decision part of the the project lifetime, where I'm most involved isn't the front end, so of course then it's the the economic part that that plays in. So so to again the choose how to spend our CapEx money basically or how to balance CapEx and OpEx and in this? Of course, the

sustainability angle also the the goes and across everything you can say again if we have, I don't know how many thousand turbines standing out there then we also have I don't know how many tons of steel out there that we could have used for something else and then that's. And of course, tabs tabs very, very much into to also the sustainability angle of it the. Yeah. Yeah, I I think I have mentioned a lot most of it before already.

Samuel Ziak: 25:31
But what?

Interviewee: 25:34
I think again the operational part is is is, yeah.

Samuel Ziak: 25:35
Yes, yes. Pusher pusher. Just the final question maybe about this one would be what about risk and safety, is that something that to be to be considered as well as part of it, of course probably yes.

Interviewee: 25:43
Umm.

Samuel Ziak: 25:48
But in which context?

Interviewee: 25:49
Yes.

Samuel Ziak: 25:49
Like which decree or?

Interviewee: 25:52
But that's that's again, that goes a little bit also across. So the the the balancing risk and safety, I think I mentioned that also earlier with the with the operational side of things, uh, so. So if we during the operational phase the it's it's a lot of stuff happened. So to be able to assess the risks to the specific case or to the operation ability of the entire form as a whole. And while knowing that it is safe to say we have with this one position on HK set where we had the huge tanker collide into during a construction which stands out there with some dents and some stuff, and the conclusion right now have been, we don't know enough of how what has happened to that structure. So even though we think it might not be able to turbine for 25 years, it might only be able to hold it for five or 10 or whatever, but we can't assess the the deformations and what has happened to to that structural integrity offer that foundation. So due to safety reasons, we cannot. We cannot defend trying, let's say, trial and error to see what can we get out of it. Still.

Samuel Ziak: 27:09
Yeah.

Interviewee: 27:09
Uh, so so safety is sort of the the the primary driver and that's also why we need to we need to do the the the let's say getting rid of conservatives or adding risk as let's say two sides of the

same coin but in a controlled way. So we don't find ourselves flipping over at the other side. You could also say, OK, we have seen what we have historically seen is yes, our design is still methodologies have been conservative, but we also see the turbines drifting to different uh characteristics now both with the eigenfrequencies and so on. So there might be assumptions we have made in the past which have been conservative or her added to our conservatism, which are now doing the opposite, which would make it a less conservative design. And then we might start chief turbine falling all over all over the place, but hopefully not. But again, this to the validation part the I think that's tapped into both the economic and the operational ability of it. But to to to have the the control over what you are actually doing and and and putting out there.

Samuel Ziak: 28:21
So essentially the technology of digital twin could even improve the risk and safety of the of the current fact.

Interviewee: 28:25
Yes. Yeah, yes, yeah.

Samuel Ziak: 28:27
Uh, but with the with the gold? The value of primary is. This is a must. However, the economic the improvement of business cases and just the returns are probably.

Interviewee: 28:36
Yeah.

Samuel Ziak: 28:39
The major drivers or values that we can say.

Interviewee: 28:41
It is. I think we may make so much effort anyway to to make sure that what we do is safe. So I think that that have not seen as a primary addition to additional value out of the digital twin specifically when we talk about the structural integrity part, there might be there might be, but I think that's just controlled in so many manners that we that we ensure the safety that. Yeah, that I don't see specific examples say come to mind on where this would would increase there. It would hopefully enable us to continue to make the safe decisions and in the yeah, we're specific operational situations, but yeah.

Samuel Ziak: 29:31
I see. And to be mindful of the time, I'm not sure if you have to jump to another meeting about maybe a few concluding words on possible challenges that that could that could arise from utilizing this technology that you could maybe just name from top of your head or.

Interviewee: 29:48
Umm the from using it. So assuming that we have it operational and and using and then what could? Could challenge us there.

Samuel Ziak: 29:55
Could be also developed. Could be also the development and transitioning into the the actual utilization or the integration whichever true phase you choose is up to you.

Interviewee: 29:59
Umm. Yep, I think the the like any development phase, there are of course a lot of of challenges during the development phase of it also specifically this the let's say the the digital and and the physical interface of of yeah the IT system both both the organizational setup let's say so how how do we ensure that we have the same priorities when we are not even in the same business units that say yes we have digital engineering but we also have an it for for all of that and fell and so on. So to get everyone to. To pull.

Samuel Ziak: 30:39
That's sort of standardization right across the cross the company.

Interviewee: 30:41
Yeah, yeah. Yes. And to find the best solutions, because I mean, yes, we might be having a team here. Who is fully focused on developing this, but it might not be the top priority of digital engineering. They might have something else that's super burning on their platform. And then that need to take their primary attention. So to get enough priority from the key players here to make sure that we make the right decisions because some of these decisions we cannot make on our own, we're not the digital IT experts necessarily. So we need them to also facilitate part of the development process to make sure that it's a solution that fits the the company as a whole and how we want to to ensure, uh, yeah.

Samuel Ziak: 31:25
And what about the standardization that you have the different IT and you have operation there at sort of sitting in the silos that could be also an issue right that there is no?

Interviewee: 31:34
It it could, I think it's, uh, I think that that since since generation currently is the primary customer for this and then it's my impression that there is a rather good collaboration in across that interface. So I don't see that so much as a silo. I see that actually more as an enabler that they are pulling so forcefully. And want this so much that it's that actually makes it easier for us to keep it under budget because there is such a clear cool for it.

Samuel Ziak: 31:59
OK. Yeah. There you go. There is a demand, but there is also the collaboration from the stakeholder.

Interviewee: 32:11
Yeah.

Samuel Ziak: 32:11
Would like this developed to.

Interviewee: 32:12
Yes, yes. And there is of course, I mean there there's also when you develop something, you might also not develop it for for yourself. So I mean it, it's it's we need to also be able to let go of parts and there is there might be also a little bit of a struggle of saying OK when stuff is done then then we give our babies to someone else and and that's let's say.

Samuel Ziak: 32:39
And that was my final question.

Interviewee: 32:39
And yeah.

Samuel Ziak: 32:40
Would that be? Would that be that you would like to apply this development of the technology within your organization or would you like to share this technology among the industry and then sort of try to try also help the other players, maybe with the limited way you know, but what what's your input on this?

Interviewee: 32:51
Hmm. Yeah. Yeah. No, I think I mean for for us to gain the most out of it and also there are many factors in this. But for for us to give the full flexibility to to choose when we spend the money, then we need this to find its way into the codes and standards. And if it finds its way into the code and standards, then it's of course also available to the industry. Then we have the same part of our our liquidity or let's say our project pipeline, we don't do that many projects at a time. So now we have had uh commissioned Vestal and and HK set over the past two years. But now there will be three years before we Commission a next one. So there will be, let's say, gaps in our learning curve of applying this at least in the let's say construction part of it where I think it would be unrealistic to assume that our competitors or the other offshore wind developers wouldn't be able to gain some kind of knowledge during those three years when we don't the so.

Samuel Ziak: 33:34
Umm. Umm.

Interviewee: 33:57
So I think it's it's I think it would benefit us to, to have some openness on on this in the industry and both too.

Samuel Ziak: 34:06
But you see that they would gain the knowledge on their own or they would be just getting to know from employees of our organization or from.

Interviewee: 34:13
Either I think most of the most of the developers have something similar going on.

Samuel Ziak: 34:14
OK. Probably.

Interviewee: 34:22
Like this so there will be, there will be developments and then OK. Yeah, perhaps we are a hit at the current time, but but then how do we stay ahead if we yeah have a thinner project pipeline than the others? And I think it's always good to, I mean always good to get other ideas or sparing from someone outside of your own bubble. So so if we have a team who's working very focused on this, then they can of course also get to a point where they're super homogeneous and just enforce their own ideas or or let's say yeah, support each other and get this. They get a little bit.

Yeah, exactly. So so I think the the sparring and the inspiration and and also because I think the the industry is is struggling as a whole right now across both of us not being able to get good business cases to to get fid. Our key suppliers also I don't, I mean I don't know where the money is going. It's it's everyone seems to be struggling to earn money on this currently, so yeah.

Samuel Ziak: 35:37
Brilliant. Thank you very much for your time and for your participation. It is really extremely valuable that you found the extended 30 minutes 3536. I apologize and but with this I will stop the transcription.

Interviewee: 35:46
Yeah, no worries. I just.

Samuel Ziak: 35:52
Umm.

Samuel Ziak stops transcription

K.7 Interview #7

Name: Participant 7

Title: Head of Digital Innovation

Company: External

Date: 27-08-2024

Time: 14:00 – 15:00

Samuel Ziak: 0:05
So we are on the same page in a way. Perfect. Perfect. Perfect.
I got that's a lot of some of the tops. Here we are.
Alright, welcome to today's interview. My name is Samuel, and before we begin, I would like to ask if you give consent to this interview to be recorded, transcribed, and then, of course, the transcription to be used for the master's thesis purposes.

Interviewee: 0:27
Yes. No problem.

Samuel Ziak: 0:32
Yes, thank you very much.
So to begin with, could you please elaborate or describe your role and responsibilities within the company you work for?

Interviewee: 0:42
Yes, I've been with the company now for almost 15 years. I've held various positions as project manager and line manager responsible for engineering, mainly for late design, structural plate design, and scoping of new products. Currently, I hold the title of Head of Digital Innovation for our development organization, which involves designing tools, design models, digital twins—things like that are of great interest to me.

Samuel Ziak: 1:16
Of course. So we can assume that digital twins are directly part of your work.

Interviewee: 1:22
Yes, I am responsible for developing our digital twin platforms as well.

Samuel Ziak: 1:23
Based on your position. So, OK, that's cool. So you are responsible for developing the platform within your company or organization.

Interviewee: 1:32
Yes.

Samuel Ziak: 1:33
OK, cool. Super nice.

So if I can ask you, what is your understanding of the term digital twin? If you had to give me your understanding because it's rather broad, right?

Interviewee: 1:42
Oh yes, now we could spend the next hour talking about what it is. For me, in the basic sense, a digital twin is about visiting the data formation. I think of it as a number of models that describe the behavior and state of the turbine. But when you see it, you might think of 3D and VR, which aren't the focus here. For me, it's about taking models, typically design models that are certified, and deploying them at scale for mass consumption. Instead of the traditional engineering approach, where you run models for a single design, I run the model on thousands of turbines in parallel to get output at scale.

Samuel Ziak: 2:58
So you're running multiple, not scenarios exactly, but...

Interviewee: 3:06
No, no. I take the same fatigue model used to verify the design, feed it with field data—many petabytes of it—from load sensors and other inputs, and come to a conclusion on lifetime consumption of a component or even hotspots.

Samuel Ziak: 3:36
This is a good point to clarify, as it addresses the introduction. Speaking of your organization's background, the most common use case of digital twins for you would be the wind turbines, right?

Interviewee: 3:56
Yes, but we also do a lot of diagnostics and predictive maintenance that are model-driven. You could call those digital twins as well—though many of these models are black box or surveillance models. For me, the digital twin is about authoritative modeling that I trust. To ensure trust in the model, it must be validated at scale.

Samuel Ziak: 4:35
Umm.

Interviewee: 4:36
It's not enough to validate on a prototype turbine; it's at TRL 9 when you have substantial data, like 1,000 years of offshore operation from multiple turbines.

Samuel Ziak: 4:55
Experience writing lessons.

Interviewee: 4:56
Yes. You have different feedback loops. For me, a digital twin supports both long-term technology development—typically 6 to 8 years—and product development, where it's about validating design assumptions. For example, using real data on actual use patterns of a hydraulic valve rather than theoretical assumptions allows you to improve designs by avoiding over-design or potential under-design.

Samuel Ziak: 7:18
Yes.

Interviewee: 7:33
For O&M, predictive maintenance uses shorter cycles, from months to days. But, generally, a digital twin creates value if it provides a reaction time you wouldn't otherwise have. For instance, detecting a failing bearing due to temperature changes is useful if you can act on it in time; otherwise, simpler models might suffice.

Samuel Ziak: 7:48
That's an excellent example. Predictive maintenance needs to be timely, but if the warning comes too late, the damage might be unavoidable. Your example highlights that well.

Interviewee: 8:12
That's where improving models through technology and product development phases becomes crucial. We prefer to develop and validate our models in the technology phase, where risks and costs are lower, and then use them more effectively in product development.

Samuel Ziak: 8:42
Yes. Speaking of digital twins in the context of transitioning from design to O&M phases, would you say a digital twin should be present throughout the entire product lifecycle?

Interviewee: 9:01
For me, yes. That's the direction we want to go. You don't just deploy a digital twin for the whole turbine immediately—you start with components and build up. For example, we might start with the blade bearing, which is an interesting component with good models. I want the digital twin to be a deliverable along with the turbine BOM in product development. And while that's initially for components where it makes sense, the key is reuse and optimization. If, for example, a model for a blade bearing is too slow for real-time data, we might need to optimize it for operational use.

Samuel Ziak: 10:29
I see. Cool, cool. So, transitioning now—you've answered my question about digital twin integration and provided examples. I noted from literature that digital twins can be defined in many ways, and I liked how you clarified it's not about virtual reality or similar things.

Interviewee: 10:49
Yeah, no. It's a very different use case. And in reality, some of it is quite boring—like our digital twin platform output, which is basically a database in the cloud.

Samuel Ziak: 11:07
So the digital twin platform is where you aggregate all the data?

Interviewee: 11:22
Yes, it's where the engineers responsible for the digital models can upload their models. We support various types, like MATLAB and Julia, and they can schedule how frequently these models are run, such as once a week or daily on turbines. The output might be something simple, like a lifetime fatigue damage count for a bearing.

Samuel Ziak: 12:23
So the frequency is set, and it's not always real-time data?

Interviewee: 12:31
Yes, but a digital twin doesn't need to be time-critical. If something needs to be time-critical, it should be handled by the turbine's onboard system. Digital twins are about long-term insights—nothing dramatic should happen on a blade bearing over a week. If significant fatigue damage occurs within that timeframe, it would be caught by other systems.

Samuel Ziak: 13:22
There could be instances like weather forecasts or other external factors that connect the dots.

Interviewee: 13:31
Yes, but most of what happens with turbines is uneventful because they're designed to last for decades. You can use a digital twin for virtual sensors, but for real-time conditions like frequency changes indicating a crack, that should be handled by the turbine in real-time, not offline in the cloud.

Samuel Ziak: 15:38
Don't you think there might be issues with interoperability when aggregating large amounts of data from different systems like MATLAB? Integrating these into one platform would require a robust digital infrastructure, right?

Interviewee: 16:10
Yes, but that's the point of our framework. The model owner can deploy their models, see cost estimates, storage requirements, and use the data as needed, whether that's for development scripts, Power BI, or other tools.

Samuel Ziak: 16:28
By model owner, do you mean an individual or a team?

Interviewee: 16:39
It's usually a team. For instance, the team responsible for blade bearings manages the digital model for that component. One of their experienced engineers develops, codes, and deploys the model. Ownership is component-based within the organization.

Samuel Ziak: 18:24
That prompts the question of human error—relying heavily on technology but also facing risks from human involvement.

Interviewee: 18:44
You're only as good as your model. We have stringent standards for design model ownership and certification, much like any big engineering organization. Of course, mistakes can happen, but we have structures in place to address that.

Samuel Ziak: 19:22
I didn't mean to catch you off-guard—it's more about acknowledging challenges like human error as part of the process.

Interviewee: 19:35
We're always learning, and while checks are built into the platform, ultimately, the responsibility lies with the component owner.

Samuel Ziak: 19:52
To be mindful of time, let's proceed. As a stakeholder for digital twins, what other stakeholders are involved in this context?

Interviewee: 20:09
It's broad. Models running on the current fleet help validate the next turbine's design, which is valuable when presenting to customers like major energy companies. They ask for validation, and we can show years of operational data to demonstrate risk management. Operators benefit too, with virtual sensors and lifetime counters that add value to service agreements.

Samuel Ziak: 21:50
Yeah, I see.

Interviewee: 21:52
Regulators, communities, and investors are also stakeholders. For investors, it's about bankability and proving risk management through validated models.

Samuel Ziak: 22:05
Would you say the technology is still in its early stages?

Interviewee: 22:15
In the last decade, we've launched the biggest turbines in the world every few years, each with new technology. From a risk perspective, scaling technology is always new.

Samuel Ziak: 22:34
So you're expanding on existing advanced technology, but if digital twins for some components don't exist yet, there's still a path forward, right?

Interviewee: 23:05
Yes, when scaling, all engineering models have assumptions. You work with what's known and adapt as needed.

Interviewee: 23:16
Some of those assumptions are no longer true or not as true as they were before.

Samuel Ziak: 23:22
Yeah.

Interviewee: 23:25
Feedback. I mean, I can also take a new engineering model. Now I can see that the plate bearing threading model no longer holds true because the bearing balls are now 10 centimeters in diameter. We've never tested that, so our primary tests show that this is no longer true. So, we

change the model. I can take the new model, run it on 1,000 turbines over the last five years, and see if it fits better with the field failures compared to the old model.

Samuel Ziak: 23:59
Yeah.

Interviewee: 24:00
So, in that way, I can use it. It's like a laboratory at scale, but I can't test it on every component, like the lattice component. There are still things we need to do the old-fashioned way, but in general, it costs hundreds of millions of euros to bring a new platform to market. The less full field testing we need, the better, and this approach supports that.

Samuel Ziak: 24:23
Yeah. I see. OK. Should we pause for a bit so you can get...

Interviewee: 24:37
I think just one comment about the suppliers and technology providers. Obviously, as we mature, I'd begin to request models from them.

Samuel Ziak: 24:51
Yes, from external providers? But at this point, do you feel like there's no existing provider or service that's reliable enough?

Interviewee: 24:53
Yes. Not yet. But we teach the big manufacturers of bearings how to model bearings—we're better at it than they are.

Samuel Ziak: 25:13
And there will be—I have one final question at the end that fits well with this.

Interviewee: 25:17
Yeah, some of the commodity things definitely aren't there yet. But, you know, gears or maybe even gearboxes, I don't know.

Samuel Ziak: 25:32
Yeah. Cool. I look forward to your response to that. Shall we say you head to the car, and I'll wait in the meeting until you join again, maybe in 5 minutes?

Interviewee: 25:44
Yeah, that's probably fine. Let me get to my car, and then I'll dial back in.

Samuel Ziak: 25:51
Yeah, I'll stay in the meeting and keep the transcription going.

Interviewee: 25:54
OK, perfect.

Samuel Ziak: 25:56
Thank you.

Interviewee: 25:56
See you in a bit.

Samuel Ziak: 26:21
Yes, 1, 2, 3...

Interviewee: 34:04
OK. Can you hear me now?

Samuel Ziak: 34:07
Yes, all is well.

Interviewee: 34:09
There was a lot of noise. I guess my air conditioning is just gonna shut it down.

Samuel Ziak: 34:15
It's actually not that bad, as a matter of fact.

Interviewee: 34:20
Well, probably they did something fancy with it. So, OK, at least now I can hear you too.

Samuel Ziak: 34:27
Yes. I'll just follow up with a question right away so you don't have to be bothered. So, that was a brilliant first bit, and I liked it a lot because you bring a completely different perspective to the overall topic. Now, we will discuss the needs and values. First, we'll speak about the needs that I try to focus on, which is the subject of this study. If I may ask, what are your needs as a stakeholder that you expect digital twins can or will solve?

Interviewee: 35:12
OK, it will solve several things, but I think the main point is moving towards authoritative models—models we trust and dare to design with. There's much more to this than just digital twins, but digital twins are a way to ensure that models are validated to the level we need.

Samuel Ziak: 35:48
Umm.

Interviewee: 35:49
Another part of that is what I call "outline," which is an internal buzzword for real conditions. As you might know, turbines are designed with certain assumptions, and most of those are wrong to varying degrees. And the design paradigm assumes turbines, but we sell farms. This means we need new modeling tools to capture these aspects farm by farm, and digital twins using our field data can accelerate that journey.

Samuel Ziak: 37:02
Mm-hmm.

Interviewee: 37:03
And, in the big picture, I mentioned using models we already have, but that doesn't mean I'm against using machine learning or AI for design. We do look at that too. But having petabytes of field data available has a lot of value if we can consume it at scale and aggregate it into decisions and results.

Samuel Ziak: 37:44
Yes, brilliant. Switching to the values, how do you perceive the value added by the digital twin? It could be economic, operational, sustainability, strategic, or any other value you identify.

Interviewee: 38:08
There are many ways to discuss value. For instance, I was responsible for the design of the 8MW turbine platform. Before we even had the first piece of hardware, we had sold over 500 turbines, making it the best-selling offshore turbine at the time. Obviously, to do that, you need to be confident about your risk assessments, like performance, structural integrity, and cost. If I had been able to use digital twins to validate our models against historical data, I could have made decisions faster with less physical validation.

Samuel Ziak: 40:51
It's sort of crucial.

Interviewee: 40:52
In terms of direct value—yes, go ahead.

Samuel Ziak: 41:01
Yeah, yeah. Can you hear me?

Interviewee: 41:03
Yes, go on.

Samuel Ziak: 41:07
Sometimes I lose the connection, but you can continue about the direct values.

Interviewee: 41:20
There's significant internal value. Predicting performance closer to the limits is valuable for new sales and after-sales services. It's also about time to market and optimizing designs. From the customer's perspective, better models could enhance predictive maintenance or sell services that provide detailed insights, which is something we are beginning to explore.

Samuel Ziak: 41:56
Uh-huh.

Interviewee: 42:13
But we aren't fully mature in understanding the value to customers yet.

Samuel Ziak: 42:19
So, if your organization delivers components like blades to a customer, you might include a digital twin as a service for monitoring?

Interviewee: 42:51
Yes, for example, customers might pay for lifetime counters for blade bearings across their wind farm. It depends on their internal business needs—some may want a full service contract, others might prefer just the digital twin service. Understanding the direct value for customers is something we need to work on.

Samuel Ziak: 44:01
I see.

Interviewee: 44:01
We also need to understand how to leverage that data internally. Operators typically have access to data, but they don't always have the design models or the broader perspective we have.

Samuel Ziak: 45:09
OK, I see. So that's one of the challenges with digital twins in the industry. As we transition towards the concluding part, I wanted to ask your perspective: Should the offshore wind industry have individual developers of digital twins for each component, or should there be a more open, shared industry standard?

Interviewee: 45:52
From an OEM perspective, we want to offer digital twins as a service. In the past, we sold servicing of turbines, but now we need new revenue streams. We need this to be competitive and provide value; otherwise, it doesn't work. There will be competitors, and maybe third-party suppliers or operators will develop their own models, but hopefully, we can do it better with design models from the turbines.

Samuel Ziak: 48:15
Cool.

Interviewee: 48:17
Of course, we need to stay competitive.

Samuel Ziak: 48:23
Absolutely. Great. In my opinion, we've reached the end of the interview, and I don't have any more questions. If there's anything else you'd like to share, please do.

Interviewee: 48:43
I think digital twins are still evolving, and it's important to understand how to scale this technology. In our industry, it's different from aerospace or military, where there's often more interest in detailed modeling. Here, it's about practical applications and scaling the engineering models.

Samuel Ziak: 49:38
I see. All right.

Interviewee: 49:41
Yes.

Samuel Ziak: 49:43
Perfect. With that in mind, I'll stop the transcription.

Samuel Ziak stops transcription

K.8 Interview #8

Name: Participant 8

Title: Solution Architect

Company: Internal

Date: 29-08-2024

Time: 16:00 – 16:30

Samuel Ziak 0:04
And I share the screen, so we are on the same page.
So nice to have you here.
And before we begin, I would like to ask you if you give your explicit consent that I could transcribe this interview and as well use it for the purpose of my master's thesis to take notes and then delete it subsequently after the handling of the assignment.
Do you consent?

Interviewee 0:30
Yes, the data will be anonymized.

Samuel Ziak 0:31
That's brilliant.
We will anonymize the company, your responses, as well as everything related to personal data.
Brilliant.
So first of all, can you briefly describe your role and responsibilities within the company you work for?

Interviewee 0:49
Yes, I'm a Solution Architect, currently at [Company Name].
And a Solution Architect specifically focused on wind, that business area.

Samuel Ziak 1:05
If you have to ask, which is perfect because today's topic is particularly focusing on digital twins and offshore wind turbines, and before we commenced the meeting, I sort of made a basic understanding of what a digital twin is.
But if I have to ask you, what is your understanding of the term digital twin?

Interviewee 1:27
I mean, what I would say is a digital twin is basically a model representing something physical out there.
It doesn't necessarily need to be physical either, but it's representing a subject of interest, a model representing the behavior and processes of a system of interest.

Samuel Ziak 1:52
And are digital twins in some way part of your work?
It can be either directly or indirectly.

Interviewee 1:59
Yes, I mean, yes, very much so.
Actually, they are part of my daily work. It depends on what class of digital twin we're talking about, but in general, yes, they are.

Samuel Ziak 2:14
OK.
So can we elaborate a little bit on that?
If we say each class, are there different categories that you would be able to categorize them by or?

Interviewee 2:24
Yeah, I mean when I say digital twin, there are many levels of digital twin. There is this famous saying, you know, "the model that you build is fit for the purpose that it's intended for."
I don't remember the exact quote, but it's a very famous quote. And technically speaking, to be able to operate a wind farm or a power system or whatever, we need to have a model of what you're operating, even to analyze or plan for the future on how the system will act given certain parameters, and so on.
The most simple one would be a model that is generic, for example, that represents certain types of inputs or, yeah, what do you call it, behaviors of the system of interest. But then you can go up in many levels, for example, to more detailed models that are able to simulate or model the behavior of multiple aspects of the system of interest.
The system which is in the loop with the system of interest, i.e., if there's a change in the system of interest, that system will also change that digital twin. And then you're moving towards more generic behavioral models to more interconnected models.
Examples of these could be, and not necessarily limited to, and not necessarily on the quality of digital twin, but for example, a monitoring or control system which contains a model of what it is controlling, what it's connected to, and then it would be, for example, collecting data on the attributes and changes of the state, and you would reflect that in the model itself and allow the operator, for example, to make the necessary decisions. This is a model called in real-time, and that would be the most, well, I wouldn't say the most advanced, but it would be an advanced version of a digital twin because there can be more advanced versions.
This is my scale of digital twins: from a generic model all the way to an interconnected model, and then perhaps you can even have a forecasted model of a digital twin.

Samuel Ziak 4:36
And there are two—

Interviewee 4:43
But that's another thing.

Samuel Ziak 4:45
Hmm. Brilliant.
And on that topic, if you could elaborate a little bit when you mentioned the term "in the loop" as well as "operator"—does "operator" mean the owner or the company, or is it the person sitting behind or operating behind the computer, etc.?

Interviewee 5:02
Yeah.

Samuel Ziak 5:02
So these are the two terms if you could elaborate on them.

Interviewee 5:05
Yeah. So I can give you a simple example, and of course, my interpretation of digital twin is based on my experience and how we've worked with it.

Samuel Ziak 5:14
Of course, but that's perfect.

Interviewee 5:14
Yes, I mean, the operator would be somebody that is interested in the system of interest and would like to monitor it for some reason, maybe to make a decision to change the behavior of the system of interest, or just wants to understand what's happening, for example, to gain observability over the system of interest. That could be an operator.
"Interconnected" means that the model of the system of interest basically receives updates. Because when we say a model, it means it could be executable. I.e., you have a set of parameters, you press play, it acts like the system of interest, but of course, it is not the system of interest. So, to be interconnected with the system of interest means that you would get parameter updates on the environment of the system of interest, the behavior of the system of interest, which would adjust the behavior of the model itself so that it reflects the system of interest.
I guess that's why people started calling it digital twins nowadays. You have a version of something, a twin of something, and it tries to replicate its behavior. When it's interconnected, it gets updates from that system of interest. A good example would be an analytical SCADA system—not just SCADA, but an analytical SCADA system, which means it's a SCADA system with a model of the power system or the transmission domain.
You could always have a power model of the transmission system, and then by feeding it with real-time data, you always get an updated behavior of the power system in the digital twin itself.

Samuel Ziak 7:17
I don't know if... Yeah, I don't know if this is helping you, but—

Interviewee 7:19
No, I mean it's—

Samuel Ziak 7:19
No, for sure. Perfect.
For me, the point of the thesis is to investigate stakeholder perception, right? So, it's brilliant.

Interviewee 7:27
Yeah.

Samuel Ziak 7:27
So we will get to the further point, but from my understanding, if we proceed a bit further, is that I was able to get some literature. Would you consider that a digital twin or some system can

operate as an entire lifecycle, or just as a single product for a different structure? How would you maybe have—what would be your point of view on this?

Interviewee 7:50
What do you mean by entire lifecycle?

Samuel Ziak 7:53
So you would, for example, apply digital twin only in the design and the construction phase of the initial phase. But then you would maybe stop gathering all the data that you did and then during the operation you would not do that anymore.
So it would be just like a product existing only for a selected part of the time of the product, and that would be it. Or would you apply it over the entire lifespan of it?

Interviewee 8:17
Yeah. So I will speak actually with power system operation in mind when I give you this example. I think you can apply it during the entire project lifetime. Again, this depends on what kind of digital twin we're talking about, but you could apply it early on before you've even built the system. So you can have a model of how the system could look like, and of course, that could be a combination of other digital twins, i.e., you already have a model of the current transmission system and you want to add a new station.
So you would have a model of that new station with its details and protection, and so on.

Samuel Ziak 8:58
Yes, yes.

Interviewee 9:01
And then you would see if it's a good fit. So you are using the current model to see if a future model would be a good fit, and based on that model, you would write a specification which you would build, and then you could test it with a digital twin. Is this how it's supposed to act according to the specification? Yes. And then you would observe it in the real system. Does it fulfill? And then, of course, you can go back to what I was saying earlier—you can interconnect that model with real-time data coming in from the realized digital twin, so you could use it through the entire lifecycle, yes.

Samuel Ziak 9:38
So, but this could bring into another question of interoperability, right? Because if we already aggregate, so we have different, let's say, structures in a wind farm, or it can be even a wind turbine on its own. But then if you, for example, try to integrate these, there could be issues of actually bringing them together. You would need some sort of digital infrastructure or maybe a digital platform where you would accumulate all these data and run these models in the background so they would be subsequently shown to the final user or the controller.

Interviewee 10:13
Of course, yes.

Samuel Ziak 10:14
Do you think this is a problematic step with the integration of the digital twin, the interoperability of the systems?

Interviewee 10:21
Yeah. So I think interoperability is actually fundamental. It's one of the success factors for digital twins in general, to be able to reuse them, especially if you want to use them through the entire lifecycle of a project. Previously, you'd have silos of digital twins, and of course, they would have different levels of quality. For example, a planning one would be less detailed than the one you would eventually bring into operations. So you're actually studying how to develop something that is not really... You're not studying multiple parameters.
There are many reasons for this, of course, again going back to the quote that the model or the digital twin is as good as its intended purpose. So if I'm planning, perhaps I'm not interested in the maintenance aspect, and I'm not interested in other aspects of that digital twin. But if you want to start working with that, let me reuse this model and extend its capabilities as I get closer to real-time, then I should be able to import it, for example, from its design system into the operational system.
And on the European level, by the way, this is a very important initiative. So there is an organization called INSCOE which is pushing the use of digital twins, and one of the main factors for that is interoperability—that the model of the digital twin is easily exchangeable between different systems.

Samuel Ziak 12:04
Meaning that different systems that... let's put a particular focus on—

Interviewee 12:08
Different platforms. Digital platforms.

Samuel Ziak 12:12
OK, but still, let's say we have a digital... let's say we have a wind turbine and we only have, for example, blades or replicas of digital twins of blades or the monopile, etc. And then this regulation or this initiative is meant to develop this platform, where everything is sort of replicable. Do I understand correctly? I'm just not sure if I understand fully.

Interviewee 12:33
I didn't really understand your question. Can you repeat it? Are you talking about composability of models so that you would have a digital twin for a blade, a digital twin for a pylon, a digital twin for the turbine parts, and so on?

Samuel Ziak 12:36
Yeah. So—

Interviewee 12:48
A digital twin for the environment they would be set in, and then can they speak to each other? Is that what you mean?

Samuel Ziak 12:55
Yes. And then you aggregate all the data on this platform, right?
Did I miss your point?

Interviewee 12:58
Yeah, but I think I intended something else, but that's a good point. That's another level of

digital twin.
What I was trying to explain was that of course, you could do all that on one platform for the purpose of design and analysis.

Samuel Ziak 13:04
OK.

Interviewee 13:05
But then you would realize these models that you would have in, for example, eventually an actual new substation which is delivered by a specific vendor.
That has most of the parameters you have studied originally in the design phase, but could have additional parameters, so you would need to improve your model. But you don't want to start from scratch; you would want to import that and maybe extend it or observe what you have bought and installed, and adjust the behavior of your digital twin based on the behavior of the one that you have installed.
But what you're talking about is basically the composability of different digital twins. And then, of course, they must share a common digital platform and a common set of rules and procedures to enable interoperability. For example, a definition of an information model on what type of information needs to be exchanged by these digital twins, and so on.
And then even other things, you know, it depends on how you implement it. One good example of this is actually from the military domain. They have something called High-Level Architecture. It's a standard to be able to compose different types of simulation models together to make one bigger simulation model, which pretty much touches also on the same topic when you were thinking of the composability of digital twins.

Samuel Ziak 14:47
I see. I see.
I would love to elaborate a bit more on the regulatory environment, but maybe we can get to it, because I like that.

Interviewee 14:55
Yep.

Samuel Ziak 14:57
I like that bit, but maybe we can get to it in the next section, which focuses on the stakeholders. If I have to ask you, if you have to put your stakeholder shoes on and you would like to get something out of a digital twin, where would you position yourself? Would there be something—could you position—that's just an example that I've provided. You can choose any others, but each one of them has different interests, right? But what about yourself? Which one do you think would be the most important, even from them? Or which one is the most important stakeholder of the digital twin?

Interviewee 15:31
Yeah, I would place myself perhaps as a supplier and technology provider since I work in architecture and digital solutions. I would say these are important stakeholders.

Samuel Ziak 15:37
Cool.

Interviewee 15:49
It depends on the industry, but ideally, it is actually operators and the designers.

Samuel Ziak 15:54
Offshore wind, so we speak about offshore wind particularly.

Interviewee 15:59
Uh, yeah.

Samuel Ziak 16:04
But you can also elaborate on your position as a supplier and technology.

Interviewee 16:05
But it could be actually both project developers and operators. I would imagine project developers... Is this like design people as well?

Samuel Ziak 16:15
Yeah, that could be.

Interviewee 16:16
People that need to design.

Samuel Ziak 16:17
It can be broad, right? So it's someone who designs it and then builds it, and then it can either own it or hand it over further, right? So it's relative.

Interviewee 16:26
Yeah, but I would say those that design need a digital twin to help or expedite their designs and to, what's the word, refine their designs, for example, improve their designs, make them more dependable, etc.

Samuel Ziak 16:36
Umm.

Interviewee 16:47
And then you would have also operators that would like to look at the behavior of the system.

Samuel Ziak 16:47
Umm.

Interviewee 16:52
For example, like we discussed earlier, coupled with feed from the real world. What if type of questions that, OK, yeah, I have real-time data, I have an updated state of the digital twin, what if I do this? What would happen before actually making a decision on doing something?

Samuel Ziak 17:08
Umm.

Interviewee 17:11
I would say these are the primary stakeholders from a user perspective. And then of course, suppliers, etc.

Samuel Ziak 17:11
Yeah.

Interviewee 17:14
But that's mostly so that they understand the technology, but also so that they would provide the building blocks for such capabilities.

Samuel Ziak 17:19
Excellent.

Interviewee 17:20
And to touch upon this topic is there, but let's—I will just transition smoothly, I'll try because now I would like to focus on needs and values in the next section, but first I'd like to touch only about the needs of these stakeholders that we identify and if you yourself identify as a supplier or technology provider, what would be the need that you can get out of the digital twin in an offshore wind farm that you would like to have out of it that you can or will be solved by a digital twin?

Interviewee 18:04
Yeah. OK. From that perspective, perhaps, yeah, perhaps they are not a stakeholder in that sense. What would the supplier?

Samuel Ziak 18:27
Maybe it's easier just to put yourself in the situation: do you directly work on developing the digital twins or do you—

Interviewee 18:27
I could think of. Sorry, go ahead. Yeah, but why would I need it then? Perhaps the need here would be to better design other digital solutions on top of it.
So for example, if I am designing a forecast model, it would be nice to have a digital twin to see the behavior and compare it with the forecast. Or if I'm designing a controller instead of just doing it theoretically on a piece of paper, I can actually apply or simulate my controller on a digital twin before deploying it out in the field, minimizing risk, for example, minimizing risk and more thoroughly testing, for example, different new routines or new algorithms before deploying them.
That would be a need. So a need for a digital twin would be the need to verify some of the digital solutions or products that, as a supplier, we would be developing. And by the way, that was common.

Samuel Ziak 19:13
Mm-hmm.

Interviewee 19:15
For example, a lot of the early efforts, let's say digital twin of communication networks, want to

be able to emulate whether these applications, these control applications, would be impacted by delays. So then you would build a digital twin of a communication network or model of a communication network and see if the software or system is stable enough, or does the protocol work under different conditions, and so on.

Samuel Ziak 19:40
Mm-hmm.

Interviewee 19:49
Sorry, I wanted to add, so yeah, yeah.

Samuel Ziak 20:19
No, no, I love the way that you elaborate on everything and provide examples. That is brilliant. So here I provided just a table if someone is utterly lost for examples of specific needs. But if I just have to clarify, do you currently work on developing a digital twin right now or?

Interviewee 20:31
Ah. Why do you think so?
But yes.

Samuel Ziak 20:41

No, just your position towards it. Then what's your current status in the current organization that you work for? Just a bit of context, so to speak.

Interviewee 20:47
Yeah. So I'm not with wind specifically, but even though there are indirect parts, we are working with digital twins like we're buying a monitoring system. Does that have a model of specific types of turbines, for example? And then how could we configure that? And in other business areas, we are working on standardizing, for example, how we see different components in the processes we're working on, in the processes we are managing, which makes it easier to do that type of analysis like I was saying—testing, for example, if a future project is worth investing in, like supporting a business case as you have up there.

Samuel Ziak 21:32
Yes, yes.

Interviewee 21:32
So I'm actively working in such a case.
Yeah, and even to better or cost-optimize both operation and maintenance. Actually, in this case, and the case I'm telling you, it's not offshore wind.

Samuel Ziak 21:44
Yes.

Interviewee 21:48
Unfortunately, it's in distribution systems or electrical distribution systems together with DSOs, where they exchange information to increase operational stability and so on.

Samuel Ziak 21:53
Yes.

Interviewee 22:02
And also to better support decision-making. I mean, the better the digital twin, the better we can make decisions on rerouting energy, capacity constraints we have in the system, etc.

Samuel Ziak 22:08
Yes.

Interviewee 22:18
So I'm actively working in these, yes.

Samuel Ziak 22:18
So, can we say that from your domain, it would be ideally applicable to different systems or structures? Ideally, this technology that you work on is replicable, right?

Interviewee 22:36
Oh yeah, yeah, for sure.
Uh, yeah, I—

Samuel Ziak 22:38
And is there a possibility to do so in a way, or do we actually apply this at the current point in time?

Interviewee 22:46
Yes, yes. We have in one project in wind tried to reuse some of the principles that are the basis of digital twins in other areas for wind. So basically, reusing the interoperability framework.

Samuel Ziak 23:01
Uh-huh, uh-huh.

Interviewee 23:04
But of course, that doesn't mean that the digital twin itself is reusable. That depends on the domain, again, the model of interest, what you're using it for.

Samuel Ziak 23:14
Of course, of course.

Interviewee 23:15
But the digital platform is reusable, sure.

Samuel Ziak 23:20
And just to elaborate, just to clarify the interoperability framework and the digital platform, maybe a one-sentence definition: is the interoperability framework the one we mentioned earlier?

Interviewee 23:31
Yeah, the interoperability platform could be, for example, the information model—how we capture it, how we exchange information, how you define attributes, etc. And then the digital platform is how you would manage different versioning of that information, how it would change over time, and perhaps even the communication infrastructure and so on.

Samuel Ziak 23:41
OK, right. Just to be clear for me on the terminology.
So I have a clear understanding of it. Brilliant. And to be mindful of time, because we are running short, I would switch over to the actual value, and it's maybe an easy question, but maybe a tough one as well.

Interviewee 24:05
Yeah, no worries.

Samuel Ziak 24:16
How do you perceive the value added by digital twins? Referring back to the previous table, which one would be the major one that could have the biggest effect on your work or your organization's work?

Interviewee 24:36
Yeah. How do you perceive the value added by digital twins? From what perspective?

Samuel Ziak 24:41
From your point of view.

Interviewee 24:44
As a supplier, etc.

Samuel Ziak 24:46
Probably if you develop it, if you were a technology provider or supplier, yes.

Interviewee 24:51
Yeah, I mean, the value added here is that it increases the dependability of what we're developing. For example, that we can test it on a digital twin, it could decrease the time to product.

Samuel Ziak 25:01
Uh-huh.

Interviewee 25:07
You know, the development time, because we have the behavior in front of us, the system in front of us; we can see how it behaves. We can test it. We can consider many different aspects that traditionally would be a very prolonged validation process, testing and validation process. Plus, the learning curve, of course.
I think the main value here is faster time to development, perhaps, or faster time to deployment and more dependability.

Samuel Ziak 25:42
Yeah, because that would lead to the realization of all the other needs we talked about before, right?

Interviewee 25:49
Yeah, exactly. And if you consider that, it could be... but that's more from a user perspective. From a supplier perspective, I think the main aspect is more dependability of the products that you could provide if you were to use digital twins and maybe faster development time.

Samuel Ziak 26:08
But of course, if you have the perspective of—

Interviewee 26:10
And more standardized, perhaps interfaces, but that's another thing, sorry.

Samuel Ziak 26:15
If you have the perspective of the user as well, that's brilliant as well. I mean, if you have a point on that as well.

Interviewee 26:22
You know, I was thinking with a digital twin, one could do what-if type scenarios without actually proving it or doing risky operations on the actual assets themselves, which makes it much cheaper to do these kinds of what-if and forecasting and looking at possible risks, which one would not have received on the level of granularity that you would have with the digital twin.

Samuel Ziak 26:33
Uh-huh.

Interviewee 26:49
So what I'm thinking is, for example, what if the weather—what if we have this weather pattern? What would happen to the turbine given its current state? Well, I can observe that if I had a model of the turbine, I can observe that and see that if I have that weather pattern, I have an increased risk. Perhaps I should do maintenance now, so it's a bit of predictive maintenance forecasting.
In fact, the value would be less downtime.

Samuel Ziak 27:15
Absolutely.

Interviewee 27:20
And of course, yeah.

Samuel Ziak 27:22
But it also requires a lot of upfront investment or investment into the development of the technology, right?

Interviewee 27:22
If you have less—of course, all these require investment in the technology, even the cases for suppliers, yeah.

Samuel Ziak 27:33
And in your understanding, what is the current status or stage of the technology of digital twins that we are right now, no matter which industry it is, but mostly applicable to the systems we spoke about today?

Interviewee 27:46
Yeah, no matter what. OK. So, no matter what industry, I think certain industries are actually quite mature in digital twins. I think the military industry, for example, and the power system industry, power system transmission, are more advanced, slightly more advanced in digital twins.

Samuel Ziak 27:55
You can also give examples if, in your experience, you have that.

Interviewee 28:08
I think we are in the, you know, the phase of awakening. I don't remember what they call this, but awakening, where we're looking at what are the possible opportunities right now when it comes to wind.

Samuel Ziak 28:14
I—

Interviewee 28:20
But I would say other domains are more advanced. So for example, in the transmission domain, it is standard to actually train your operators on a digital twin; you don't just train them in real life. You could replicate real-life situations, but usually have a full digital twin of a control room with the same system and the same kind of behaviors and alarms flickering, and then you could simulate stress scenarios, for example. I don't think we're there yet in the wind industry.
There could be different areas, maybe, for example, for structures that are slightly more advanced since it's not limited to the wind industry. It's also offshore oil and gas, etc. Maybe they are slightly more mature than other areas, but I don't think we have identified all the possible benefits we can get from digital twins in the wind production area yet.

Samuel Ziak 29:29
So the assumption is that there could be a lot of experience derived from the old oil rigs or the transmission stations that—

Interviewee 29:36
Or other industries. Exactly.
I think that would be a good way forward—to look at what else we can learn from other industries and how they have implemented it.

Samuel Ziak 29:38
Brilliant. For sure, and—

Interviewee 29:47
I still think that because the wind industry is also quite complex, there is also, like we just discussed when we started this, that there are different classes of digital twins, and I think different parts of the industry, like structures, might be more interested in system-in-the-loop types of digital twins. But so, there is no common perception of what a digital twin is. That's what I'm trying to say.

Samuel Ziak 30:23
But we are over time, but I have a few final questions. From your point of view, what could be the challenges of integrating digital twins? It can be interoperability, initial upfront costs, or anything else that you have encountered?

Interviewee 30:39
Yeah, I mean, of course, usually such initiatives are quite expensive, and there are always cost constraints, you know, and that's always an aspect, you know, we're in an industry for profit, of course. Nobody wants to work for a loss. But interoperability and standardization of technologies, I think, are the main challenges right now, especially since a lot of systems are actually very vendor-specific. So even digital twin initiatives are sometimes vendor-specific, and these are the challenges: how can we establish a common language for the different components we have in the wind industry and define them in a vendor-neutral way?
Having a common terminology, a common model, for example, and there has been some work there, like IEC 61400, where they talk about structures of turbines, for example, but more needs to be done.
Yeah, I think these are the biggest challenges right now that I see going forward.

Samuel Ziak 31:49
And do you believe that there should be a wider scale standardization of the utilization of digital twins in offshore wind, or should it be that each company, developer, or investor retains their technology as a sort of competitive advantage? What's your take on this?

Interviewee 32:14
Yeah, I think your question is quite wide. I mean, we should—

Samuel Ziak 32:18
Yeah.

Interviewee 32:19
We should have standardized digital twin models.

Samuel Ziak 32:23
Umm.

Interviewee 32:23
Which are widely quality-controlled and validated.
The risk is that if you have very small silos of digital twins that are not integrated and are specific, it's difficult to actually determine their quality. And the dependability of these models or these twins are—so it would be better if we had a wider, standardized approach to digital twins.

Samuel Ziak 32:55
Umm.

Interviewee 32:55
But I think that's going to be extremely difficult for one company to do. I think this has to be an industry effort.

Samuel Ziak 33:04
Absolutely.
Unless there is anything else on the topic, I would—

Interviewee 33:07
Yeah, no.

Samuel Ziak 33:11
Thank you for the interview and the time you found.

Interviewee 33:11
No worries. I would just recommend you look at ENTSO-E's R&D; they are a European transmission system operator.

Samuel Ziak 33:21
I will.

Interviewee 33:22
Yeah.

Samuel Ziak 33:22
I will stop the transcription. I will drop this transcription and we can—

Interviewee 33:27
No. Yeah.

Samuel Ziak stopped transcription

K.9 Interview #9

Name: Participant 9

Title: Head of Operational Excellence

Company: Internal

Date: 02-09-2024

Time: 09:30 – 10:00

Samuel Ziak: 0:04
All right. Welcome to this interview, and before we begin, I would like to ask if you give explicit consent to transcribe the interview. Thank you very much.

Interviewee: 0:14
Yes, I do.

Samuel Ziak: 0:16
So, I have a lot of myself to share on the screen, and the first page is just the interview consent form that informs the interviewee.

Interviewee: 0:21
Umm.

Samuel Ziak: 0:22
But to begin with, let's jump straight to the questionnaire, which was also attached to the email. I'll read through the whole conversation, so don't worry. Can you briefly describe your role and responsibilities within the company you work for?

Interviewee: 0:36
Yes, I am Head of Operational Excellence, which is all about offshore wind operations. My responsibility involves aligning teams, aligning teams with processes, people with processes, and integrating technologies—essentially ensuring everything works together across the company to help us deliver our strategic value.

Samuel Ziak: 1:03
Brilliant. So now, transitioning into the topic of this interview: digital twins in offshore wind.

Interviewee: 1:10
Umm.

Samuel Ziak: 1:12
That's the scope.

Interviewee: 1:12
Yep, yep.

Samuel Ziak: 1:14
If I can ask, what's your understanding of a digital twin? How do you define it from your perspective?

Interviewee: 1:21
Yeah, I think the description you provided is pretty good. I've been involved in discussions around this topic over the years. To me, there's a physical object out there in the world, and the digital twin represents the current state of that object. It can also predict forward, modeling future evolution of the state based on environmental effects, operational conditions, etc.

Samuel Ziak: 1:58
Brilliant. Is the digital twin part of your work in any way, directly or indirectly? Have you come across them?

Interviewee: 2:12
I have in previous jobs. Right now, I'd say it's very indirect because we don't really use digital twins in the company.

Samuel Ziak: 2:22
OK, so in your current position, there's no digital twin just yet?

Interviewee: 2:24
Not what I would call one, no. Not really, no.

Samuel Ziak: 2:32
OK.

Interviewee: 2:33
We have some predictions from a couple of products brought in from the outside that one might label as digital twins for marketing purposes, but they're not truly digital twins. They help predict failures, for example, or assess current health more precisely.

Samuel Ziak: 2:59
And this service is provided by an external party?

Interviewee: 3:02
Yes, by a third party.

Samuel Ziak: 3:05
OK.

Interviewee: 3:05
They look at data from certain components and tell us about the current health, identifying issues.

Samuel Ziak: 3:13
Do you know which part of the wind turbine this applies to?

Interviewee: 3:13
Yes, it's within the nacelle, covering gearboxes, generators, and similar components.

Samuel Ziak: 3:20
I see. That also answers the next part about how digital twin technology is integrated within your project. Now, in your experience, do you see the digital twin as part of the entire product lifecycle, or is it more often used as a single product phase, like design and construction, and then used elsewhere?

Interviewee: 3:52
For me, as I alluded to, a digital twin without a physical object it maps is not a digital twin; it's just a model. We've been doing engineering models for decades, so calling it a digital twin doesn't add value unless it represents a real object. It's about inverse modeling to understand the current state and then predict how it will behave under certain decisions. So, they're mainly useful when you have an operational object, and their purpose is to make control and operational decisions.

Samuel Ziak: 4:49
Umm.

Interviewee: 4:49
For example, in a wind farm, you could have a digital twin of a blade, and you might slow the turbine during rain to extend blade life. Or with drivetrain components, if there are supply chain issues or delays, you might lower production rates to keep running without full failure until repairs can be made. It's about balancing income, repair costs, and other factors with massive uncertainty and probability in those calculations.

Samuel Ziak: 5:44
Yeah.

Interviewee: 5:46
Digital twins alone can't make decisions. They can run "what-if" scenarios, like downgrading performance to extend life, but they don't provide the business answers directly. It's about how those models integrate with logistics, simulation, and business decision-making. That's when they become really useful.

Samuel Ziak: 6:31
So, to elaborate on your last point, you're aiming for interoperability and composability, making sure different parts of the wind farm communicate effectively?

Interviewee: 6:36
Yes.

Samuel Ziak: 6:43
Making sure different parts or components, like turbines and logistics, integrate well.

Interviewee: 6:45
Yes, absolutely.

Samuel Ziak: 6:53
Good question. I understand interoperability could mean these devices talk to each other and even make decisions or recommendations on their own.

Interviewee: 7:01
Yes, but that level of interoperability might be 15 years away. What I've worked on is more about integrating state data from logistics simulations, running scenarios to capture probability and decision-making. You can't optimize gearbox maintenance in isolation—it has to account for other ongoing maintenance, vessel availability, spare parts, and supply chain setups. Full optimization is only achievable when these are part of one integrated estimation of the wind farm's future revenue and costs.

Samuel Ziak: 8:13
Umm.

Interviewee: 8:19
There's a potential future where a turbine diagnoses itself and makes repair decisions, or where wind farms balance repairs across turbines. But for now, that's a long way off.

Samuel Ziak: 8:47
Exciting. Thank you for your input. That's brilliant. I love your perspective and the experience you bring. Moving on, let's discuss stakeholder roles and collaboration. Would you consider yourself a stakeholder in digital twin initiatives, and if so, how?

Interviewee: 9:00
Sure. I work in an owner-operator role, so we're the end customer of digital twins in some ways.

Samuel Ziak: 9:48
Can you elaborate on that within your team or department?

Interviewee: 9:58
Yes, digital twins cost money and require sensors, which also cost money, so we need to understand the benefits well. Typically, we do trials and design experiments to assess their value, often hoping for a failure to test effectiveness. There's no standardized test bench on the market to unequivocally establish their accuracy, which I'd love to see developed. As an industry, suppliers and technology providers should collaborate more to provide comprehensive decision-making products rather than just predictive ones. This would make it easier to justify the business case.

Samuel Ziak: 12:13
Could this apply to gearboxes, blades, or other components where suppliers already exist?

Interviewee: 12:16
Yes, exactly, but it's challenging. Turbine manufacturers, or OEMs, serve as a layer between the part manufacturers and the end users, which complicates integration. The actual part manufacturers design to specifications that may not account for nonlinear effects fully. We need better collaboration between modelers, turbine manufacturers, and part suppliers to create integrated solutions, although current incentives don't favor this.

Samuel Ziak: 13:35
It's not an easy task, is it?

Interviewee: 13:40
No, it's not. It requires vision, and the short-term incentives aren't always aligned.

Samuel Ziak: 13:49
To be mindful of time, let's proceed to the final part of the interview, focusing on needs, values, and future perspectives.

Interviewee: 13:52
Yep, sure.

Samuel Ziak: 13:59
First, let's talk about needs. Putting yourself in the shoes of a stakeholder, what needs do you think a digital twin could address for you?

Interviewee: 14:20
I think I've covered it a lot already. For me, it's about decision support during the operational phase. A digital twin, through engineering, physics, and statistics, should help us understand how to optimize wind farms, going beyond simple scheduled maintenance or run-to-failure approaches. It's about time-based optimization, like scheduling interventions before failure across multiple turbines. This more flexible and holistic approach could transform maintenance and control, eventually leading to self-optimizing wind farms.

Samuel Ziak: 16:06
That would be amazing, wouldn't it? I think many in the industry, not just us, are looking forward to this development.

Interviewee 16:20
It would be, but you need to prove each step along the way, and at the moment, people aren't even breaking even if they make those choices.

Samuel Ziak 16:23
For sure.

Interviewee 16:30
So if they say, "I want to do this," they cannot quantify the impacts of that decision. You need a system that's able to do that.

Samuel Ziak 16:38
And that's also, for example, part of my thesis. That's why I chose the qualitative approach due to time constraints, but also because it would take much more time to actually quantify the actual results or performance I'm looking to deliver for this research.

Interviewee 16:41
Yeah. Yep, yeah.

Samuel Ziak 16:53
So let's say it is within the line as you describe it.

Interviewee 16:58
No, no, no, it's possible. We could have done it. The government refused to fund it when I was in a previous role.

Samuel Ziak 17:04
Different, and again, being mindful, switching to the value aspect: as part of operational excellence, where could the biggest value lie?

Interviewee 17:06
I see, yeah. Yep, yep.

Samuel Ziak 17:17
I categorized value by economic and operational aspects, but don't feel constrained by them. From your perspective in operational excellence, where do you see the biggest value that could be delivered utilizing digital twins on wind turbines?

Interviewee 17:26
OK. Yeah. Well, I mean obviously, once you trust them, the benefits include moving towards much more risk and uncertainty-based operations, so there's massive economic advantage there potentially.

Samuel Ziak 17:55
But how do we get to the point of trusting them? Would that involve running multiple models or something else?

Interviewee 18:04
Well, it's always a mixture of verification and validation, right? You need to show that they work in principle, and then you need to demonstrate that they work in practice through controlled experiments.

Samuel Ziak 18:09
Okay.

Interviewee 18:17
And this is the point: technology alone doesn't solve your problems. Technologies are a means of accelerating good strategy and supporting business processes, but you can't succeed just by throwing technology at the problem. You need a business that's capable of making uncertainty-based decisions, which means people need some statistical training. There's potentially a lot of efficiency gains here too—beyond the economic benefits—because a lot of things that currently take up people's time to estimate and argue about could be calculated relatively quickly, allowing us to make more decisions faster.

Samuel Ziak 19:10
But wouldn't this also be a significant cost for the company, to train employees to understand and utilize this technology properly?

Interviewee 19:21
Yeah. But the cost of not training them is higher.

Samuel Ziak 19:26
But it also depends on the employees' willingness to embrace it.

Interviewee 19:30
That's where strategy comes in, right? Good strategy recognizes reality, and the reality is that we are operating in a highly uncertain environment.

Samuel Ziak 19:41
Yes.

Interviewee 19:41
Everything from wind and waves to markets— all the key factors we care about are uncertain and probabilistic. To make good decisions, we need to average over potential futures. If the business or the people making decisions don't understand this, then we're always making suboptimal decisions, even with all the information available.

Samuel Ziak 20:07
Absolutely.

Interviewee 20:07
So, to me, that's a key enabler. Otherwise, you reach this point where the IT system predicts something, and then it doesn't happen, or it fails to predict something that does happen. Is that because the model is flawed, or is it just bad luck?

Samuel Ziak 20:29
I liked your earlier point.

Interviewee 20:29
Right, you need to know that to build trust. If you don't understand uncertainty, which none of us are born understanding, you have to learn it. It has to be trained, and we have to avoid questioning these systems when they're already performing better than human intuition.

Samuel Ziak 20:49
I liked your earlier comment that digital twins are distinct from simply running models—they need to be applied in practice, not just in the background.

Interviewee 20:57
Yeah, otherwise it's just another engineering model, disconnected from the actual business process. It has to support decisions to be useful.

Samuel Ziak 21:10
Yeah, yeah.

Interviewee 21:13
And that's the only way it becomes useful.

Samuel Ziak 21:16
For sure, for sure. Brilliant. I love it, and again, as we push towards the end—

Interviewee 21:19
Yeah, we got 9 minutes, friend.

Samuel Ziak 21:24
It's been really insightful discussing the challenges and your future perspectives.

Interviewee 21:25
That's good, that's good.

Samuel Ziak 21:31
I might have one or two more questions. From your previous experience, or even considering your current organization where digital twin development and operation might not be as prevalent, what are some of the challenges you foresee? Could it be related to interoperability, security, or something else you've experienced?

Interviewee 21:33
Umm.

Samuel Ziak 21:43
Maybe the security of actually having that digital replica? It could be anything else you've experienced.

Interviewee 21:55
Yeah, especially... well, it's a great question. Normally, you achieve cybersecurity by having layers and one-way systems, and primarily through human factors.

Samuel Ziak 22:23
Understood.

Interviewee 22:23
In the current situation, not the utopian version where everything's perfect like Skynet, it's important that the digital twin's predictive modeling is contained—data goes in, but nothing goes out that affects control systems. Humans should still set points and commands. So cybersecurity isn't an issue; I've not seen anyone trying to cross that boundary. Data integration is always an issue: Are we measuring the right data? Is the data reliable? These problems persist, but the biggest issue is making the outputs useful.

Samuel Ziak 23:24
Yeah.

Interviewee 23:25
Honestly, it's about integration with business processes, integration with all other components needed for operations and maintenance—vessels, supply chain, etc. Importantly, it's also about integrating different components across turbines.

Samuel Ziak 23:47
Yeah, I see.

Interviewee 23:47
To make sensible decisions, you can't just optimize for one component or one turbine. For us, with a portfolio of wind farms, we need to account for different turbines in proximity, varying ages, and different revenue rates. I'd love to make those trade-offs using models, not just rules of thumb.

Samuel Ziak 24:17
Brilliant.

Interviewee 24:17
Or extensive calculations that take weeks.

Samuel Ziak 24:23
My final questions: Is there any current development of this technology on offshore wind turbines within your organization? Is it something covered in your portfolio?

Interviewee 24:43
I think people are. There's a lot of data analytics and engineering modeling happening, as there should be, and people have been doing these things for a long time. When these two aspects—analytics and modeling—are combined, and we can predict, say, how long something will last if we operate at 80% capacity, then I'm willing to call it a digital twin. It's about specific components, not generic averages over all components of that type—like that particular gearbox on that turbine.

Samuel Ziak 25:27
And...

Interviewee 25:31
So, you have individual models for every single component, each updated with real data from the wind farm, predicting forward with environmental and operational inputs. That’s when we’re talking about digital twins. I'm not sure if that's the current roadmap.

Samuel Ziak 25:56
Got it.

Interviewee 25:58
I don't know. That's not my area.

Samuel Ziak 25:59
But it's something you envision for the future, something you'd like to see.

Interviewee 26:04
Yeah, and I think it's possible. I think other companies might already be getting there.

Samuel Ziak 26:10
Exactly. My final question: Would you support this technology being shared across the industry, or should companies retain it as a competitive edge? What's your take?

Interviewee 26:11
I'm a realist. That's not gonna happen, is it? There's a lot to be said for the competitive element, and I think we'll see a lot of consolidation. What I'd really like is a standardized, accurate test bench with modern turbines and real data, operated by a trusted third party where suppliers and customers can participate. Customers like us provide data, and suppliers get their models tested, so they understand bias and error, making more informed, quicker purchasing decisions that benefit the whole industry. But one company building everything? That's not gonna happen.

Samuel Ziak 27:31
Thank you.

Interviewee 27:34
I'm not sure it would be worth it. It could help either way.

Samuel Ziak 27:39
I understand. Thank you very much.

Samuel Ziak stopped transcription

K.10 Interview #10

Name: Participant 10

Title: Head of WTG Engineering

Company: Internal

Date: 04-09-2024

Time: 08:00 – 08:30

Samuel Ziak 0:03
Yes, alright, good morning. It's nice to have you here. Before we begin, I would like to ask if you give explicit consent for me to transcribe the interview.

Interviewee 0:18
Yes, that's OK.

Samuel Ziak 0:19
Thank you, and just to confirm, your responses, your name, and the company you work for will be anonymized, and the transcript will be deleted after the final grade is received on December 24.

Interviewee 0:31
OK.

Samuel Ziak 0:34
So, can you briefly describe your role and responsibilities within the company you work for?

Interviewee 0:40
Yeah, sure. My role involves heading the WTG department and the new department, so I have responsibility for the turbine design from early development to generation, and also partly for decommissioning. This role includes sales force support to offshore operations and ensuring proper function on the turbine side.

Samuel Ziak 1:04
Alright, let's move smoothly to the next question. What is your understanding of the term "digital twin"?

Interviewee 1:13
The term "digital twin" in the industry can mean many different things. For example, there’s the high-fidelity model with a lot of data—that's the high end of digital twins.

Samuel Ziak 1:18
Yes.

Interviewee 1:30
It’s essentially a complete mirror of your assets. But the term is also used for simpler models, like basic 3D models or simpler algorithms.

Samuel Ziak 1:38
Yeah.

Interviewee 1:53
So, in general, the term "digital twin" is used very broadly, which leads to confusion in the industry about what it means. This often results in different parties talking in slightly different "languages" when discussing technology.

Samuel Ziak 2:17
For sure. So, it seems there are many different technologies under this term, which causes confusion for everyone working with it.

Interviewee 2:21
Exactly.

Samuel Ziak 2:31
Are digital twins a part of your work, directly or indirectly?

Interviewee 2:37
Not directly, but indirectly, yes. There is ongoing work to incorporate these technologies into the business. There’s also some confusion because some people refer to training modules that simulate turbine scenarios as digital twins. For me, that's not accurate. A digital twin, in my view, needs to have some intelligence behind it. That’s the distinction for me. In my leadership role, I’m not directly working with digital twin content on a daily basis.

Samuel Ziak 3:48
For clarity, let's stick to the term "wind turbine." Is that correct for what we are discussing?

Interviewee 3:56
Yes, wind turbine.

Samuel Ziak 3:59
If we say "wind turbine," are we referring to the entire structure?

Interviewee 3:59
Yes, that includes everything from the tower to the nacelle, the blades, and all turbine components, but not the foundation.

Samuel Ziak 4:09
Okay, so the foundation is not part of your team's scope?

Interviewee 4:09
Correct, the foundation is not included.

Samuel Ziak 4:16
Alright, let's focus on that for our discussion. Are you aware if digital twin technology is currently applied to any parts of the wind turbine above sea level? Is there progress in this area within your organization?

Interviewee 4:19
Most of the digital twin work is handled by OEMs (Original Equipment Manufacturers). They integrate digital twins into their design processes. On our side, we have our models, but sometimes these are mistaken for digital twins when they are actually VR models. I don't see VR as a digital twin; they serve different purposes. The digital twin is particularly useful in early design phases, and since turbine design is done by the OEM, they have most of the design capabilities and simulations.

Samuel Ziak 5:55
When you mention OEM, do you mean Operations and Maintenance?

Interviewee 6:00
No, OEM refers to Original Equipment Manufacturers—the turbine suppliers.

Samuel Ziak 6:04
Got it. I was confused when thinking of design in terms of operations. Thanks for clarifying.

Interviewee 6:13
Yes, OEMs are the turbine suppliers.

Samuel Ziak 6:16
Thank you for clarifying. So, if we have a turbine, it would be the supplier who integrates or develops this technology and delivers it as part of the product?

Interviewee 6:34
Currently, it's not delivered as part of the product, although it can be requested. If you consider where digital twins are most valuable during the project lifecycle, I'd say it's in the design and construction phases.

Samuel Ziak 6:48
I see.

Interviewee 6:51
Yes, and also in the operation and maintenance space.

Samuel Ziak 7:00
Mm-hmm.

Interviewee 7:01
Innovation and training are trickier. For me, training is where VR technology often comes in. Some people equate VR with digital twins, but I see a digital twin as a copy of the asset that

reflects how the asset behaves. While training may involve a digital aspect, it's different. Some work on digital twins has been done in the foundation area as well.

Samuel Ziak 7:58
Let's focus on that because my background involves Norway, but my topic is related as well.

Interviewee 8:03
Yes, yes, I understand.

Samuel Ziak 8:05
Focusing on this, how does your part of the organization prioritize digital twin technology? Could it be a priority to optimize operations or extend asset lifetime?

Interviewee 8:36
I definitely see the value of digital twins, but you need to be very specific about the use case. What value do you want to bring? What are the requirements before setting it up?

Samuel Ziak 8:47
Right.

Interviewee 8:49
It's crucial to determine the value you aim to create because there's a risk of having a very simple digital twin that doesn't provide much value, or spending so much on development that the digital twin's cost outweighs its benefits.

Samuel Ziak 9:15
Understood.

Interviewee 9:30
I'm sure digital twins will become more prominent, and they are already used in some areas. But it's all about seeing the specific use case and driving it based on that.

Samuel Ziak 9:51
So we can assume that the technology in offshore wind is still relatively young and needs to prove its value, given the high initial investment required to implement it?

Interviewee 10:07
Yes, there's still a lot of research ongoing. I was at a lab yesterday where they are developing digital twins for marine construction and the energy sector. But it all comes down to the application; without intelligence behind it, it's not truly applicable to your use case.

Samuel Ziak 10:28
I found from theory that a fully functional digital twin should have a model complemented with analytics, which together create a working digital twin.

Interviewee 10:42
Yes, that's correct.

Samuel Ziak 10:56
It seems similar to what you're implying—they complement each other.

Interviewee 10:56
Exactly.

Samuel Ziak 11:05
Great. To proceed further, I'd like to ask you about specific stakeholders. Let's say you are a stakeholder for a digital twin project—where do you see yourself fitting in, and which stakeholders do you think are most important for the digital twin developer to engage with?

Interviewee 11:53
It depends on the use case for the digital twin. What value do you want to bring?

Samuel Ziak 12:00
Let's stick to wind turbines.

Interviewee 12:02
Right, but if you look at the operational phase versus the design and construction phase, you'll have different stakeholders.

Samuel Ziak 12:10
I see.

Interviewee 12:15
In the early or project phase, the developer is key. In the operational phase, it's the operator.

Samuel Ziak 12:25
OK.

Interviewee 12:31
Based on my experience, staying close to the stakeholders is crucial because, otherwise, you may not create the value needed.

Samuel Ziak 12:41

Yeah. Yeah, yeah, yeah, too. So it's essentially to capture the value fully in a way so you don't lose sight of it.

Interviewee 12:47
Yes, yes. Yeah. And also in the development, you know, it's really important that the digital twin is developed in close cooperation across all parties because otherwise, we're developing a solution that doesn't target the end customer at the end of the day.

Samuel Ziak 13:09
And the final question in this topic would be where would you position yourself as a stakeholder of this technology for wind turbines? Of course, it can be. It doesn't have to be derived from the table, right?

Interviewee 13:21
No, but I would say project developer or the engineering part, and by that, also being part of seeing the development of it. But that is where I see it.

Samuel Ziak 13:31
Oh, brilliant. Brilliant. Brilliant. Super. So now we will discuss the needs and values, but first, we will focus only on the needs in relation to digital twins. Here is another table which I've provided as an example, but feel free to come up with your own as well. This is just for our help, but if I have to ask you, where are your needs as a stakeholder that you expect a digital twin can or will solve for you in the future?

Interviewee 14:06
For me, there are two elements. The digital twin can either provide stronger design and construction capabilities in the project phase, or it's in the operational phase where you get more intelligence by your digital twin and the ability to actually test something in your digital twin prior to testing it in the real environment. Those are the two areas where I see the main benefits.

Samuel Ziak 14:38
Brilliant. And if we have a look at the table of needs, do any of them resonate with what you just said? Would that be, for example, supporting business cases? Of course, it can be decision-making, but what I'm trying to say is that if there were one or two needs you would like to highlight, would there be any out of these? Can you see them well, or?

Interviewee 15:04
Yeah. Yeah, I can see them. For instance, optimization of production as well. The lifetime extension I could also see as part of it, specifically.

Samuel Ziak 15:24
Because that would also increase everything.

Interviewee 15:25
Yeah, yeah. For me, the part of the company's product realization process is not a need.

Samuel Ziak 15:38
OK.

Interviewee 15:39
If you look at it, yeah, that’s the frame you're working on, but that's not a need for the business.

Samuel Ziak 15:45
Yeah. Alright, brilliant.

Interviewee 15:49
Yeah.

Samuel Ziak 15:50
And let's proceed to the values so that we only have... actually, we're almost at the end, so we only have two more sections: value and challenges.

Interviewee 15:56
Mm-hmm.

Samuel Ziak 15:58
And then we're done. But if I have to ask you this, this table is just grouping them. So if you look at the previous ones, they're grouped by economical value, but how do you perceive the value added by digital twins? We partially already answered it, right? But also, if we had to cherry-pick one value, would you be able to do that?

Interviewee 16:24
For me, it's either the economic or the operational part.

Samuel Ziak 16:29
Which also go closely hand in hand, right?

Interviewee 16:31
Yes, yes. Sustainability, yes, definitely I can see the value there. However, at the end of the day, the economic part is also important to set. You know, the frame prior to developing the tool—what is the value that it brings? What is truly the business case behind the digital twin? Where is it that we will either, you know, add, improve safety, improve operational ability, or improve our ability to optimize the assets? At the end of the day, that's coming back to economics as well and the value for the business.

Samuel Ziak 17:16
Absolutely. Now, of course, it's a great and maybe exciting technology, but it currently could be labeled maybe more as a buzzword in a way as well because it could entail technologies such as virtual reality that we described, or it can be a machine learning model that you just take a bunch of models, et cetera.

Interviewee 17:34
Mm-hmm.

Samuel Ziak 17:37
But how does your organization address the challenges currently that relate to aggregating a lot of data? My assumption is, and correct me if I'm wrong, that currently we have a lot of sensors on the wind turbines, so we are already aggregating a lot of data, but then the technology of digital twin could come in, and as the intended purpose is, create the replica and process the data and then take some actions on it.

Interviewee 17:53
Hmm.

Samuel Ziak 18:09
What is the current status when we install the sensors? Is there any issue with interoperability or gathering the data? Do we work with the data? Just your perception on this topic?

Interviewee 18:22
Essentially, if you look at the landscape of that, then both the OT (Operational Technology) and IT security elements are very high. We're talking about critical infrastructure that's becoming more and more critical. So, the whole digital twin part—the first step is to get the data in and then make the intelligence of your digital twin afterward. But in that, you need to first understand how you get your data in. Even that, because you see now, with the situation in Ukraine and how security elements have increased over the last couple of years, right? So there's no doubt that if you look at the data, integrating the cybersecurity, and the technology, it's also a matter of whether those providers of digital twin technology are actually able to comply with the regulations and requirements for security, both on the OT and IT sides. So there is a lot involved in securing that. When you have it in a company, at least I have been part of developing a digital twin in another company, and you shouldn't underestimate both the time, cost, and mapping it out to create your digital twin, to get the data in, and also to make it intelligent.

Samuel Ziak 19:57
Now you touched upon the Pandora's box. I would like to ask you, but feel free to reject if it's not suitable. In your experience from the previous company, could you elaborate on how you underwent the development or what the lessons learned or takeaways were?

Interviewee 20:31
The takeaway is mainly that the whole data infrastructure, your data landscape, your overall security level—you really need to have all that mapped out before you even start, because there are quite some hurdles to either get over or get around, and some blockers as well. That is something to be quite consciously aware of, because these factors can entail a lot of costs. Understanding this before starting the journey and not getting too far down the road is essential because we can all get an external consultant or company to show what a digital twin can do, but in our specific landscape and with the security requirements we have, there will be boundaries that give additional work to achieve the value afterward.

Samuel Ziak 21:57
Was this development of the digital twin also in the offshore wind industry or in a different industry?

Interviewee 22:02
It was in a different industry but still within the energy sector, so it involved similar security challenges. In the energy sector, you're often providing directly into the TSO (Transmission System Operator) or national grids, where the dependency is high on ensuring top delivery standards, otherwise, there's no electricity. This also means you need to understand the security risks when developing these technologies.

Samuel Ziak 22:04
OK, so TSO—would you explain what it means?

Interviewee 22:54
In Denmark, for instance, the TSO is Energinet.

Samuel Ziak 22:58
OK.

Interviewee 22:59
Yes, similar to the TSOs in other countries, like TenneT in the Netherlands.

Samuel Ziak 23:00
Alright, got it.

Interviewee 23:01
Yes.

Samuel Ziak 23:01
That clarifies it for me, thanks.

Interviewee 23:03
Yeah, no worries. It's just specific to each country.

Samuel Ziak 23:11
Yes, when you mention a specific one, it's clearer.

Interviewee 23:14
Yeah, yeah, no worries.

Samuel Ziak 23:16
So, as we see, we have about 5 minutes left, and I'd like to conclude with maybe two more questions.

Interviewee 23:19
Yeah.

Samuel Ziak 23:23
In your perspective, how do you see the role of digital twins evolving in the future of offshore wind?

Interviewee 23:33
I think it needs to mature more. It needs to really come with the ability to create value. There's still an element of the industry needing to align on what digital twin technology actually is—whether it's just a digital twin of a component, like a box, or a full wind farm. So, what exactly are we talking about? There's been a lot of development, but there's still a need for more research and defining real use cases because it's really about sharpening those use cases to create value.

Samuel Ziak 24:42
And the follow-up question is, do you believe that it should become an industry standard to share knowledge of digital twins, or should that remain more within the knowledge of individual companies and be kept as a competitive advantage? What's your position on this kind of industry movement?

Interviewee 25:06
For me, there are two elements. First, it's too early to say because the technology is not fully developed. Second, it also comes back to some of the overarching boundaries we work under as an industry. Sharing across the industry involves different IP rights as well, which need to be adhered to. I think there are areas where we can share best practices across the industry, but overall, there's still quite a way to go.

Samuel Ziak 26:08
So, sharing ability to a certain level, or within certain boundaries?

Interviewee 26:10
Yes, but I even think the technology needs to be defined first. What exactly are we talking about when we say digital twin technology that we want to share? Is it the early design of a component, or is it the VR model? It's so widely spread. For instance, is it the digital twin that Ramboll will do on their design? They also call that a digital twin. If you look at the foundation, they have a digital twin of the design of the foundation.

Samuel Ziak 26:20
For sure.

Interviewee 26:45
Right, is that what should be shared across the industry to see improvements? Of course, there are things you could share, but for me, it's not specifically about digital twins; it's more about standardization across the industry. But that has to come with the standards that are rolled out across the industry and not just by the digital twin.

Samuel Ziak 27:08
So, it must be regulated or overseen by some authority?

Interviewee 27:12
Yes, similar to how, within the wind industry, we have agreed on certain standards for safety, design, and quality. Standards exist there.

Samuel Ziak 27:23
For sure, absolutely. Brilliant.

Interviewee 27:31
Yes.

Samuel Ziak 27:31
That brings us to the end of the interview. I'm really grateful for the 30 minutes you've found.

Interviewee 27:38
Yeah.

Samuel Ziak 27:39
This really helps, and I will stop the transcription now.

Interviewee 27:42
Alright.

Samuel Ziak stopped transcription

K.11 Interview #11

Name: Participant 11

Title: Manager of Data Analytics

Company: Internal

Date: 05-09-2024

Time: 14:35 – 15:05

Samuel Ziak 0:04
All right. Good afternoon and welcome to this interview. Before we begin, I would like to ask you if you give consent to this interview being transcribed.

Interviewee 0:14
Yeah, sure. No problem.

Samuel Ziak 0:15
Okay, so just for your information, all your personal information and the company you work for, your name will be anonymized for the purpose of this thesis, and of course, the transcription will be deleted after the hand-in, which will be after the final grades, which will be in November or December this year. Hopefully, let's jump straight into it. So can you briefly describe your role and responsibilities within the company that you work for?

Interviewee 0:42
The role? Yeah, I started as a senior data scientist in the business unit, offshore. Offshore wind and then became the manager of the Data Analytics team, which is responsible for the development of machine learning, data science application for predictive maintenance of the turbines, and reporting.

Samuel Ziak 1:07
If we say turbines, do we include each and every component of the turbine in addition to foundations, or?

Interviewee 1:16
The foundation has its own department, and they are doing data analysis based on the sensors that they install. But generally, what we are doing is about the mechanical part, electrical part, and the balance of the plant, like cables, substation, and those things, they are under my responsibility.

Samuel Ziak 1:38
OK. So it would be covering the entire wind farm, not just the wind turbine.

Interviewee 1:43
Yeah.

Samuel Ziak 1:44
So the entire ecosystem.

Interviewee 1:45
Exactly. Yeah. Yeah, exactly.

Samuel Ziak 1:49
And if I can ask you, what is your most common understanding of the term digital twin? If you could give it a definition.

Interviewee 1:57
So digital twin? I would say it's a type of mathematical description of the system that we are under—it's under our consideration. So basically, we expect to give the input to our system, and at the same time, the same input to the digital twin, and we are getting the same output from both of them. It's not necessarily nowadays just a kind of mathematical description. It could also be a visual description, a geographical description—it could be anything.

Samuel Ziak 2:47
And if we say description, could you elaborate on that a little bit?

Interviewee 2:53
As an example, we have a component, and it has physical behavior. For example, you have a transformer, and you can model the transformer based on physical descriptions, kind of, I would say, differential equations. That differential equation could be a mathematical description of the system, or you have a kind of room where every part of the room has its own facilities.

Samuel Ziak 3:18
Mm-hmm.

Interviewee 3:28
And those visual maps that we are creating from that room could be a digital twin. After all, you are adjusting the components in the room in this digital twin, and you would like to see how it looks like in real life.

Samuel Ziak 3:45
Mm-hmm. And if I may ask, the final part of this section is: are digital twins directly or indirectly part of your work in your organization?

Interviewee 3:50
Both. They are kind of directly part of our work in the team, and we are developing digital twins as well.

Samuel Ziak 4:05
So could you please elaborate maybe on that a little bit? In which context do you develop them, or what's the use case for integration?

Interviewee 4:15
Yeah, the main use case for us is to do kind of early failure detection or predicting the failures. For instance, we have a component in the turbine like a reactor. We have a lot of data during the operation of this reactor when it was healthy, and we are using those data to create a kind of data-driven digital twin of that reactor component.

Samuel Ziak 4:52
Umm.

Interviewee 4:52
And we are running this digital twin in parallel to the real systems. This means we are getting the input from the systems which go to the reactor, and we are putting the same inputs into this reactor digital twin, and then we are comparing the outputs. So if the reactor behaves the same way as it has in the non-faulty case, we expect to have the same output. If we see some deviations, it indicates a problem that is starting to develop in that component.

Samuel Ziak 5:27
So that already sounds like you are utilizing this technology within your department, at least?

Interviewee 5:34
Yes, exactly. We wanted to start to have a digital twin for the entire turbine, particularly the nacelle part, but it was not feasible, and we also got some help from some external companies who said they had digital twins for that. We tried that, and we saw it wasn't as good as we expected. So our strategy in the team right now is to define digital twins for each component in the turbine and then aggregate them together.

Samuel Ziak 6:06
Of course. Which would be the composability of each?

Interviewee 6:11
Exactly. So, ultimately, from the physics of the turbine, we know the output of these components flows into others: the output of the generator goes to the inverter, and then to the transformer later. Knowing these dependencies, we can also connect our digital twins together and hope that we are having a more accurate digital twin in the end.

Samuel Ziak 6:33
Brilliant. But do you think there might also be some issues with interoperability when trying to connect different components of the wind turbine?

Interviewee 6:45
There are some disturbances that come from outside, and you cannot avoid that. So, if you want to have a perfect digital twin, I would say you need to also have a digital twin of the context of these things that you are considering—the digital twin of the location of the turbines, the digital twin of how the turbulence looks like. So, those disturbances are a bit challenging, but we need to make sure that those digital twins we are developing are robust against those disturbances that come from outside.

Samuel Ziak 7:18
So, disturbances meaning some external factors, such as weather?

Interviewee 7:23
Exactly. Yes, exactly—weather conditions, abrupt changes in some factors that we didn't consider when we were developing our digital twins. It's a kind of iterative work; you need to always adjust it based on new information.

Samuel Ziak 7:39
Brilliant. Is there any specific or main objective why your organization tries to develop digital twins, and does it focus on a particular stage of the lifecycle? For instance, it could be early on or throughout the entire lifecycle of the wind turbine.

Interviewee 7:56
It's more related to the operation part because, in operation, we want to be able to detect failures as early as possible before they develop and cause secondary damage to the turbines. We also want to optimize our maintenance strategy, like when we need to visit the turbines in an offshore environment. You can't be there every day, so it would be beneficial if the maintenance teams have a list of tasks when visiting a turbine—knowing what's going on, which components might be at risk of failure—to optimize maintenance and increase the uptime of the turbine.

Samuel Ziak 8:39
Of course, I see. Brilliant. To be mindful of the time, I will proceed to the next part, which is related to stakeholders and the roles of the stakeholders. I've provided a little table, but that's just for reference. If you had to position yourself as a stakeholder of this technology, it sounds to me like you could be the supplier or the developer, but in your point of view—also correct me if I'm wrong—who would be the most important stakeholder of the digital twin?

Interviewee 9:19
I mean, digital twins can be used everywhere. For example, before we start to build the park, we can have a digital twin of the park to see how it would react in the future and which aspects we need to consider. It could be applicable from the very start, like in the development phase, where you can estimate how much the operational expenditures (OpEx) of the turbines might be. You can use digital twins during the building of the turbines; after development, during the build of the wind parks, you can have digital twins of the components to see how they fit together. If I pick this component for building my wind park, how does it behave compared to another component? Based on that, we can optimize our build as well. And as I mentioned, in the operation and maintenance of the turbine, you can use digital twins for training new employees instead of bringing them physically to the turbines. If someone is on the turbine, you need to turn it down. Instead, you can have a visual digital twin of the turbines to train them. During decommissioning later on, you can also use digital twins to see how to decommission the turbines efficiently. I see a lot of possibilities throughout the entire lifecycle of the projects—from development to decommissioning.

Samuel Ziak 10:54
But it also entails a lot of different technologies, such as visualizing the wind farm or using virtual reality, correct?

Interviewee 10:58
Exactly. And it also needs collaboration between suppliers, us as operators, and developers.

Samuel Ziak 11:13
Hmm.

Interviewee 11:13
Some components we don't have fully. It would be beneficial if OEMs could provide digital twins of their components when we are developing, to see what's the best match for us.

Samuel Ziak 11:27
Absolutely. So you would, so you could say that once we purchase the component, having a built-in digital twin feature would be ideal?

Interviewee 11:35
Even before purchasing, because you want to make sure that if you purchase it, it fits your goals.

Samuel Ziak 11:42
I see.

Interviewee 11:42
So when discussing with the OEMs, and they say, "We can provide this transformer, we can provide this generator," we can ask them, "Can you provide me with a virtual or digital twin of that component?" Because later on, I want to see if that component I bought from you complies with our grid codes or other requirements. These kinds of simulations before construction are very helpful.

Samuel Ziak 12:02
OK, I see. Brilliant. Now, we will discuss the needs and values, and first, we will focus only on the needs in relation to digital twins. So, if I have to ask you, imagine yourself in the shoes of the stakeholder again: what would be your needs as a stakeholder that you expect a digital twin can or will solve for you? We've touched upon this a little bit already.

Interviewee 12:36
Umm, I would expect that it's real and can solve our problems—some of the problems, but it indeed depends. I mean, we cannot solve everything with the digital twin, as I mentioned.

Samuel Ziak 12:49
Ideally, it’s in an ideal world, it is.

Interviewee 12:52
In an ideal world, yes, but as I mentioned, there are some uncertainties that couldn’t be modeled. So, I wouldn't, at the beginning, expect that the digital twin I provide to my stakeholders is going to 100% fit their needs. But the thing is that over time, we can make it better and better. We collaborate closely with them.

Samuel Ziak 13:19
Yeah, I've also provided a short list of possible needs if my interview struggles to come up with some of them.

Interviewee 13:25
Yeah, exactly. And they are very valid, especially for planning specific lifecycle repair phases, as I mentioned. For example, when you're developing the wind park, you can use digital twins to see how it will look later. And in the training of people for lifetime extension, you can see what's going to happen. If you want to extend the lifetime of the turbines, for example, what are the damages or what was the stress on the turbines during this lifetime?

Samuel Ziak 13:49
You know.

Interviewee 13:54
And can you also put the turbines on rest for another year? That could also be a very nice use case—cost optimization of maintenance. And as I mentioned, maintenance campaigns—you can optimize them by knowing what's going on with your turbines using the digital twin.

Samuel Ziak 14:11
Have you had any experiences with either of these needs in your line of work or in your department? Which would you highlight as having a need, and in your work, could there be one?

Interviewee 14:23
The most significant one would be cost optimization of O&M (Operations and Maintenance). That's something we are aiming for—we are trying to help the organization reduce costs by providing them with the capability to know what's going on with the turbines.

Samuel Ziak 14:44
That's great. You see, I'm also trying to keep the interview smooth, not to bombard you with too much.

Interviewee 14:55
No problem, that's good.

Samuel Ziak 14:56
But now, to switch over to the actual values that can be derived or taken out of the digital twins. Again, we've touched upon this as well, but if you had to cherry-pick from this short table, I grouped them by categories this time, not specific ones.

Interviewee 15:16
Umm.

Samuel Ziak 15:16
Which value, in your perception, could be the biggest one or have the biggest contribution, either to the operation of the assets or within the company?

Interviewee 15:30
From my experience, one person spent two weeks developing a small, tiny digital twin, and with that tiny thing, we were able to inform the team that a fan on the turbine was not working. They went and repaired it, and if they hadn't, and the fan continued in a faulty mode, the turbine would have stopped. Restarting the turbine and sending someone to repair it might take several days, leading to several days of downtime. Depending on the turbine scale, this downtime could be significant, and achieving this by spending just two weeks of one person's time demonstrates the value. Nowadays, data platforms are available, and the cost of operating digital twins is low, but the value they generate can be drastically high.

Samuel Ziak 16:44
I see.

Interviewee 16:44
And—

Samuel Ziak 16:46
That brings me to a fascinating point—coming back to our earlier conversation about composability and interoperability. You also need some sort of digital infrastructure and platform where you gather all the data and process them into a format or make analyses. Have you had any experience with this in your work as well?

Interviewee 17:21
We may not be developing those digital platforms, but there are lots of digital platforms available, developed by Google, Microsoft, Amazon, etc. In our company, we use Microsoft's digital infrastructure platforms to run our digital twins and store data.

Samuel Ziak 17:38
Okay. Are there specific tools or specific software as a service provided by Microsoft that you use?

Interviewee 17:47
There are platform-as-a-service and software-as-a-service options. Depending on the need, we use different technologies. For example, we use Microsoft's Data Lake House to store data, Azure Machine Learning for running our digital twins or analytical models, and Databricks for data exploration and digital twin development. There are many platforms available that are quite affordable as well.

Samuel Ziak 18:21
Yeah, so you need some sort of infrastructure provider first, one that ideally has all the infrastructure needed, rather than developing it on your own.

Interviewee 18:24
Exactly.

Samuel Ziak 18:31
You're not going to develop it on your own.

Interviewee 18:34
Yeah, exactly.

Samuel Ziak 18:35
OK, brilliant. Having about 5 minutes left, maybe let's turn our attention to the challenges. What challenges have you encountered while developing these digital twins?

Interviewee 18:50
Initially, it was a challenge to create acceptance for these digital twins and build trust with the stakeholders. But once they see the benefits, they begin to trust them.

Samuel Ziak 19:08
Could you elaborate a little, maybe provide examples of what the issue was or how you got from point A to point B?

Interviewee 19:16
We showed them the value. We demonstrated that the models and digital twins were providing useful information. For example, we had a model that informed the sites about a problem. At first, they didn't see or accept it, but after six months, the problem did occur. By showing the positive aspects of these models and how their outputs relate to reality, we gained their trust.

Samuel Ziak 20:14
I see.

Interviewee 20:15
Now they approach us, asking if we can connect those digital twins directly to the turbines to enable automatic decision-making, like curtailing or stopping the turbine automatically. Initially, they just received notifications, but now they want to take action based on the digital twin outputs.

Samuel Ziak 20:40
So it's like preventive maintenance?

Interviewee 20:43
Exactly. You can curtail the turbine and avoid the consequences, then solve the issues the next time you're at the turbine. Initially, they didn't want anything, then they accepted notifications, and now they want automatic actions without human intervention.

Samuel Ziak 21:05
I see. So from no requirements, they went to "we want everything tracked and analyzed."

Interviewee 21:09
Yes, exactly. It required a bit of advocacy on our part.

Samuel Ziak 21:23
Mm-hmm.

Interviewee 21:23
But nowadays, I see it's a sort of industrial boom; they also see how others are adopting these solutions, and now they trust these technologies.

Samuel Ziak 21:42
I see. My final two questions to sum up: if you have already progressed further with the development of digital twins for specific parts of the park or turbine, would you be willing to cooperate with other departments within your organization to share the knowledge and delve further into this topic?

Interviewee 22:04
Yes, exactly. We are already doing it. To create digital twins, you need some specific knowledge. My team has developers, but they don't necessarily know about the turbines themselves, the engineering behind them, or the different components. So we need interaction with those who have that knowledge to build the digital twins. Later, if you want it connected to some processes in the systems, like how to react to notifications from the digital twin, you need to collaborate with the end users to make it part of their daily processes. It's important to be connected with others. As I mentioned, we cannot develop a complete digital twin of a turbine or wind park at once; we need to go component by component and then integrate them. We also need to team up with other parts of the company for a real, comprehensive solution.

Samuel Ziak 23:19
Join forces and proceed further. The final big question—would you be willing to share that this technology should mostly remain a competitive advantage within a single company, or should it be more of an industry standard?

Interviewee 23:21
Exactly. If I mean some parts are company-specific, but some parts could become industry standards. As I mentioned, you can get digital twins from OEMs; they could provide it to us, but some things related to our company—like how we use digital twins—should remain our knowledge. The way we operate our turbines is something we know, and others may do it differently.

Samuel Ziak 24:04
I see.

Interviewee 24:04
So, that part is for us.

Samuel Ziak 24:07
Brilliant. Thank you very much.

Interviewee 24:10
You're welcome.

Samuel Ziak 24:10
I'll stop the transcription now.

Interviewee 24:10
You're welcome.

Samuel Ziak 24:16
Thank you very much for your time.

Interviewee 24:17
You're welcome.

Samuel Ziak stopped transcription

K.12 Interview #12

Name: Participant 12

Title: Asset Manager

Company: Internal

Date: 05-09-2024

Time: 15:35 – 16:05

Samuel Ziak 0:04
So we are on the same page. OK, good afternoon. Before we begin, I would like to ask you if you give your consent to transcribe this interview.

Interviewee 0:17
Yes, I do.

Samuel Ziak 0:18
And just to summarize, I will transcribe this meeting, use the notes to make some findings, and then use them in my master's thesis. This recording will be deleted after the final grade is received in November or December. Everything will be anonymized, including your name and company. That's it. So let's jump into it.

Interviewee 0:44
Yep.

Samuel Ziak 0:46
Can you briefly describe your role and responsibility within the company that you work for?

Interviewee 0:52
Umm, I'm an asset manager. I've been in this function for roughly three years now. Our offshore wind project is ending the construction phase and starting the operation phase. We took over the last turbines' operations, I think two or three months ago. It's now officially in generation, producing energy, and the project is phasing out with just some last works. My role as an asset manager is more focused on the operational phase of the asset, where I should focus on value-adding. As one of the few teams, we have the whole lifecycle of the assets within view and try to optimize the value throughout the lifetime. Meanwhile, the operational maintenance teams have the task to keep the park with the highest availability possible, but that's more short-term. They focus on this year, what to do next year, and then it kind of stops, whereas we focus on years three and beyond.

Samuel Ziak 2:09
I see. If I can ask, what is your understanding of the digital twin in offshore wind?

Interviewee 2:18
Everything I know about digital twins, like I've heard the phrase before. During my studies, it wasn't really relevant yet. But from the Structural Health Department and the Foundations

Department, I've heard about it. My understanding is that it's a model of the wind turbine in the computer, kind of trying to replicate the real thing. You feed it with data and it can replicate the actual turbine and also forecast what happens if certain scenarios play out.

Samuel Ziak 3:04
Yeah, that's perfect. Don't feel pressured or anything—this isn't a test. It's just for us to—

Interviewee 3:10
No, no, I'm trying to be as accurate as possible.

Samuel Ziak 3:14
Yeah, so can we assume that digital twins are either directly or indirectly part of your work? Maybe indirectly in some way?

Interviewee 3:25
It's indirect, if at all. The only touchpoint I had with digital twins was during a meeting discussing lifetime extension for asset management. We reached out to the Foundations team because we needed to provide feedback to the government on how far we can demonstrate that our park is capable of running longer, and by how many years. I think the question from the government was more about how we can guarantee a certain amount of availability. The foundation team said they have the data and models to show at any point how much lifetime each turbine has remaining. They also mentioned that, whenever a big storm or something happens, they can immediately show how much lifetime was lost, and how much remains. They suggested not to agree on a fixed number of years for lifetime extension with the government but to show the remaining lifetime of the park based on real-time data, with a safety margin. This way, the turbines can run until the lifetime is fully used up or the business case doesn't fly anymore. It was an interesting conversation because the government is currently trying to establish the rules for lifetime extension. They reached out to us for insights, and we could argue the other way around, instead of adhering to arbitrary requirements. We could show them the latest scientific data, making it an economic decision while ensuring safety by showing how much lifetime is left in the structures.

Samuel Ziak 5:37
Excellent. You mentioned that you weren't sure how much you could contribute, but you've provided a completely different perspective on the topic, which is brilliant. Keep going!

Interviewee 5:47
I think that's my only touchpoint so far with digital twins.

Samuel Ziak 5:51
We can remain on that—that is brilliant.

Interviewee 5:51
Sure, that's my limited exposure to digital twins.

Samuel Ziak 5:56
My next section would be—how you actually answered it already because you described the

project well—is whether the project you're working on deploys this technology. It's been constructed recently, but do we actually have this technology in this project?

Interviewee 6:16
Yes, to my knowledge, the sensors are there. We developed the project and innovated the measuring devices on the turbines; we can capture the data we need. The Structural Health Department is still working on getting everything into the system, but I'm not sure if what they showed was based on our offshore wind project or on real data. There was a lot of still-standing steel in Holland, and the park was delayed, so I'm not sure how up-to-date it is. But the data should be there; it's being captured, and the devices are out there.

Samuel Ziak 7:12
I see. So, it means that in the future, if this technology develops further, it can be brought to life?

Interviewee 7:21
Yeah, if it's not already done—I'm not sure, I'd need to reach out. But they're working on it, and the data is there. It just needs to be modeled, and then we're there.

Samuel Ziak 7:24
Of course, of course. You've touched a bit on the lifecycle of the asset. In your opinion, can a digital twin accompany an asset during the entire lifecycle, or would it be preferred, for example, just for lifetime extension? Or could it be only in the design and construction phases? What's your take or perception on this?

Interviewee 8:00
I think my original understanding was shaped when I was an asset manager in the Heat Department with gas plants before. There, we always talked about different stages of maintenance, like instead of replacing something every five years, you check how many hours it has been running and fine-tune from there. Measuring was the next step in maintenance; you measure, and once you detect something off, you know it's time to replace it. To my understanding, the ideal scenario is having digital twins where you input real-life data, run models ahead by a few years, and not only react when something goes wrong but forecast when something is likely to fail. This way, you can better schedule maintenance, order spare parts in advance, and optimize your maintenance strategy. Right now, many cases still rely on set schedules, like doing something every year, every two years, or every four years because there's no better data. And still, downtime and unavailability are very expensive, so it's better to do a little more maintenance a bit earlier than to risk having the turbine offline during the whole winter.

Samuel Ziak 9:20
Umm.

Interviewee 9:30
It's about moving from fixed schedules to more data-driven, predictive approaches, minimizing risks and optimizing operations.

Samuel Ziak 9:52
I understand. To be mindful of the time, let's proceed to the stakeholder point. If I have one

direct question—if there is a technology of digital twin, where would you position yourself as a stakeholder? I've provided the table for reference, but feel free to just get inspired or answer from the top of your head. Where do you stand as a stakeholder of a digital twin?

Interviewee 10:21
I think between operators and investors. You haven't mentioned it, but part of my role is also the interface with the joint venture, so with our investors. I would say digital twins, if they provide more insights into what we need to do on-site, offer good feedback for value optimization in terms of operations. They also provide great insights for investors, especially when discussing major replacements towards the end of the asset's lifecycle. You need a business case to justify investments, and investors need to agree or not. If you gain time and can prepare decisions ahead, that's an enormous benefit. But the model must be trustworthy to convince people to invest in it.

Samuel Ziak 11:17
Umm. Which is not an easy task to accomplish, I guess, right?

Interviewee 11:28
No, I haven't seen much yet, so I can't say.

Samuel Ziak 11:34
OK, brilliant. But I would like to touch on the topic of regulators, particularly the Dutch Government in this context. As you've mentioned, they might not have direct experience because the government is not a developer of offshore wind turbines, but they're trying to seek help or inspiration from developers like your company. They might be trying to find a way forward with your collaboration.

Interviewee 12:03
Hmm.

Samuel Ziak 12:07
Could this technology help bring value in the future as well? Is this what you mentioned earlier? Did I understand correctly?

Interviewee 12:16
Well, I think the regulator looks for optimizing space, especially because the North Sea is quite crowded, and there are a lot of different use cases out there. The government has an interest in making the best use of that space. In that sense, they're interested in extending the lifetime of assets. Once it's built and producing energy, they're open to lifetime extensions as long as it's safe and utilized effectively. What they're afraid of is having an asset standing there, taking up space but not producing anything.

Samuel Ziak 13:06
Umm.

Interviewee 13:07
They have little experience, so right now they would just give you 10 years with some hard requirements. But if you can provide a more realistic picture showing the actual situation and

potential, they might be open to adjusting on the fly. I'm pretty sure they'd be interested because, for them, saying "10 years" is just because they feel comfortable with it. If you can demonstrate that 15 years is also OK, or that for some parks it's only 8 years, then you move away from this fixed decision point and really use the remaining lifetime of assets in the best interest of everyone involved.

Samuel Ziak 13:41
Yeah. Umm.

Interviewee 13:58
And I think that is the shared interest we have with the government.

Samuel Ziak 14:04
Of course. Before we proceed, have you had the chance to see how the Foundations team developed their digital platform or infrastructure to aggregate all the data from the sensors? Have you had any exposure to that?

Interviewee 14:22
Using your observations on the turbine, someone said that there's a sensor. There's, like, yeah, a gray box somewhere in the world—interesting—but I saw some graphs in the PowerPoint from the team. But that's about it.

Samuel Ziak 14:27
Umm. OK, I see.

Interviewee 14:38
If they tell me, I don't need to know more. Like if they have a fancy dashboard that says, "Look, you capture everything, it's working, it's approved, and certified by people who know about it," then I'm happy to get the outcomes. Like, OK, you have so many years remaining.

Samuel Ziak 14:59
So, in your point of view, you don't really care how it's accomplished as long as it's accomplished?

Interviewee 15:06
I'm afraid I'm not capable of understanding the details.

Samuel Ziak 15:10
Yeah, which—

Interviewee 15:10
I assume there's quite a complex mathematical or statistical model behind it, so I'm fine leaving the details to the experts as long as I understand the principle.

Samuel Ziak 15:14
Which is the same for me.

Interviewee 15:26
And the outcome is great.

Samuel Ziak 15:28
And of course, it doesn't endanger anyone or cause harm.

Interviewee 15:33
Safety is always the first priority that needs to be guaranteed. But also, as I mentioned, we had some turbines that were standing still for quite a while, and there are certain activities we need to perform to ensure the lifetime isn't consumed too quickly.

Samuel Ziak 15:53
Mm-hmm.

Interviewee 15:53
If you have a model that shows you, "OK, overall, we have 80 years remaining, but some parts of the park, due to certain issues like standing still or failures in the corrosion protection system, are already down to 50 years," then you'd know that whenever something happens to those specific turbines, we need to tackle them first to maintain the overall integrity of the park. That would also be helpful—you'd know which turbines to prioritize for fixing issues like corrosion.

Samuel Ziak 16:19
Of course, I see.

Interviewee 16:31
You can make decisions based on these kinds of models.

Samuel Ziak 16:34
Yeah, brilliant. Now, let's proceed to the second part. We'll need to be a bit smoother or faster here. So now we will discuss the needs and values. First, we'll talk about the needs. If you put yourself in the shoes of a stakeholder, what are your needs as a stakeholder that a digital twin can or will solve for you, apart from lifetime extension, because we already mentioned that?

Interviewee 17:00
Maintenance optimization—that's actually not my part but rather operations.

Samuel Ziak 17:07
Umm. And for yourself, would there be a need that you could highlight?

Interviewee 17:12
My need is lifetime value optimization.

Samuel Ziak 17:15
Very good.

Interviewee 17:17
So, it ties into lifetime extension, or making sure we don't run out of structural lifetime before

the end of 25-35 years. A good tracking tool is a good tool for getting alarms or for highlighting which turbines need extra attention.

Samuel Ziak 17:41
Brilliant. Switching to values, what would be the biggest value derived from digital twins? It can be inspired by the previous table—such as cost optimization or business case support.

Interviewee 17:58
Yes, business case support is, for sure, a key value driver alongside lifetime extension and cost optimization. Those are the big topics I see. Improvement of safety—I don't know. I've heard we have enough lifetime remaining, so that shouldn't be an issue.

Samuel Ziak 18:19
But it should always be included as a priority or first thing, right?

Interviewee 18:21
Yeah, of course.

Samuel Ziak 18:26
Yeah. I won't bombard you with more because I understand you only know as much as I do. I'm only a bit smarter because I've already interviewed 10 people. The final part will be about challenges and future perspectives. So if we switch to that—let's imagine we have a wind turbine, not a farm but a single turbine, with different components like the monopile, the tower, the blade, etc. There needs to be some composability, so they communicate with each other. Ideally, the intention is that all of them communicate and we have a digital twin for each component. But in reality, it's difficult to accomplish. Do you think this would be applicable to your project as well, apart from focusing only on the monopiles?

Interviewee 19:31
Yeah, ideally, that would be the case. My concern is that you only measure what you know, and you only know what you measure. For example, if you have a sensor here and a sensor there, that's your database for creating digital twins. But I worry about what happens in between. I'd be afraid that we might miss something, and then based on our data, everything looks fine, but there's actually a hole in the tower that we missed.

Samuel Ziak 20:08
Yeah, that's a good point.

Interviewee 20:09
But that's also my lack of understanding of the technology, so maybe it's not a problem. And there are so many components that interact. For instance, you might have vibration in one part that you measure and think is fine for the blades, but it ends up compromising some bearings. There are many small parts in the turbine, so extending to more components adds a lot of data, and there might be hidden dependencies that complicate things. But that could just be me not understanding how it works.

Samuel Ziak 20:51
But as a final consumer or user of this technology, ideally, it would be some sort of dashboard or

application on your phone, right? You could select the visual replica, click on individual components, and track the KPIs.

Interviewee 21:10
Yeah, ideally, like the dashboards we have now that show the real-time status of the park—what's running, what has a problem. But you could also fast forward and see what the model predicts for the next half year.

Samuel Ziak 21:27
Umm.

Interviewee 21:30
That would be the most advanced version I can imagine—not just the current situation but also predictions for the future.

Samuel Ziak 21:42
Of course, but you'd also have to account for certain factors—like weather conditions and other external influences.

Interviewee 21:50
No, of course. It's always a model, it's always a scenario, but in that line of thinking, making predictions visible is important. Nobody wants to dig through tons of data; it needs to be easily approachable. Basically, a system that flags the next potential problem.

Samuel Ziak 22:14
Yeah, I see. And the final question: as we perceive the development of this technology, do you think your organization should keep the know-how or rights to this technology within the company, or should it be more of an industry standard shared among companies or competitors?

Interviewee 22:48
Yeah, I don't know. It's nice to have an advantage and be a leader in something because that's how you beat the competition. It sounds nice to have that—it's valuable. But on the other hand, people rotate a lot in offshore wind, so it's hard to keep it within one company.

Samuel Ziak 23:16
Yeah.

Interviewee 23:16
There's so much to gain from the whole industry using the technology better. There's a broader societal benefit, and I think sharing is a good thing.

Samuel Ziak 23:29
Maybe the first step could be just approaching governments, like you mentioned. There could be talks between developers, operators, and governments.

Interviewee 23:39
Yeah, there are overall benefits, and you gain more if you share the knowledge.

Samuel Ziak 23:51
For sure. Brilliant. I don't think I have any more questions, unless you have anything else to add from your experiences or perceptions.

Interviewee 24:01
No, I'm surprised at how much I could talk about something I hardly know about.

Samuel Ziak 24:06
But you did really well.

Samuel Ziak stopped transcription

K.13 Interview #13

Name:	Participant 13
Title:	Business Controller
Company:	Internal
Date:	06-09-2024
Time:	09:00 – 09:30

Samuel Ziak 0:06
Before we begin, I would like to ask if you consent to this interview being recorded and transcribed.

Speaker 1 (anonymized) 0:13
Yeah, we can do that.

Samuel Ziak 0:14
For your information, your company name, your name, and everything you mention will be anonymized, and everything will be deleted after the final grades are received this year in December.

Speaker 1 0:25
Umm.

Samuel Ziak 0:25
To begin with, can you briefly describe your role and responsibilities within the company you work for?

Speaker 1 0:33
I'm a business controller for project delivery and engineering.

Samuel Ziak 0:39
What is your understanding of the term digital twins?

Samuel Ziak 0:44
If I ask, particularly focused on offshore wind, what is your understanding of a digital twin?

Speaker 1 0:53
With my finance background, I would say it's basically a virtual wind farm.

Samuel Ziak 0:57
Umm. Umm.

Speaker 1 1:03
In that sense, it's having a virtual environment where you can try things without needing to do

that on the operational wind farm. You can see how that works. It's basically a sandbox, I would call it. That would be my take on it, yeah.

Samuel Ziak 1:24
Yeah, yeah, yeah, for sure. Are digital twins in some way part of your work, either directly or indirectly?

Speaker 1 1:36
No, I don't have that much to do with it directly. I mean, it has an impact on the financials if we get it up and running, that's for sure. In general, for example, I think it's a good technology that we're moving into because it makes the prediction of certain events much easier, which of course feeds into the business case and has an impact in the end.

Samuel Ziak 2:09
OK.

Speaker 1 2:09
Because it helps us tailor the technology towards its specific environment.

Samuel Ziak 2:16
Yeah, yeah, yeah. To a specific use case, right? But to your knowledge, is there any wind farm that we operate where this technology is already deployed?

Speaker 1 2:21
Yeah, exactly. Yeah. But it's a bit tricky for me to answer because I'm on the financial side, so I'm quite far from the technical implementation, to be honest.

Samuel Ziak 2:38
That's fine, we could—

Speaker 1 2:45
So I can't answer that for sure.

Samuel Ziak 2:48
If we say that you are on the financial side, would that mean you would be checking whether the technology is viable within your company? Could you elaborate a bit on that financial point of view—where would you come into contact with digital twin development or integration?

Speaker 1 3:03
Nice. I would say it's basically about funding. In the end, you need to have a customer who is deploying the technology that we are developing. I mean, that's the whole purpose of having the engineering department sitting somewhere. You shouldn't do something without having a use case or a customer in the end, and that is probably where I come into play. In the end, it's also about trying to ensure that the costs we have are ending up in the right place, which is, of course, the customer side.

Samuel Ziak 3:47
Umm, so—

Speaker 1 3:48
You have one thing that's basically finding a customer that aligns with the line organization. They need to align on the scope, if there's a use case, and then you need to mirror that in the financial flows, which is basically what I do. The financial flows are similar to funding, more or less; you need to have someone paying for it.

Samuel Ziak 4:11
Of course, of course. So, on the stakeholder role, would you be considered an investor, as you mentioned, or how would you describe your position in relation to digital twin development?

Speaker 1 4:23
Another—

Samuel Ziak 4:26
How would you describe your position as a stakeholder?

Speaker 1 4:30
From my role, as I said previously, I need to ensure the financial flow and that we have the funding in place. But it's also that if we are above budget and don't have any funding in place, I need to raise that topic because it leads to a cost impact in our area. From a controlling perspective, it's not good to work on products that don't have a customer.

Samuel Ziak 4:58
And?

Speaker 1 5:06
In the end, that's something we should not do.

Samuel Ziak 5:09
Of course, I understand that makes sense, but how do you prioritize or determine that? Because there are multiple teams and departments within project delivery, right? How do you know which ones to focus on? Do the teams have to promote themselves, or do you take into account specific metrics? Just trying to understand it better.

Speaker 1 5:32
In the end, it's a portfolio view that we have on project delivery and engineering. We're basically collecting the demand and trying to fit it to the resource base we have. I mean, that's what you should do in a company, and the prioritization needs to be done on the business side.

Samuel Ziak 5:54
Yeah, I see it.

Speaker 1 5:54
What you can do, of course, from a financial perspective, is put a KPI behind the measures and

then bring them in a natural order, where you can say this measure or product is, from a financial perspective, the most beneficial one for the company overall. Then you should go for that, that's clear. But there are some other factors you need to consider, like environmental impact. For example, I can say that green steel, from a pure financial perspective, is always more expensive than the alternatives you have. But you might still go for it because it fits the policy you have, or you just want to promote the technology.

Samuel Ziak 6:30
Yeah.

Speaker 1 6:41
So it's not solely a financial decision in the end. The only thing I can do is look at the benefit that the measure has, the financial impact, and then say that from a pure financial perspective, this would be the order you should execute them in.

Samuel Ziak 6:47
Of course.

Speaker 1 7:03
But in the end, it needs to be a business decision. And that's the case with green steel, for example.

Samuel Ziak 7:06
I see, I see. Yeah, brilliant.

Speaker 1 7:10
Or it could be that certain generations think the digital twin technology is something they would like to look into because they see the benefit in 10 years' time. You can also go for that. It's not only a financial decision, that's what I'm saying.

Samuel Ziak 7:29
But it would also affect the financials, particularly if their aim is to provide lifetime extension, which would probably have an effect on other KPIs.

Speaker 1 7:39
Yes, I particularly think it's a super good tool. Yeah, sure.

Samuel Ziak 7:43
Yeah, just in this context, particularly speaking, yes.

Speaker 1 7:47
Yeah, yeah, yeah.

Samuel Ziak 7:48
I won't ask about challenges related to interoperability, but a final question in this part, then we can jump to another. If we develop a digital twin on a wind turbine—just one of them, not the entire wind park—do you think we should do so maybe early in the design phases, or should that

stretch across the entire duration of the product's lifetime? And, of course, provide also the extension, possibly, right?

Speaker 1 8:20
Yeah, but it's fun. That's a pretty technical question, yeah.

Samuel Ziak 8:26
But you can answer as best as you can.

Speaker 1 8:31
I would say, of course, if you're looking at it—

Samuel Ziak 8:35
It can be from the financial point of view, of course. You can look at it from that angle as well.

Speaker 1 8:40
Let me try from there. From a financial perspective, it would be good to have the data in as early as possible, because you can link it to the development phase. For example, you should start it in the early stage because then you can still shape it. And you also have a good idea where the project stands. So I would say, from that perspective, without being a technician, as early as possible.

Samuel Ziak 9:06
Mm-hmm. Of course, that would allow additional value creation down the line as well, if you can then keep it along the entire lifecycle.

Speaker 1 9:16
Yeah, but I would also say that it limits the amount of work you need to do. If you have proper information at the start, you don't need to go back.

Samuel Ziak 9:28
I see, I see. Cool. Now we switch into the needs and values. First, speak about the needs and focus on your point of view—so financial. If I can ask, what are your needs as a stakeholder that you expect a digital twin can or will solve for you from a financial point of view?

Speaker 1 9:55
It's not an immediate impact, that's clear. But I would say, in the end, if you're looking at the business case data and so forth, the advantage is in data gathering. The better the database, the better the decisions in the end because it's the technical parameters that steer the business case and the operations that you have.

Samuel Ziak 10:18
Umm.

Speaker 1 10:25
So I would say it's probably not an immediate impact or linked to any financials, but in the long run, with the data you are collecting or have in place, I would say it leads to more stable

operations. And, of course, it will benefit almost any financial figure you have. For example, if you have a lifetime extension, you can generate more revenue. If it's beneficial for the business case because you can use the investment longer, or if you're using less steel, it's just good to have the data in place and be able to make a proper decision based on that.

Samuel Ziak 11:06
Yeah, I see. I provided a little table for inspiration if interviewees were stuck with providing one, but you found a great answer which I like. Maybe to conclude the part on needs, would there be one specific need in your position where, for example, a solution like digital twins could help you?

Speaker 1 11:37
In my position directly, not really, because it's a bit different. It has an impact on the development side of the business case, on the construction project side, and I'm more from my task description. I would describe myself as an OpEx controller in project delivery and engineering, and we are talking about investments in that sense.

Samuel Ziak 11:59
OK. I see, I see. Brilliant. On that note, let's switch to values. We've already touched upon it a little bit, but how do you perceive the value added by digital twins mostly? Could that relate mostly to business case improvements, operations, improved safety, or any other aspects? It can be any that come to mind.

Speaker 1 12:33
It's like a sandbox, isn't it?

Samuel Ziak 12:35
Yeah.

Speaker 1 12:35
Yeah, that's what I mean.

Samuel Ziak 12:36
So you create some sort of replica or environment, right?

Speaker 1 12:41
Yeah, exactly. And that's it. That would be the added value. I mean, all other things are based on that differential impact, yes.

Samuel Ziak 12:57
Would you highlight anything you could do specifically in that sandbox? Maybe scenario testing? It could also be that you just take a lot of data, right? But there could be issues with interoperability of the data, or you might have a lot of data but still need to analyze it effectively.

Speaker 1 13:18
Yeah, I mean, the digital twin, as I understand it, gives you the chance to see, for example, the impact of certain types of bases on the foundation and so forth.

Samuel Ziak 13:24
Yes.

Speaker 1 13:37
I mean, that's simply the advantage—you can actually see how to deal with these impacts. I think Michael usually says it's a minor portion of incidents that lead to downtime, but still, they matter.

Samuel Ziak 14:00
It's also important to say we're talking about just one aspect of the digital twin, right? It doesn't have to be limited to monopiles; it can be used for multiple things.

Speaker 1 14:13
No, no, it could apply to everything. It was just an example. It's good to have that because you can be proactive. You can take a worst-case scenario or a regular case and tailor the setup of the wind farm to that specific environment.

Samuel Ziak 14:18
Yes.

Speaker 1 14:33
It's pretty valuable, especially when combined with data collection. Then, you're making decisions not based on assumptions but on how things worked out in the past, feeding that into the scenarios you're looking at. That leads to better decision-making—it's that sandbox approach.

Samuel Ziak 14:57
Brilliant. Now, moving to the final parts of the interview related to challenges and future perspectives, let's focus on those aspects.

Speaker 1 15:07
Yeah. But I must admit, you probably invited the person with the least knowledge on the other side.

Samuel Ziak 15:17
You're doing well, so don't worry. I can't see you, but I can tell you're doing fine.

Speaker 1 15:21
Thanks, but I'm just saying.

Samuel Ziak 15:22
I can't ask you technical questions, of course. What I'm trying to understand is each stakeholder's point of view towards this technology. Right now, I've discovered that in our organization, there's development in different parts of the wind turbine.

Speaker 1 15:34
Umm.

Samuel Ziak 15:45
I'm mostly focusing on the foundations, but through these interviews, I've discovered that another team from digital engineering already has some digital twins in place. I don't know if they're in contact with the SSI team, but I can include this in my results or further interpret it for the SI team, which could help them down the line.

Speaker 1 15:59
OK, yeah.

Samuel Ziak 16:12
So what?

Speaker 1 16:12
That's an interesting finding, yes.

Samuel Ziak 16:15
My goal is to conduct objective research by aggregating information and stakeholder perceptions from everyone involved with digital twins, even marginally. Your input still helps a lot.

Speaker 1 16:32
Yeah, but you shouldn't duplicate efforts. It's a good finding, though.

Samuel Ziak 16:39
Exactly, but I don't want to stress you with technical questions. Let’s stick to the financial point of view and challenges. From your experience, you've mentioned there's an upfront investment because it's a relatively young technology in the context of offshore wind. Are the costs high to develop or integrate this technology? Any other challenges or barriers?

Speaker 1 17:10
I'm not sure. If you look at the regular project sizes we're handling, SSI might seem significant. Compared to a large construction project like Cebong, it's a minor investment. The challenge is, in the end, nobody wants to take the costs. It's like wanting the product but not wanting to pay for it.

Samuel Ziak 17:45
When you say nobody wants to take the cost, can you be more specific—not names, but which parts of the organization?

Speaker 1 17:54
In the organization, it often comes back to having a customer in place. You shouldn't develop something without a use case. It ensures that if, for example, operating wind farms take a portion of SSI, they're convinced of the product and will use it going forward. Then you find the second portion needed.

Samuel Ziak 18:10
Of course.

Speaker 1 18:29
Construction and development projects also benefit, and all parties that benefit should share the costs. But that's not always easy in an organization with budget constraints.

Samuel Ziak 18:51
Especially in the offshore wind industry, where each year is unpredictable.

Speaker 1 19:11
Yes, the landscape changes rapidly. Two years ago, the industry was all about growth, and CapEx wasn't an issue. But that has started to change.

Samuel Ziak 20:07
So, is CapEx problematic within offshore wind from your perspective?

Speaker 1 20:15
In offshore in general, yes. That's evident everywhere.

Samuel Ziak 20:23
Would the development of this technology fall under CapEx?

Speaker 1 20:34
Yes, but compared to big-ticket items like steel prices or turbine generators, SSI is peanuts. We're talking billions for construction projects.

Samuel Ziak 20:55
I see.

Speaker 1 21:07
From a financial perspective, it would be easier if you could replicate successful projects consistently. But things change over time.

Samuel Ziak 21:28
I won’t ask about data interoperability or cybersecurity, but do you have any concerns about cybersecurity threats if we implement digital twins? If you're a final user, would you prefer a digital platform to handle this data securely?

Speaker 1 21:52
From my limited technical knowledge, I wouldn't say it changes much. Digitalization is becoming more important, which naturally increases cybersecurity threats. It’s linked to automating processes—you're more vulnerable, but that's just how work environments are evolving.

Samuel Ziak 22:33
Do you think the work environment in your organization should be more digital in the future?

Speaker 1 22:41
Yes, exactly. But that also means cybersecurity becomes more critical.

Samuel Ziak 22:49
Teams should also be aware of what each develops and ensure communication across functions, like engineering and IT, because they all converge.

Speaker 1 23:04
No, definitely. You're right.

Samuel Ziak 23:21
Final question. Should we keep digital twin technology as a competitive advantage or share it with regulators or other industry players to gain momentum and get it running ASAP?

Speaker 1 23:52
It depends. If you need funding and can solve it through partnerships, you should. If sharing data extends your database and offers mutual benefits, then it's worth considering. But if the gain from keeping it internal is greater, then don't share. It's a strategic decision.

Samuel Ziak 24:39
It's a strategic decision in the end.

Speaker 1 24:42
Exactly. Why not explore partnerships if you trust the partner and share data equally? It could be beneficial, especially if you're investing in the same area. Gathering data without your own operations wouldn't be a bad move.

Samuel Ziak 25:10
Yeah, of course. Thanks for your time and insights today. I'll stop the transcription.

Samuel Ziak stopped transcription

K.14 Interview #14

Name: Participant 14

Title: Data Delivery & Software Development

Company: Internal

Date: 06-09-2024

Time: 13:00 – 13:45

Samuel Ziak 0:04
All right. So, hello, welcome to this interview. And before we begin, I would like to ask you if you give consent to this interview to be transcribed.

Speaker 1 0:14
Yes.

Samuel Ziak 0:15
All right, for your information, your name and the company name will be anonymized, and the notes will be used only for the purpose of my master's thesis, as well as the notes will be deleted after the final grade is received. Let's jump into it. Can you briefly describe your role and responsibilities within the company that you work for?

Speaker 1 0:37
Yes. So as you know, I'm working in the SI support structure and integrity team, and my role in that team is, I'm in charge of data delivery but also the development of software where we will visualize our digital twins basically. And I've been here for three years now, so I've been one of the guys who have been on the path almost the whole way. I joined when Michael and Jonas were here as well. So I've been working with everything from sensor systems to installation, commissioning, troubleshooting campaigns, been offshore, developing my own software as well as a proof of concept for what we are doing now. So basically, yeah, I've been working with all aspects from sensors to the screen basically, yeah.

Samuel Ziak 1:43
Brilliant. And just to know, that means you are the perfect stakeholder to interview because you will be able to give an accurate picture of how that goes within your organization more or less hopefully.

Speaker 1 1:50
Yeah. Hopefully, yeah.

Samuel Ziak 1:56
But if I can ask you, what's your first—before I would get back to what you've said that you've been part of since the project started, but what's your understanding of the digital twin in its sense?

Speaker 1 2:10
Yeah, so many use digital twins as a buzzword, and people have different perceptions of this buzzword. From my understanding, a digital twin is a digital representation of the real world and its behavior. So that means in my understanding it's not enough with just a computer model, a design computer model of some turbine, or if it was an offshore jacket or whatever it is. So my understanding of a digital twin is that you also have a true representation of the structural behavior or whatever it can be; it can also be used in other things than structures, right? So there are different levels within digital twins. I have a background at Ramboll where we used the technology of a true digital twin. I don't know how much I like it, but anyway it was to tell that you update your computer model with true measurements. So you have the physical representation of the true world in your computer model, and that is, for me, a digital twin. Yeah. Yes.

Samuel Ziak 3:37
So based on what you've mentioned, that means that you've come across digital twin development even before you joined your current organization.

Speaker 1 3:46
Yes. A digital twin could also be just a design model of something you have built, right? And maybe you update that design for this build. For example, you can specify that the thickness of a monopile or foundation has to be 8mm. Let's say that. But then when you actually manufacture it, you find out after measurements it's only 7mm. Then you update your computer model after that. So people will also call that a digital twin, and it's a very low level of the digital twin in my world, yeah.

Samuel Ziak 4:32
Of course, I see. And if we have to categorize or maybe break down these levels, could you characterize them or maybe define them?

Speaker 1 4:42
Yeah, usually we use levels 1, 2, 3, 4, 5—I can't really remember—but it's something like this. First, you do investigations on the computer model you have, right? Is the computer model updated as precisely as you can, right? So, for example, if you have some measurements of the thickness of the steel, is that updated in your computer model? Is your computer model as-is, and have you sharpened your pencils everywhere you can, so you have the best baseline of your computer model representing what is actually designed? That is the first step in my world. Then the next step is that you actually go out and monitor. You put some sensors on the structure, and you capture the physical behaviors of the structure. So, in terms of frequencies, it's also the mode shapes. The mode shapes are how, for example, the tower deflects. A turbine is a very simple structure—basically, a stick. It can sway back and forth side to side, but it can also sway with a bending around the second mode shape. By having sensors on the structure, we can capture the physical parameters: the frequency, the natural frequency of the structure, the mode shapes, the deflection pattern, and also how much damping it has, along with other physical parameters. Then you can take those and look at your computer model to see how much they correlate. Often, we see that they are not correlated very well because of conservative assumptions in your computer model. Even though you try to sharpen your pencil as much as possible according to standards, there will always be a large amount of conservatism built in. Also, maybe in your computer model, you have big uncertainties in different parts. All physical parameters have a

distribution. For example, the density of steel doesn't have the exact same value each time—it actually has a distribution of some sort, but usually, we use the mean values of this distribution in many of our parameters, especially in design. But we know there are uncertainties, and it can vary. There are some parameters with bigger uncertainties than others. For example, if you have an oil platform and the topside weight, there's a lot of steel on the topside weight. So just having the mass of the topside can vary a lot in this distribution. It could also be the stiffness of the structure, or the soil conditions. Soil is very hard to predict in a computer model because it's so nonlinear. So there's a lot of uncertainty in the soil when we design. When you have the measured values, the true physical behaviors, and your computer model, you can tune your computer model against these values—for example, the frequency and the mode shapes. Then we tweak parameters where we know we have large uncertainties, such as the soil, until we have the same physical behavior as what we have measured. That is what is called an update of the model, or FE model update—finite element model update. Then you correlate or update your computer model to the physical parameters, which is when you really have significant value because then you suddenly have a computer model that represents the real-world physical behavior. Then it starts to get very interesting, because you can do some nice stuff with that, including future predictions. That's the second layer. The third layer is about the loads. In load calculations for our structures, there's also a lot of uncertainty. But when you measure the real-world behavior, you indirectly also measure the loads. The next step is to calibrate the load calculations as well, getting closer to the real world, and creating aerodynamic models that are more representative of the real world. The fourth step is to quantify the uncertainty of your digital twin—to quantify how much you trust in your digital twin, or more precisely, what is the uncertainty of the digital twin? Then, with that, you can start the fifth layer: making predictions about the future. With an updated model, updated loads, and knowledge of the model's uncertainty, you can predict future scenarios. With a lot of data, as we have, we can maybe base those predictions on machine learning, which is also very interesting. So those are the layers in high-level terms, I would say.

Samuel Ziak 11:42
Brilliant. I think you've covered them excellently and provided the most descriptive description of digital twins I've gotten so far. Amazing.

Speaker 1 11:52
OK, that's good.

Samuel Ziak 11:54
Really, really cool.

Speaker 1 11:56
Ah.

Samuel Ziak 11:58
Now switching from the layers that you've described, can you describe how digital twins are currently integrated in your projects? Do you have any projects or assets in your organization that are currently utilizing digital twins? Are you taking data and already have the technology deployed? Is there any?

Speaker 1 12:21
Yeah. Yeah. So basically, that's what we have been working on for the last three years. We've basically just touched upon layer one and two, I would say. Right now, we have, I think, almost 200 wind turbines where we have sensors located in each one of the turbines. So we get a lot of data coming in. We sample with a frequency of 25 Hz in three positions in the tower, and then we do some magic, and we can actually tell the stresses throughout the whole structure, from the tower down to the bottom of the monopile. It's called virtual sensing if you want a word for it, and we have installed these sensors and are getting that data in right now. That's the whole data delivery part that I've been working on quite heavily. Apparently, it's a big task, much bigger than I anticipated in the beginning. We are setting up automated processes to calculate the damages of the monopiles. So we account for the fatigue damages of the whole structure every day in, let's say, 500 points of interest all over the monopile and tower.

Samuel Ziak 13:57
But that would include the tower. Do we also include the tower as part of the foundation of the monopile or?

Speaker 1 13:58
So we're working a lot with it, yeah. We include it. In one file, we designed the monopile ourselves and we buy the tower, and that has some advantages for my work.

Samuel Ziak 14:15
Yeah.

Speaker 1 14:22
Basically, our sensors are located in the tower, and that is almost brand new technology. Previously, most of these condition monitoring systems, especially in the structural part, involved measuring structures with low-frequency responses. It was most common to use strain gauges before, and it's very difficult to install a lot of strain gauges in the monopile because it has to be pile-driven down. It's very expensive. They often die and cannot function as long offshore, and so on. But we have developed a new system, which Mark can tell you much more about, where we use accelerations in the tower instead, and it's much more economical. It also has better lifetime, better performance; it's just much, much better. That is why we can install that on all turbines. I think that we are one of the first in the world who are monitoring all turbines in a wind farm. Previously, it was just done here and there. That, of course, gives us a lot of other opportunities that I can come into later.

Samuel Ziak 15:44
But if we say that we monitor, let's say, 200 turbines, we are speaking only about the foundation, the monopile, and the tower, right? We do not include the gearbox and the blades?

Speaker 1 15:55
Yes, exactly. No, that is true.

Samuel Ziak 16:06
And we can get to that maybe later. My question is, because it's part of composability as well, that you would like to have the entire—maybe we can take it now if you want.

Speaker 1 16:14
Yeah, yeah, yeah, we can easily take it now. You're absolutely right. In order to have a full-fledged digital twin of the whole turbine, it would be very nice to include the blades, the drivetrain, gearbox, cables as well, which is also a big thing.

Samuel Ziak 16:37
But that's part of the wind farm already, not the turbine.

Speaker 1 16:41
Yeah. Yeah, yeah, yeah, you can say that.

Samuel Ziak 16:44
And you need to connect the individual turbine, right?

Speaker 1 16:47
Exactly. But all the theory that we are using can also be applied to all the other components. You have a slightly different theory when something is rotating, but it would be very nice to have a full-fledged digital twin with everything included because then you can predict how well each component is performing and also maybe predict upfront when we need to change different components. That could be a huge business case. The reason we have success with our scope right now is that the monopile, especially, is very, very expensive to change. It's the one part of the structure that you cannot change because it's too expensive.

Samuel Ziak 17:40
Umm.

Speaker 1 17:46
The tower might also be expensive, but it's doable. The blades are off-the-shelf items that you can just get again. The drivetrain and nacelle are also things you can just buy. You know what I mean by just—it's not just; it's a significant amount of money, but—

Samuel Ziak 18:07
No, of course, I know because the monopile—you have to take everything apart.

Speaker 1 18:11
Yeah. You have to cut it open or get it up again. That is very, very difficult. With the monopile there, and potentially the tower, if we can say this support structure here that we designed to have a design life of 25 years, but actually, because it did not experience all the load cases that we assumed and the design, or that we were very conservative in the design, we can actually see that this structure can hold for 200 years.

Samuel Ziak 18:48
Mm-hmm.

Speaker 1 18:48
So that means we can tell the guys who make the business planning that the foundation will hold, you don't have to worry about that. You can just buy a new nacelle and blades, and you can extend the lifetime significantly. If they have the permit to operate that wind farm for a longer

period, then it might be a very good business case. So that's basically our idea. But of course, as a technician and engineer, the aim must be to have a full-fledged digital twin, maybe in 5-10 years, something like that—ten years maybe.

Samuel Ziak 19:34
That would cover the entire wind farm or wind park.

Speaker 1 19:39
Yeah, that would be the goal—must be the whole wind farm, including cables.

Samuel Ziak 19:46
But right now, we are focusing on individual turbines.

Speaker 1 19:49
Yeah, and only on support structures, at least in our team.

Samuel Ziak 19:53
Not on cables, substations, etc.

Speaker 1 19:57
Not now, but there are other teams in the company who focus on that as well.

Samuel Ziak 19:59
OK. Mm-hmm.

Speaker 1 20:04
They might also tell you they do structural health monitoring, and maybe they will even use digital twins as well. But from what I've learned from the other guys, it's one of the lower levels of digital twins. It's not really— I don't think they do model updating and stuff like that.

Samuel Ziak 20:25
I see.

Speaker 1 20:26
Yeah.

Samuel Ziak 20:26
Brilliant. And now, I mean, we are having a really nice interview. I like it a lot. It's great, valuable input, but now can we get back—

Speaker 1 20:34
That's good.

Samuel Ziak 20:36
Maybe to what you mentioned initially, that you've been in your company for three years now. My question is more about how you are able to ensure the interoperability or integrity of the data and how you aggregate it. That's what you are working on right now as well, right?

Speaker 1 20:43
Yeah.

Samuel Ziak 20:54
So you are pulling loads of data right now, but that's in raw format, and you need some sort of digital infrastructure or platform to store all this.

Speaker 1 20:58
Yes.

Samuel Ziak 21:07
Could you elaborate a bit on this topic?

Speaker 1 21:09
Yes, and if you want all the details, it would take a year to explain, I think.

Samuel Ziak 21:14
You can keep it brief.

Speaker 1 21:16
I'll keep it short. But as a fly into the topic, it's clear that in the data infrastructure, the whole industry has faced challenges previously. If you go to RWE or any other big operator, they'll tell you that data infrastructure is very difficult due to many reasons. I've also worked with Equinor, and they faced similar issues with data infrastructure, which is why they couldn't implement live monitoring of structures. However, what we do is that we collect data for each case set; for example, we have 139 turbines out there. Each second, we are receiving 36,000 data points that must be transported via the Internet to our cloud, which is located in Azure.

There's a whole team of individuals working on transporting this data, setting up automatic pipelines to land this data in raw format in Azure Cloud, specifically in an Azure cloud environment. We have processes that ensure the redundancy of the data, which means that we store all raw data forever. We're working on a backfilling procedure so if we lose some data, we can retrieve and backfill it.

Of course, we comply with IT and security governance, ensuring that everything lands in a database where we have our whole processing schema. Our team is developing a big tool called VOSS. While VOSS has its own team, it's a collaborative effort. VOSS is an in-house design tool where we have our design models, perform model updates, and run those models in the cloud. We calculate the damages for each turbine once a day across all wind farms, distributing our calculations on the cloud to numerous nodes or virtual computers. These nodes compute everything and return the results, providing data such as displacements at all points of interest, stresses throughout the structure, and damage assessments.

We're also working on implementing automated quality assessments of the data in the cloud before it reaches us. We calculate various parameters, including damages and stresses, based on each 10-minute interval throughout the lifetime of the structure. Our output tables are extensive, and we're building a pipeline towards a web-based dashboard—a software that visualizes our digital twin. This dashboard allows us to see how each specific turbine is performing, where

damages occur, and identify anomalies compared to expected results. This development scope is quite large, and we refer to it as 'Insight,' the Swedish word for it. Essentially, it provides real-time structural health insights for all turbines, with a latency of about a day.

Samuel Ziak 26:21
And if you have this dashboard, do you primarily keep it for your team, or do you distribute it further to stakeholders or end customers?

Speaker 1 26:35
That's a good question. It's a step-by-step approach. Initially, it will be used as an engineering tool within our internal team. Later, it will be used as a communication tool towards stakeholders once it has been tested and is fully functional. A critical aspect of this dashboard is to ensure a common communication platform. As you know, working with engineers often results in varied responses to the same question, so this tool aims to ensure consistency in the information shared.

Samuel Ziak 27:31
Speaking of stakeholders, could you highlight the most important ones that you've encountered during the development of this technology?

Speaker 1 27:42
Of course. We're developing it primarily for our own purposes. We need this tool to handle the massive amount of data and use it as a sensor system surveillance to ensure our sensors are functioning correctly. Key stakeholders include our own foundations team—I'm part of the Foundation Department—and Asset Management, who have sponsored the development. Additionally, Digital Engineering is a major stakeholder, ensuring governance, security, and IT compliance around Insight for web-based hosting. So, these are the key players.

Samuel Ziak 28:56
So, it requires close cooperation with different stakeholders who have slightly different primary focuses, right?

Speaker 1 28:56
Absolutely, it does.

Samuel Ziak 29:10
Great. Now, moving to a slightly less technical section, but you've done a fantastic job explaining it all from a technical standpoint.

Speaker 1 29:21
Thanks.

Samuel Ziak 29:26
Now let's focus on the needs and values. First, speaking about needs, if you are a stakeholder, what needs do you expect a digital twin to address for you?

Speaker 1 29:51
As a stakeholder, I would expect that we can identify and quantify how conservative we are in the design—meaning how much additional lifetime we have compared to what we designed for.

Additionally, we should improve operations with real-time digital twins, focusing on safety and reliability. Are we in control of our structures in real-time? Are they performing better than anticipated, and are they within our safety margins?

Samuel Ziak 30:57
And now, what would be the top value that digital twins deliver from your perspective?

Speaker 1 31:10
Ensuring the safety of assets in real-time. It's crucial that we know the structure's performance, identify any issues early, and pinpoint where those issues are occurring. This approach helps prevent critical failures and extends asset lifetime, which is valuable from a business perspective.

Samuel Ziak 32:09
So, ensuring that turbines or wind farms are fully operational without significant issues?

Speaker 1 32:19
Exactly. We can ensure the structures are performing well, identify potential issues early, and address them before they become critical. There are many secondary benefits, such as lifetime extension, which could offer a strong business case going forward. Controlling operational safety means that we're not just scratching the surface; we're leveraging the data's full potential to optimize everything from fatigue management to operational strategies. For instance, if we can prove extended lifetimes with certified data, it could also improve resale value or simplify new design standards.

Samuel Ziak 33:06
Of course.

Speaker 1 33:07
Lifetime extension is one example. By staying in control of safety and operations, and integrating data into operational strategies, we could greatly improve business cases. We have already shown that we can extend the structure's lifespan significantly, and that's just the beginning. There are untapped potentials, such as optimizing operations, that could yield additional value. There’s also potential in integrating this data into new design models, improving future designs by understanding where conservatism exists today and adjusting accordingly. For example, our studies have shown that including scour protection correctly in design models could save up to 20% of the steel used, which is a massive benefit.

Samuel Ziak 34:44
Of course.

Speaker 1 34:51
These insights could push the industry forward. For example, current design standards often use conservative factors, like multiplying loads by a factor of three due to uncertainties. But if we're continually measuring and validating with our system, there's less need for those conservative buffers. This approach could eventually lead to updated norms and standards, which would be beneficial across the board.

Samuel Ziak 39:27
And speaking of sharing this knowledge, would you advocate for sharing what you've learned about digital twins with the broader industry, or should the company keep it as a competitive advantage?

Speaker 1 40:07
Personally, I believe we should share everything. Sharing our insights and data would challenge the industry to evolve and help us in our journey to convince certifiers that these approaches are needed to make wind a more profitable market. Changing industry standards is a complex task, especially alone, so having others alongside would be beneficial. We're even developing a data-sharing platform, where our data will be accessible to the whole industry. We've already shared data packages with companies and students to explore, and I think this open approach is the right way to go.

Samuel Ziak 41:00
Is that data-sharing platform already developed, or is it a future plan?

Speaker 1 41:04
It's currently under development, but we've already shared some data packages with various companies and institutions. We aim to share as much as possible, including our methods. We've published articles on our sensor systems, and I believe that's the right approach. We won't gain much by keeping this knowledge to ourselves. We will stay ahead because of ongoing development, so sharing only accelerates overall industry growth.

Samuel Ziak 42:24
Brilliant. That concludes my questions. Is there anything else you'd like to add on the topic that might be helpful?

Speaker 1 42:44
No, I think we've covered a lot. Just one note: if you write about the business case of digital twin technologies and sensors, don't forget the scale of work required for data infrastructure. It's a huge challenge and one that many have failed at in the past.

Samuel Ziak 43:17
That's a point I've been exploring in my other interviews as well. Many have mentioned the need for a unified platform to manage and compute vast amounts of data, which is not an easy task.

Speaker 1 43:41
Exactly. It's definitely not easy. It's a significant task, and we work closely with Digital Engineering on all aspects. We've even hired a full-stack programmer to help bridge the gap between our team and Digital Engineering. He understands both our needs and the technical complexities, which has really helped.

Samuel Ziak 43:54
Are you in close contact with Digital Engineering, and do they support you adequately?

Speaker 1 44:00
Yes, we are in close collaboration, and they've been supportive. Our programmer acts as a

bridge, helping us align with Digital Engineering's requirements while keeping our project's integrity intact. Politics in a large company can also be challenging, as digital twins span different departments. There has been considerable debate about where this product should sit—within Foundations because it's monopile-focused or in Digital Engineering as it's a digital product. Balancing these internal dynamics and stakeholder management has been a big part of our journey.

Samuel Ziak 46:57
Indeed, I had an interview with a Digital Engineering stakeholder who mentioned they have their version of a digital twin, but I wasn't able to get specifics on that.

Speaker 1 47:07
Well, I wouldn't quote me on this, but I think their digital twin is more of a basic level. I haven't seen any highly developed digital twins from their side.

Samuel Ziak 47:28
Got it. I'll stop the transcription here.

Samuel Ziak stopped transcription

K.15 Interview #15

Name: Participant 15

Title: Principal Engineer in WTG

Company: Internal

Date: 06-09-2024

Time: 14:00 – 14:30

Samuel Ziak 0:03
I'll share the screen so you can see the questions. Good afternoon. Before we begin, I would like to ask if you give your consent for this interview to be transcribed.

Interviewee 0:14
Yes.

Samuel Ziak 0:15
For your information, your name, the company name, and your responses will be anonymized. The transcript of the interview will be deleted after the final grade is received in December this year. Can you briefly describe your role and responsibilities within your company?

Interviewee 1:04
Yes. I'm a principal engineer in the WTG group, similar to how you work with the foundation group. We are responsible for defining requirements for the new turbines, including the turbine, the foundation, and the tower, and we communicate these requirements to the suppliers. We call this AM. After defining the requirements, we also advise the sites when they experience technical problems. I'm mainly focused on new purchases—like which turbine we will buy in 2030, for example.

Samuel Ziak 2:09
I see. Are you a manager of the team? Do you have people working under you, or are you part of a larger team?

Interviewee 2:16
I'm not a people manager; I'm purely a technical mentor. I handle the technical responsibility of the department. In a typical organization, you have a CEO and then a CTO.

Samuel Ziak 2:44
Yeah.

Interviewee 2:46
So, I see myself as the CTO of the WTG group. I have a boss who's responsible for managing all the people, getting resources, hiring the right people, and all that stuff.

Samuel Ziak 3:06
I see. Transitioning to my next question: What is your understanding of the term digital twin in your line of work or your perception?

Interviewee 3:19
I see two types of digital twins: the real-time digital twin and the retrospective digital twin.

Samuel Ziak 3:31
Hmm.

Interviewee 3:36
The retrospective digital twin is quite computationally heavy but simple in concept. It takes measurements from throughout the lifetime—say 20 years—and looks back at what has happened to the turbine. We gather all input data from anemometers, wind, waves, etc., and input it into a simulation tool like HAWC2, which can simulate both turbine and wave interactions. This allows us to calculate historical vertical loads and extreme loads and compare them to the original design loads, letting us know if conditions have been harsher or more favorable than expected, which aids in lifetime extension assessments.

The other kind, which is what most people refer to as a digital twin, is a real-time model that shows whether the turbine is experiencing more fatigue loads or higher extreme loads than anticipated.

Samuel Ziak 5:19
That's brilliant. Are digital twins directly or indirectly part of your work?

Interviewee 5:29
For lifetime extension, it’s a direct part of my work. For real-time digital twins, it’s more advisory because most of that work is done in our foundation and IT teams. While it impacts the turbine and the tower, it’s much more critical for foundation designs, which we handle ourselves.

Samuel Ziak 6:11
I see. Can you describe how digital twin technology is currently implemented in any projects or wind farms you’ve installed in your organization, if you’re aware?

Interviewee 6:26
Yes, we are exploring whether we need additional sensors. As you've heard from the foundation guys, we use the same data for retrospective analysis, which is heavily used for lifetime extension. Last year, we did a lifetime extension for the first Danish offshore site, Horns Rev 1. We conducted a full simulation of what had happened over the past 20 years and evaluated if the turbines needed refurbishing or if we could extend their lifetime based on this digital twin.

Samuel Ziak 7:20
So, did you only consider the retrospective aspect, or did you also incorporate fatigue loads and the real-time aspect?

Interviewee 7:30
Yes, it includes fatigue and all other aspects as well. We use all the historical data and input it

into our normal simulation tool to compare it with the original design. Part of the improvement is due to having better models today than we did 20 years ago, and we don't need the same safety factors. We assess what happened and calculate how much fatigue life remains in the turbine. We determined there was about 10 years more life. The foundation team had done the same assessment prior to us.

Samuel Ziak 8:39
So, the conclusion was that the lifetime could be extended by 10 years?

Interviewee 8:45
Yes.

Samuel Ziak 8:46
And that's remarkable. I was wondering whether digital twins could be used in the two modes you described—both retrospective and real-time—along the entire product lifecycle.

Interviewee 8:55
Yes, yes. For new sites, we have installed anemometers in the tower and foundation to monitor turbine performance over time. For example, you might have a situation where something goes wrong with the controller, leading to accelerated fatigue that could prevent lifetime extension unless corrected.

Samuel Ziak 9:54
I see.

Interviewee 9:55
So yes, I agree with having it throughout the lifecycle.

Samuel Ziak 9:57
Cool.

Interviewee 9:58
That's the short answer.

Samuel Ziak 10:01
In this example, have you or your colleagues encountered any challenges related to data retrieval, interoperability, or other digital twin-related issues?

Interviewee 10:34
My biggest concern is that we have detailed information about the foundations because we design them ourselves, but for the turbines, we don't have detailed designs for components like blades. This limits our ability to evaluate how well the turbine is performing relative to design.

Samuel Ziak 11:01
Yes.

Interviewee 11:08
I expect that in a few years, we'll be able to build very precise models based on actual data and measurements, allowing us to simulate how the turbine should behave and detect deviations. For instance, if the turbine isn't aligned with the wind, we can react. Our biggest problem is getting detailed information on the turbine's design, assembly, and control.

Samuel Ziak 12:08
And that's because initially, years ago, this wasn't done?

Interviewee 12:15
No, it's more because the turbine manufacturers don't want to share what they've done.

Samuel Ziak 12:25
I see, OK.

Interviewee 12:27
Our biggest challenge is getting sufficient knowledge about the design because they just send it to an approver and tell us it was accepted.

Samuel Ziak 12:49
I understand. To be mindful of time, I'll proceed. Regarding stakeholders and roles, if I am part of the foundations team and you are my stakeholder, how would you position yourself? I've provided a short table—you could be a developer, managing operations, etc.

Interviewee 13:23
As a supplier or technology provider.

Samuel Ziak 13:26
OK. Can you clarify what you mean by supplier and technology provider?

Interviewee 13:29
Yes, it refers to the person or institution that develops the technology and keeps supplying it.

Samuel Ziak 13:39
I see. Which stakeholders do you think are the most important at this stage of digital twin development, considering the technology is relatively young in offshore wind?

Interviewee 14:16
Could you elaborate? I'm not sure I understand your question.

Samuel Ziak 14:18
Yes. Imagine I'm pitching the idea of digital twins for foundations or towers—who are the major stakeholders I should be aware of, approach, and pitch this idea to?

Interviewee 14:26
Yes, within our organization, we need funding internally from Vattenfall to get this going. The

main internal contributors are the foundation and wind turbine departments. Externally, I would look towards other project developers for potential partnerships.

Samuel Ziak 15:47
So, potential partnerships, if our organization has the knowledge?

Interviewee 15:50
Yes, a joint industry project or something similar.

Samuel Ziak 15:55
Brilliant. Let's switch to needs and values. First, what are your needs as a stakeholder that a digital twin can or will solve for you, particularly concerning monopiles or towers?

Interviewee 16:25
There are two main needs. First, with a real-time digital twin, we can prevent major incidents by detecting when conditions exceed design levels, allowing us to intervene. Second, we can better ensure the longest possible lifetime for the site.

Samuel Ziak 17:25
Which would probably impact other families as well, right?

Interviewee 17:25
Yes, it's strongly connected.

Samuel Ziak 17:33
There's a strong relation, I see. Switching to values, if you had to choose one, what is the biggest value derived from digital twins? It can be something we've mentioned or something new.

Interviewee 17:58
Extended lifetime, I would say.

Samuel Ziak 18:00
Would that be the top one?

Interviewee 18:02
Yes, the biggest one.

Samuel Ziak 18:05
And?

Interviewee 18:06
Remember, I'm only talking about offshore turbines.

Samuel Ziak 18:09
Of course, that's the scope.

Interviewee 18:09
If we were onshore, safety would also be an issue. But offshore, if we lose a blade, it just falls into the sea.

Samuel Ziak 18:20
Yes, we're speaking only about offshore. Are there any other values that could be important?

Interviewee 18:32
Minimizing OPEX costs—maintenance and operation costs—is also significant.

Samuel Ziak 18:40
Brilliant. Apart from the Horns Rev project you mentioned earlier, have you or your team applied digital twin technology in other projects or assets?

Interviewee 19:00
Yes, we used it for another site called Thanet, where we predicted blade failure due to fatigue, and it proved accurate. They are now retrofitting the blades to extend their lifetime.

Samuel Ziak 19:25
So, it was a proactive approach?

Interviewee 19:29
It started as a proactive approach to extend turbine life. But when we calculated it, we found the blades were overloaded. Digital twin analysis revealed that, leading to retrofitting the blades to keep operating. They're now planning to run for another 10 years.

Samuel Ziak 20:06
So, it was verified with inspections?

Interviewee 20:34
Yes, and the calculations proved right. Without it, we would have had to stop the turbines.

Samuel Ziak 20:49
That's really cool. Finally, regarding challenges, have you or your team faced any difficulties implementing digital twins into towers or foundations?

Interviewee 21:16
Yes, we get too little information from turbine manufacturers about their controllers and detailed designs.

Samuel Ziak 21:26
Would that include towers and blades?

Interviewee 21:38
Yes.

Samuel Ziak 21:39
Ideally, there should be more openness in sharing this information once we purchase the component, right?

Interviewee 21:42
Yes, they could anonymize the information so we can't use it against them but can use it for digital twin purposes.

Samuel Ziak 22:01
That's a great point—you're the first to mention this. I interviewed an external company, one of the O&M, who said they work on digital twins for blades.

Interviewee 22:15
Yes, and that also shows the main problem—blades have low safety margins, which is why they focus on them.

Samuel Ziak 22:43
Regarding the future, do you think the company developing digital twin technology should keep it proprietary or share it within the industry?

Interviewee 23:06
They should share it, at least with their customers, so we can use it.

Samuel Ziak 23:16
So, at least that?

Interviewee 23:19
Yes, and they should cooperate with us because we handle the foundations, and they can't do it alone.

Samuel Ziak 23:39
I see. Brilliant. I have no further questions. If you have anything else to add regarding digital twins, please do so now—it's your last chance.

Interviewee 23:49
No, I like it very much.

Samuel Ziak stopped transcription