D6.5

Use-case demonstration into O&M Platform

Communication, intelligent reporting & information visualisation

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List of Abbreviation

Abbreviation	Description
API	Application Programming Interface
AR	Augmented Reality
BIM	Building Information Modelling
BSI	British Standards Institution
CAD	Computer-Aided Design
CAPEX	Capital Expenditure
DT	Digital Twin
GIS	Geographic Information System
HSE	Health, Safety, Environment
ISPs	Individual Service Providers
KPIs	Key Performance Indicators
LiDAR	Light Detection and Ranging
LoD	Level of Detail
MDT	Mean Down Time
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
O&M	Operation & Maintenance
OPEX	Operational Expenditure
OFW	Offshore Wind
RDS-PP	Reference Designation System for Power Plants
ROSAP	Ramboll Offshore Structural Analysis Programs
SCADA	Supervisory Control and Data Acquisition
TDT	True Digital Twin
TSOs	Transmission System Operators
UNIDO	United Nations Industrial Development Organization
VR	Virtual Reality
VSL	(Ramboll's) Virtual Solutions Lab
WF	Wind Farm
WTG	Wind Turbine (Generator)

1 Executive Summary

This document summarizes the work on ROMEO Task 6.5 – Communication, intelligent reporting & information visualization (chapters 3 and 4) and collects information produced in the demonstration phase of the O&M platform (chapter 5).

For Uptime Engineering (Uptime), the work on Task 6.5 focussed on the development of communication, reporting and visualization technologies for the Uptime Solutions Information management platform. The outcome of these activities is a **powerful timeseries visualization tool for large time series which has been developed, implemented and successfully tested in multiple use cases**. For further visualization of generated Information such as KPIs, a standardized interface for the integration of external Business Intelligence tools has been developed and implemented.

Ramboll focussed on the demonstration of the Digital Twin visualization tool RamView360 for effective communication during the life cycle of offshore wind farms. The **presented demonstration of the visualization tool use cases is considered a generic showcase for covering different requirements of wind farm stakeholders** like wind farm owner (Iberdrola), WTG manufacturer, foundation designer, TSOs, external advisories/ government, independent service providers for O&M/construction etc. In this document, the Wikinger WF is considered as a reference site for the development of the digital twin 3D model. The scope of this digital twin 3D model is limited to the wind turbine foundation, while WTG sub-components as the gearbox, transformer, etc. are not considered due to the unavailability of the CAD models.

Under this project, a Wikinger WTG-64 is considered as a reference WTG and an exemplary DT 3D model of WTG is created. The foundation CAD model transformed into the 3D model via virtual reality software Unity [1] and 360° pictures were extracted as input for RamView360 to create DT 3D model. After creating the DT Model in RamView360, annotation points are mapped in the 3D environment to present the asset information, O&M tasks, documents, etc. In the ROMEO exemplary model, five annotation points are created (chapter 5.3) to show five different use-cases of RamView360. This finalized DT model will be incorporated within the RamView360 tool as a key deliverable. Then RamView360 tool will be linked with the Uptime Solutions information management platform developed by Uptime, to map the O&M tasks information into the DT 3D model of WTG. Through shared URLs, Uptime Solutions user can easily access the DT model into RamView360. This DT show the effective communication use case through the BIM approach. The key outcome of this exercise will be to develop a future concept for effective communication between different WF stakeholders through advanced visualization technology like Ramview360. This leads to improvement in communication transparency, HSE standards on site, workflow optimization and cost optimization. Further evaluation and testing of developed functionalities and use cases will be documented in the scope of ROMEO WP7.

2 Introduction

The O&M information management platform developed in WP6 is intended to provide several user interfaces and visualization functionalities for the communication of information generated by the platform components itself and information generated by the ROMEO analytics ecosystem. These user interfaces are developed by Ramboll and Uptime in task 6.5.

For Uptime the objective of task 6.5 is to develop suitable visualization and communication technologies for the information generated by the wider ROMEO analytics environment and by the analytics functionalities of the platform. This has been accomplished through a powerful timeseries visualization tool for large time series, which has been developed, implemented and successfully tested in multiple use cases. For further visualization of generated Information such as KPIs, a standardized interface for the integration of external Business Intelligence tools has been developed and implemented.

For Ramboll, the overall objective of task 6.5 is to develop a proof of concept for a lightweight visualization tool for effective communication between different WF stakeholders through advanced visualization technologies like Virtual Reality (VR)/ Augmented Reality (AR) as a final goal for effective communication and cost optimization. VR is likely to become a key changemaker in wind energy especially in the visualization of the windfarm digital twin model during the whole life cycle of wind farms from development to decommissioning phase. In this context, VR can be a powerful technological solution that deliverers a more realistic visualization model with interactive functionalities. Ramboll is actively working on the virtual reality business area to develop an advanced solution for the offshore industry. Ramboll is developing the RamView360 tool to visualize asset information data with 3D models of offshore wind turbine substructures. This initiative is part of Ramboll’s Virtual Solutions Lab (VSL) [2] to transform the way of working style through digitalization. The VSL provides an innovative working environment equipped with cutting-edge VR equipment.

3 Interface and visualization Technologies

The O&M Information management platform developed in ROMEO project is built as a web-based software which makes different types of data and information available for the user. The general goal of the platform is to provide relevant information for particular stakeholders in the O&M process, to support their work and facilitate decision making in this context. Different stakeholders in the O&M process will have different information need and will also require different ways of information provision and visualization needs. Therefore, in the scope of ROMEO Project several visualization and interface technologies have been developed to serve the needs of

- Management level decision makers
- O&M Experts and Engineers
- O&M Service technicians

For the three ROMEO demonstrator wind farms Wikinger, East Anglia and Teesside the following data / information types are provided to the above mentioned user groups:

- Time series data in multiple sampling intervals
- Event & Status Information
- Results of physical and statistical failure diagnostic & prognostic algorithms
- Health Status Information
- Aggregated key performance indicators
- Maintenance Advisory Statements and failure related O&M knowledge

3.1 Digital Twin Technologies

Visualization is one of the key aspects of True Digital Twin technologies. This represents how a user can easily interact with the tool to find specific information. There are many different visualization tools available in the market, but it is necessary to choose the right tool according to specific applications. The main challenge of visualization tools is to identify the ideal scope for specific applications during the life cycle of the wind farm. The application of visualization tools can be different according to user requirements. Therefore, it is requisite to identify the best ideas/concepts to implement them effectively for the wind energy sector. This research demonstrated the overview of use cases of the visualization tool RamView360 in offshore wind industry according to different WF stakeholders. An exemplary digital twin model of the Wikinger WTG is created in RamView360 to demonstrate as a proof of concept model.

3.1.1 Solution: Ramboll's True Digital Twin Technology

Digital twin technology is the novel approach to create a digital copy of the real assets, which can be used to update the numerical mode, visualize and monitor the asset condition, and to maintain it over an entire lifecycle by simulating in close to real-time based on monitoring data. In the wind industry, digital twins can be beneficial in many areas for example the asset information system, O&M optimization, structure health monitoring, risk assessment, maintenance planning, etc. Ramboll has developed its digital twin technologies to create a digital copy of offshore wind assets: it is called *"True Digital Twin"* [3]. The digital twin visualization tool RamView360 developed under the ROMEO project aims to further improve the understanding of offshore wind farm assets.

3.1.2 Baseline Assumptions

In this research project, there is some limitation on the scope of the digital twin model assumed before starting the research work. Baseline assumptions for the executed work are:

- The research work is focused on offshore wind industry use-cases.
- The scope of the RamView360 demo version is limited to the WTG foundation model. While WTG sub-components (e.g. Gearbox, transformer, etc.) and substation models are not considered due to unavailability of detailed CAD/3D models.

- The Wikinger wind farm is considered as a reference wind farm and WTG–64 is considered as the reference WTG for the proof of concept model.
- The demo case-study is concentrated use-cases in the O&M phase after construction and commissioning.
- Only visualization aspect is considered in the demo model from DT enable technologies.
- No high-level technical simulation or algorithmic analysis is involved in the demo version of RamView360.
- Due to lack of data availability, no SCADA/sensor data are considered.

3.2 Digital Twin Concept

This section provides a general introduction to the Digital Twin Concept. The research starting in Section 3.2.2 is only focused on the visualization of the digital twin model with the representation of integrated data. It gives a detailed description of the RamView360 tool in combination with virtual reality.

The Digital Twin concept was firstly introduced by Dr Michael Grieves in 2002. He describes that the digital twin is not just a digital model of the physical system, but it contains valuable information about the physical system like functionalities, behaviour in different conditions, technical specifications, etc. that makes the digital twin more valuable than just a 3D model. As he defined the digital twin concept in his paper [5] as follows:

> *"Digital Twin (DT) – the Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin."*

The DT concept might differ as per the use case and requirements from the user. For better understanding, a simplification of the concept is applied. An example of the DT concept is shown in Figure 1. The digital world is a digital copy of the physical world. The digital world can be used as a reference model to simulate the different scenarios or problems of the physical world as input data. The iterative learning process helps to implement different scenarios in the digital world and finds the best suitable output. The outcomes of the simulation process give us information on recommendations or implementation needed to improve the physical world. E.g., if we want to predict the effect of temperature due to climate change, then we need to implement real scenarios on the digital world model. This digital world model simulates different scenarios through iterative learning loop and predicts the most suitable scenario as an output. As an exemplary output, we receive recommendations on how much CO_2 emission we need to reduce. Those recommendations can then be implemented in the real world to mitigate the future temperature rise.

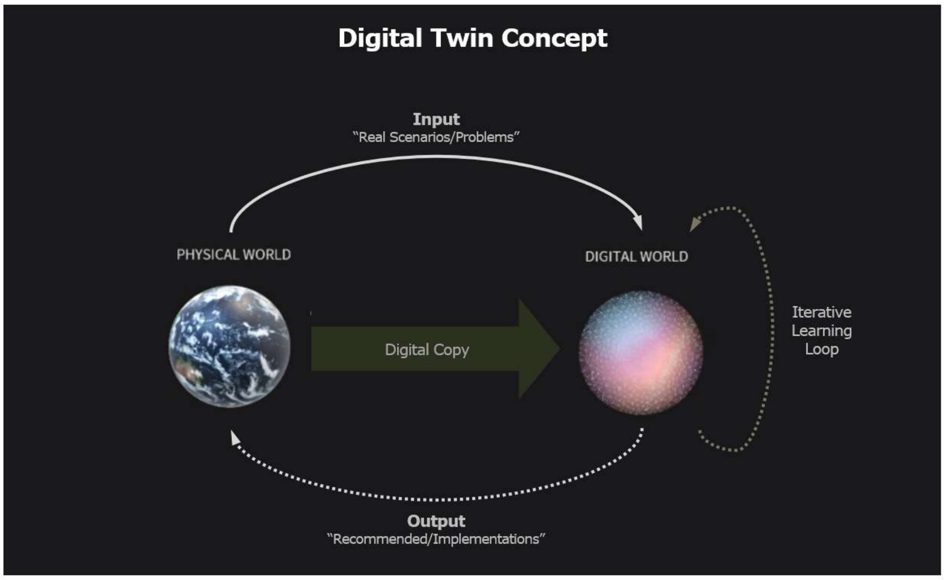


Figure 1 Digital Twin concept example

A similar example is also mentioned by Wang, Z. [6], that data as input and information as output can be shared between real and virtual models. The feedback loop helps to improve the digital model continuously. It is requisite to define the level of detail of the DT model as per requirements from users. DT model can be set up by a corresponding virtual model for specific industrial use-cases like in production facility, workshop application, factory lines, manufacturing resources, complex equipment monitoring like jet engines, wind turbine structure, bridges, buildings, etc. [7]

The research paper by Haag, A. [8], shows that the digital twin concept can be implemented with any system in the world, from simple systems to more complex systems. He mentions that the communication channel like web-based interactive software can be a key to monitor the digital twin system effectively. This communication channel provides effective information to the user by 3D model visualization with integrated asset data. This type of advanced technology is already introduced in the next industrial revolution called Industry 4.0. As described by Akulenko, E.; et.al. [9] the DT concept is getting more recognized in the industry since the last decade. This leads to increase utilization of the DT concept in emerging industries like wind energy. Ramboll is also making an impact as the key developer of digital twin solutions for wind energy industry partners.

3.2.1 Visualization of Digital Twin Model

Balakrishnan, S.; et. al. [10] describes that the digital twin is the cutting-edge technology of the new era of the 4th industrial revolution. The digital twin is the concept to create a detailed digital representation of the system to optimize the behaviour of the system/assets by applying the real-time environment scenarios through sensors. The digital twin concept is the combination of different DT enabling technologies such as the Internet of Things (IoT), cloud computing, data analytics, artificial intelligence, simulation modelling, 3D visualization, etc. These technologies help to create a robust digital twin concept as per requirement from the user. As the cost of sensors and computing hardware is reducing constantly, the total costs for DTs also reduced drastically in past years.

Revathi, A.R.; et. al. [11] describe that visualization is a graphical approach to represent a digital copy of the physical asset or the system. Visualization of the 3D model is the first step toward the establishment of a digital twin model. Visualization is the central piece of the DT concept because it presents the information that is valuable for the user while interacting with other DT enabling technologies. DT models can be classified according to the level of detail of information/data. As mentioned by Umamaheswari, R.; et. al. [12] DTs can be defined from the highest to the lowest hierarchy e.g. from system level to component level. He also gives an overview of how DT enabling technologies like IoT, simulation, etc. places a key role to make the DT model more robust and realistic.

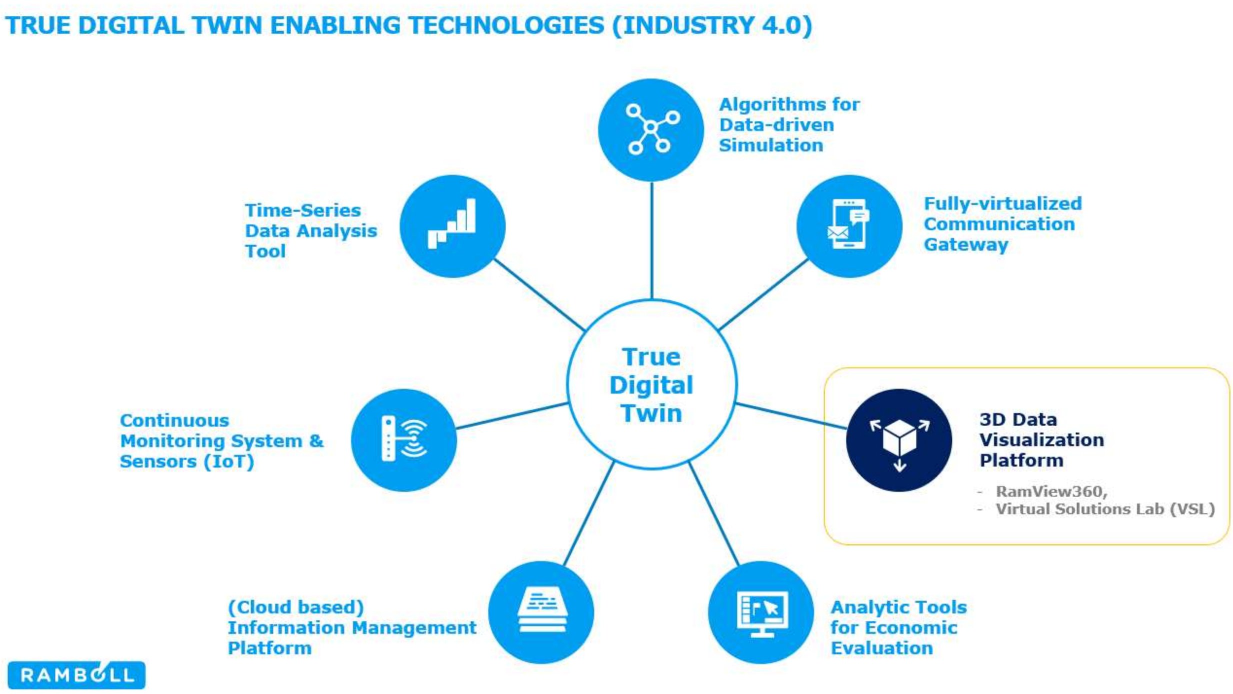


Figure 2 True Digital Twin Enabling Technology (Industry 4.0)

Figure 2 shows the list of key digital twin enabling technologies. These technologies help to create a digital twin environment to support activities in the wind energy industry. Each technology can be derived as per the use-case and level of integration needed with the DT environment. The detailed description of seven key DT enabling technologies are mentioned below:

1. **Analytic tools for Economic Evaluation:**
   A series of tools that help to calculate and analyse the economic KPIs as per the requirement, e.g. CAPEX/OPEX tools, spare parts management tools, etc.

2. **Information Management Platform:**
   An information management platform helps to store and maintain the data related to the DT model. Cloud-based technology has proven as an effective solution to share data with IoT systems compared to traditional solutions. The data streams are continuous (real-time sensor data) or static (maintenance manuals, O&M planner, graphs, etc.).

3. **Continuous Monitoring System & Sensors (IoT):**
   Monitoring system and sensors need to be mounted on the physical asset. It provides information about the current state and behaviour of the physical asset. Through continuous monitoring and sensor system, the digital twin model can quickly implement those behaviours of the physical asset. This Monitoring system & sensors measures system behaviour in the time-series format then it is visualized through a data analysis tool.

4. **Time-series Data Analysis Tool:**
   Time-series data analysis tool helps to visualize and evaluate the time-series dataset generated by the monitoring system and sensors. This tool analyses those sensor datasets and finds any anomaly on system behaviour. If there is any anomaly detected, then it warns the user to review this behaviour of the system. This tool can also generate graphs of specific KPIs e.g. structure displacement, oil temperature of WTG gearbox, etc. versus date & time stamp.

5. **Algorithms for Data-driven Simulation:**
   Computer algorithms can simulate the complex problem of the digital twin system. Algorithms are the predefined finite sequence of computer-implemented instructions to solve the computational problem. Sensor data can be used as input for algorithms to predict the system behaviour.

6. **Fully virtualized Communication Gateway:**
   The communication gateway allows the platform to connect and share data remotely with other users. As communication technology is advancing, the system has become more reliable and faster. It can be used for any remote site/offshore activities in the wind industry. Thus, fully virtualized communication allows end-to-end live streaming between technicians on-site and experts in the office.

7. **3D Data Visualization Platform:**
   This tool is used to visualize the digital twin model in a 3D view with overlaid information such as numeric values, KPIs, graphs, tables, etc. Ramboll has developed a web-based DT visualization tool named “RamView360”. All types of digital twin models can be viewed through the Ramview360 tool. This tool is compatible with any VR devices or VSL equipment.

3.2.2 What is VR?

Virtual Reality (VR) is the technology to visualize the 3D/CAD model into a simulated environment with interactive user functionalities. Compared to the traditional 3D visualization on screens in front of the user, VR Solution places the user inside an interactive virtual environment with a digital blueprint of the real wind turbine and wind farm. RamView360 tool is also compatible with VR glasses, refer to Figure 3. Offshore environment conditions can be simulated in VR to mimic the real scenario. Those scenarios can be helpful to understand all local aspects in-depth which can affect the operation of the wind farm. Any high-level work/process simulation can be performed through the virtual solutions lab (VSL). For example, technicians can pre-train in VSL to identify the level of risk during the construction phase or O&M activities.

Figure 3 VR glasses example

VR is not an entirely new technology; it has existed since the late 1960s. But it highly depends on specific market conditions, requirements, and maturity level to accept this technology. According to the United Nations Industrial Development Organization (UNIDO) report, the wind market is entering the 4th industry revolution [4]. In which VR is one of the next cutting-edge technologies that could solve the current challenges of wind energy production. According to market reports, the market for VR applications will be doubled in the next five years. VR technology is proven to be a game-changer for the offshore wind industry to optimize the workflow of the technician as well as improve the HSE level through pre-training in VR simulation.

3.2.3 Virtual Solutions Lab (VSL)

Virtual Solutions Lab is helping to improve the performance of technicians through VR based pretraining for offshore wind energy. The main purpose of the VSL is to visualize the digital twin model of the wind turbine in a virtual environment through VR devices and perform a pretraining course in a VR simulator. e.g. optimization of O&M workflow, HSE pre-training, structure degradation model, the design review process, etc.

ROMEO's goal on VSL is to develop a new VR solution to visualize the complex offshore wind turbine structures more realistic and interactive way during the design phase and in-service. VR models can be proven as an advanced communication solution with stakeholders as project deliverables as well as a "new way of working" during team and client meetings, workshops, etc.

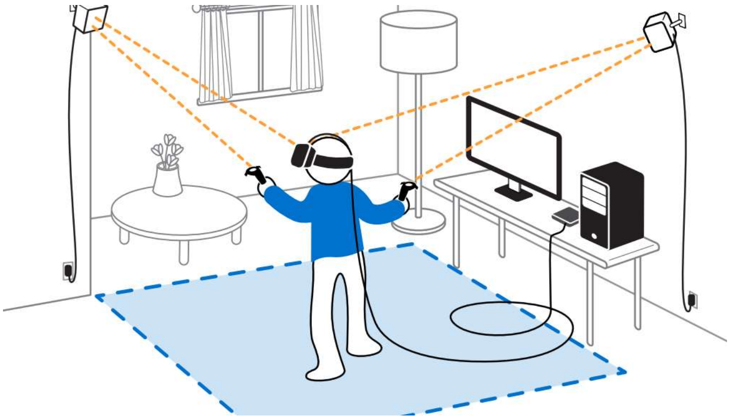


Figure 4 Virtual Solution Lab (VSL) concept

The three main parts of the VSL equipment consist of VR glasses, high-end computer and a projection screen as shown in Figure 4. VSL equipment varies according to the use-case and requirements of users. The basic characteristics of VSL hardware & software should be user-friendly, flexible and widely renowned in the VR industry. They should also fulfil the minimum technical requirements, e.g. number of users that can access the license at a time, frequency of new software versions, access to supporting toolkits, etc. More detail on Ramboll's Virtual Solutions Lab concept can be found in [13].

4 Implementation of Visualization Technologies

4.1 Uptime Solutions Visualization

Modern wind turbines are typically equipped with a variety of sensors producing time series data in different sampling frequencies from high resolution data like vibration signals for condition monitoring to 10min averaged SCADA data. For O&M Engineers it is of great interest to have easy access to this time series data in order to perform monitoring tasks, detect abnormal behavior or investigate failures.

For this purpose, a time series data visualization tool (Figure 5) has been developed and implemented in Uptime Solutions. General requirements for the developed functionality were:

- Asset selection functionality
- Time series channel selection functionality
- Time range selection functionality

- Aggregation functionality, zoom in and out
- Download of aggregated Data

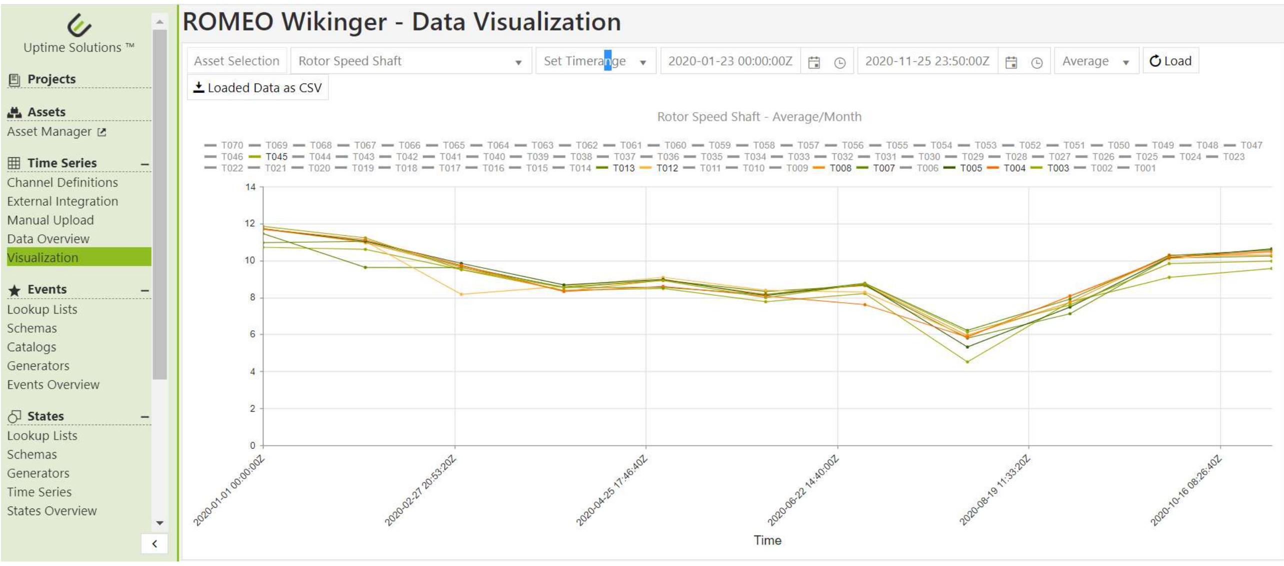


Figure 5: Uptime Solutions Time Series visualization

A typical use case for the visualization tool is to investigate the characteristics of a particular time series data channel over a certain period of time and across multiple turbines. In this case the user would first select the turbines and time series channel under investigation. In a next step the user can specify the time range by either selecting the total available time range or specifying start and end time stamps for investigation. Especially in the case of large time ranges or high sampling frequencies large numbers of data points need to be visualized. Therefore, the system aggregates the available data points to a suitable level in order to produce clear picture. By choosing a smaller time range the tool will automatically adapt the aggregation level up to original sampling frequency. Hereby, the aggregation method (average, min, max) can be selected by the user.

4.1.1 State & Event Information

As described in detail in D6.4, the determination of many Key Performance indicators such as availability or MTTF rely on the determination of process and system status information as a basis for analysis. In most cases the status of a system or system component is determined by the occurrence of Events. This principle is depicted in Figure 6.

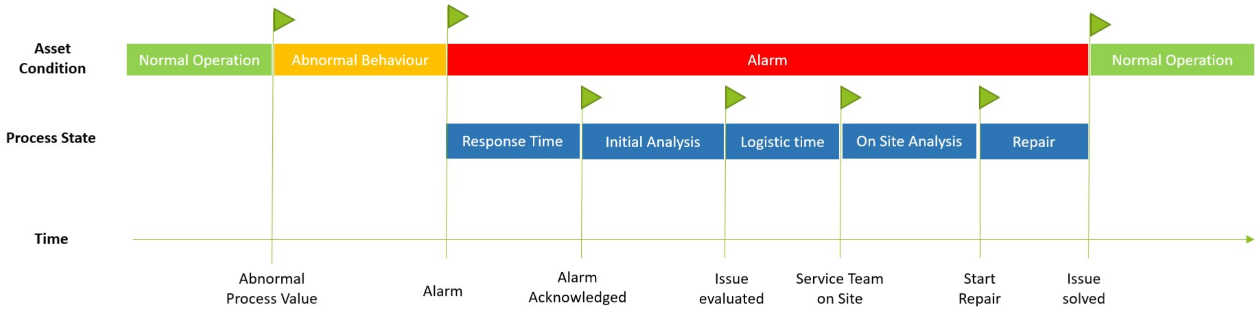


Figure 6: System and Process States&Events

Besides the functionalities which determine the generation of States & Events, Uptime Solutions provides an *Event Overview* (Figure 7) and a *State Overview* (Figure 8). Both provide several filtering and sorting option which enable the user to filter by instance (e.g. Turbine) source of Event, Event / State type and timestamp. In this way events and resulting system or process states can be easily accessed, analysed and manipulated.

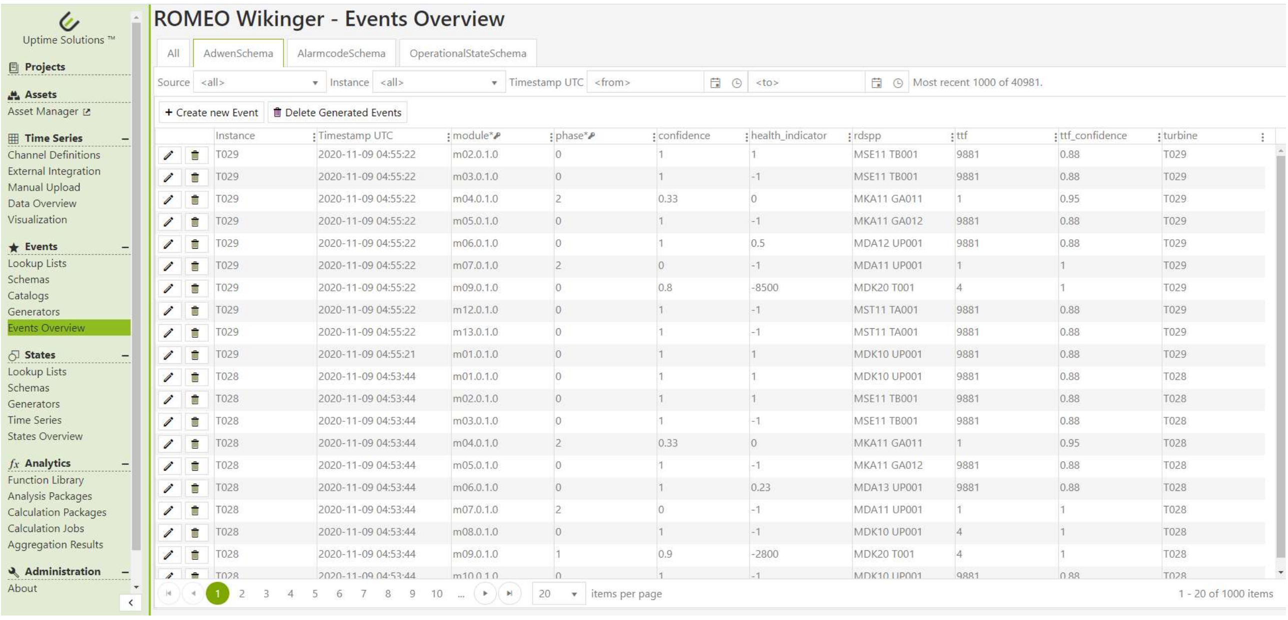


Figure 7: Uptime Solutions Events Overview

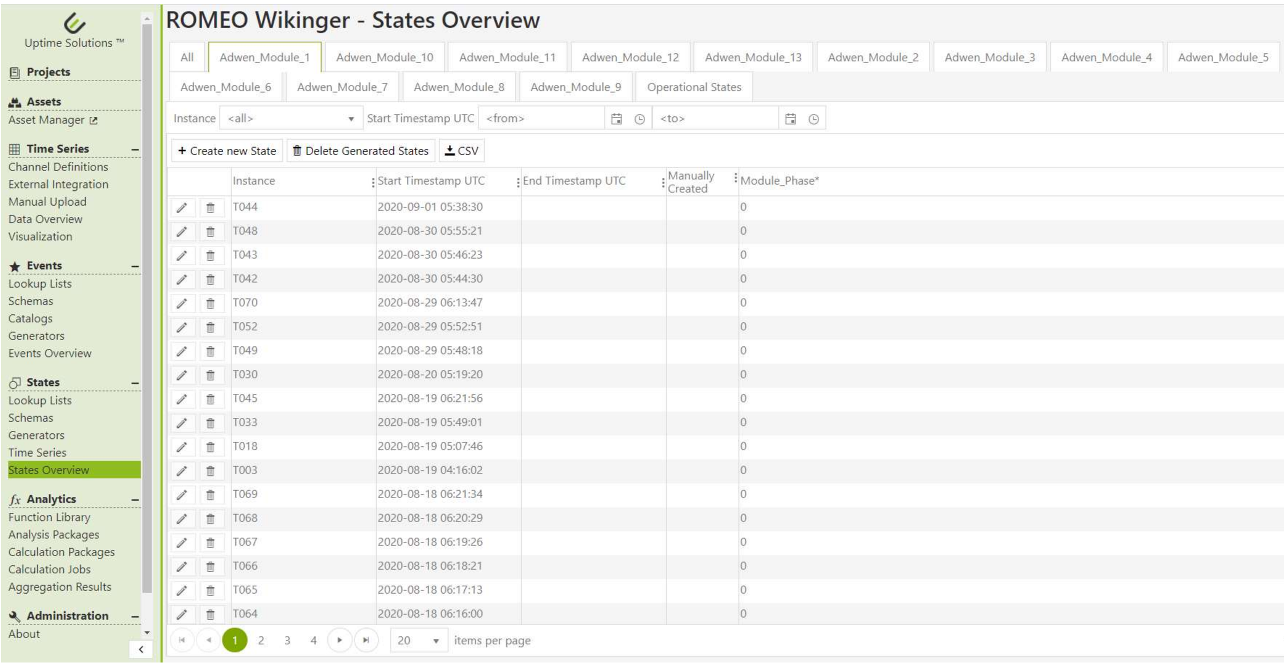


Figure 8: Uptime Solutions State Overview

As an additional interface Uptime Solutions provides a functionality which generates standardized timeseries data representations of the generated system or process states. These timeseries can either be used for calculation within the software or be directly downloaded for use in external visualization, analysis or reporting tools.

4.1.2 Advisory Statements – Interface to WO Management

As described in D6.4, Uptime-Solution includes a functionality which provide maintenance advisory statements in the form of initial diagnosis statements and further maintenance related information. The functional focus of Uptime Solutions is on the integration of multiple information sources and the generation of insights for the maintenance process. The organization of the maintenance process in terms of workorder management needs to be realized by a specialized workorder management tool. In order to integrate workorder management tools efficiently in the overall O&M process an interface concept has been developed. This concept is depicted in Figure 9.

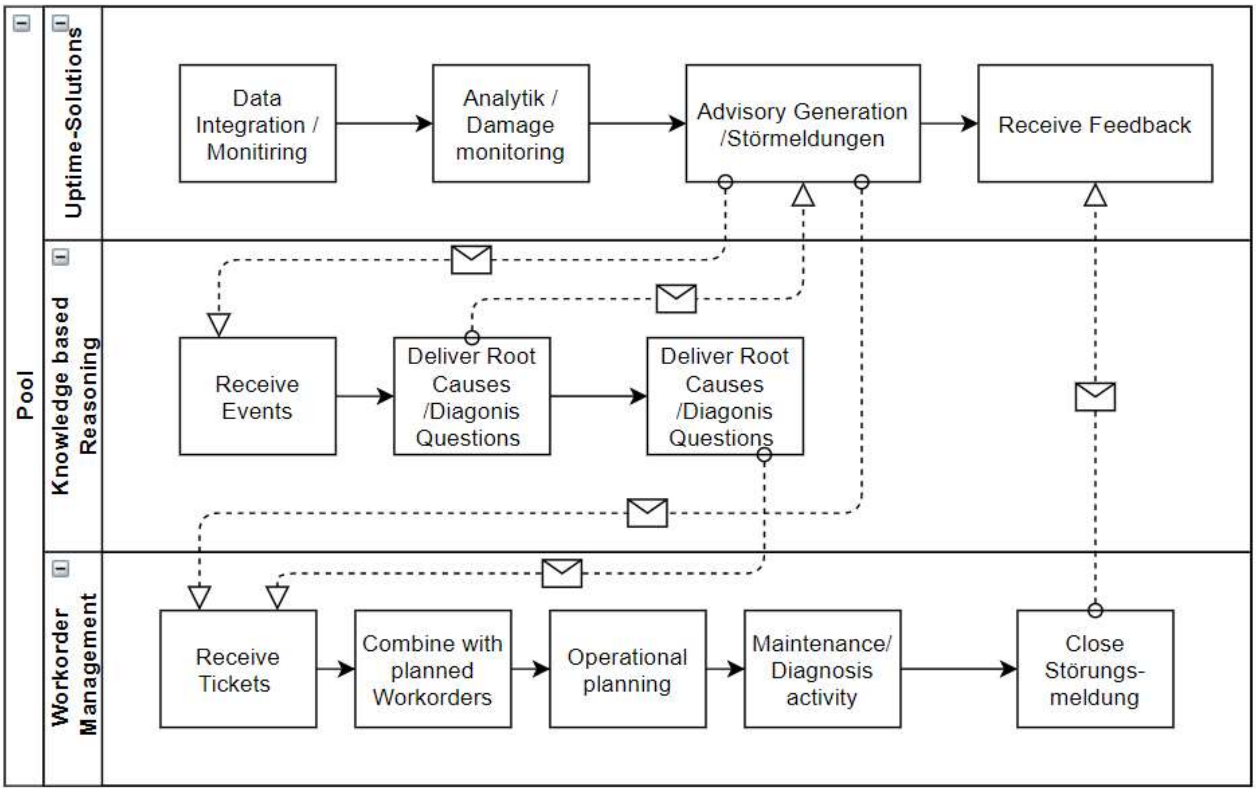


Figure 9: Uptime Solutions Interface to Workorder Management

While the analytics and monitoring as well as the communication between reasoning logic and Uptime Knowledge base takes place within Uptime Solutions, generated advisory statements are handed over in the form of standardized tickets. These tickets are integrated processed in the work order management process. A standardized way of feeding back information on the accuracy of the generated advisory statements is vital for the continuous improvement of the system.

4.1.3 Reporting Technologies

Reporting functionalities aim to provide relevant and concise information on the performance and the health status of the monitored assets on a regular basis. Typical addresses of periodic reports are site supervisors, asset managers and O&M experts. Typically, operators do have a reporting system in place which does not only include technical information but also other asset management related information like realized revenues or other performance metrics. Therefore, the developed O&M management platform does not aim at providing a standalone reporting system which is separated from other already existing reporting standards within a company. The intention of the developed reporting functionality is to provide an interface to existing business intelligence and reporting tools and to provide guidance in integrating the information provided by the O&M information management platform.

In ROMEO project an interface to the business intelligence tool Power BI has been developed and a variety of informations for different stakeholders in the O&M process has been included. The generated reports are described in chapter 5 for Wikinger demonstrator wind farm.

4.2 Ramboll Digital Twin

4.2.1 RamView360

RamView360 is a web-based visualizing tool for the digital twin model of the system and it is developed by Ramboll. RamView360 provides a 360-degree view from the specified viewing location in the 3D environment. This tool gives a wide range of functions to visualize the DT model as per user requirements e.g. BIM visualizer, CFD simulation model, CAD model and point cloud model generated from LiDAR scanning. (LiDAR is a remote sensing method that uses laser light in the form of a pulsed laser to scan the physical object and generates a point-cloud model of the object.) RamView360 uses 360-degree photos from detailed 3D modelling software or point-cloud dataset from the LiDAR scanner. RamView360 uses the BIM method to represent the 3D model with overlaid technical information like component's RDS-PP code, MTBF, MTTR, documents O&M manuals, HSE guideline file, weather data, water depth and temperature measured by sensors, etc. The detailed overview of the BIM method in RamView360 is mentioned in Chapter 4.2.3. The BIM approach provides user-friendly navigation to find specific information in the Digital Twin model.

Ramview360 tool is easily operated through any web-browser on a computer/tablet/phone (refer to Appendix A). No additional plug-in or software installation is needed. Due to its low bandwidth data requirement, the DT model can swiftly load and operates very fast compared to traditional comparable software. RamView360 is also compatible with VR glasses or VR cardboard [28] setup (a mobile enable VR glasses made from paper/box material). RamView360 model can easily be shared through the URL sharing function available from the quick access panel in the tool. RamView360 can also communicate data through software API connection with Ramboll's internal web interface and/or any external software applications. RamView360 can be configured as per the customers' requirements. A screenshot of the RamView360 user panel with an example boiler room CFD model is shown in Figure 10. For more information and examples can be found on RamView360's official webpage [14].

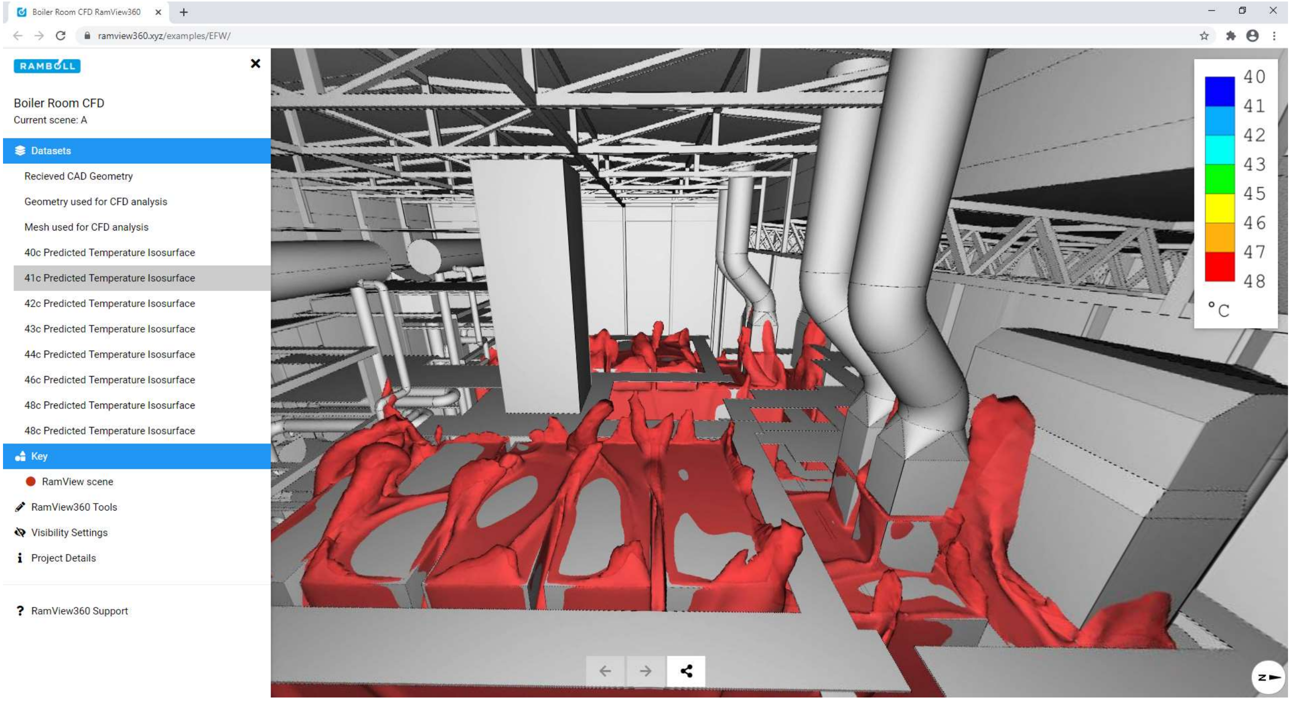


Figure 10 RamView360 example Boiler Room CFD [13]

4.2.2 Features of RamView360 Tool

The RamView360 tool has a wide range of functionalities to visualize the digital twin model in a 3D environment with overlaid informational data. Those functionalities can be implemented for offshore wind turbines and are demonstrated in chapter 3.2.1. Users can interact with RamView360 tool through different user-interaction platforms like office computer devices, remote tablet/smartphone and VR glasses in VSL.

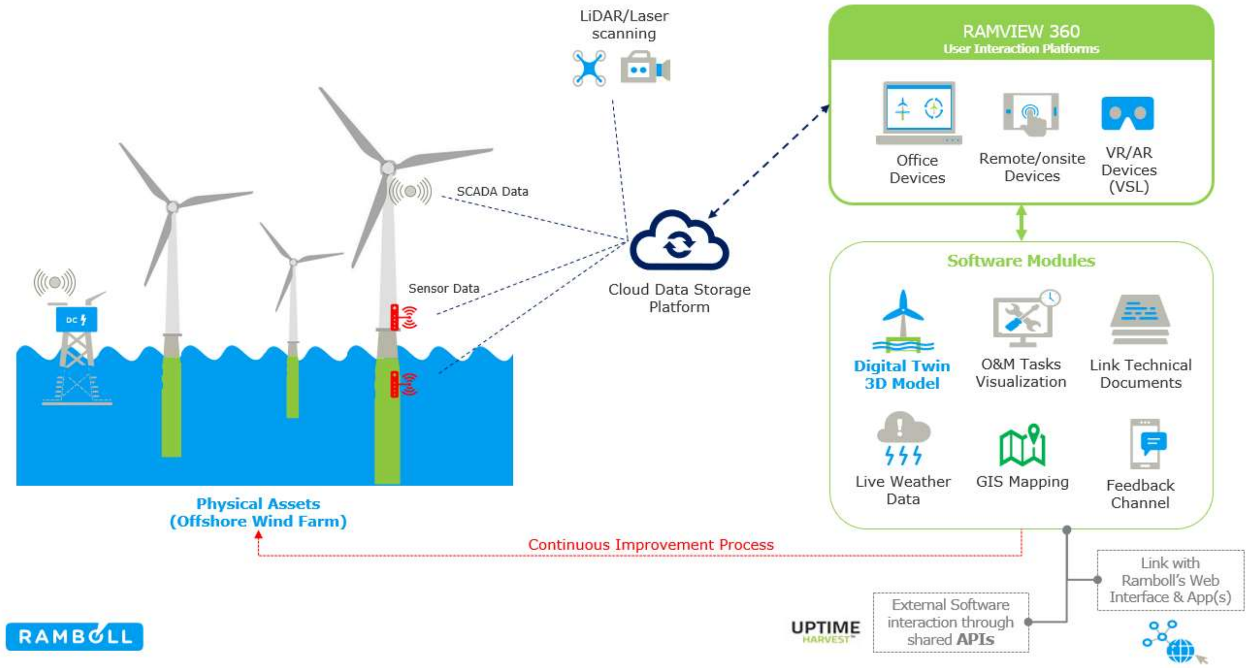


Figure 11 Feature of RamView360 Tool

Ramview360 has six basic integrated software modules to establish the generic function of the tool. Additional software modules can be integrated into RamView360 tool according to user specification & requirement. The detailed description of those six modules are as following:

- **Digital Twin 3D Model:** This module helps to create digital twin model in a 3D environment. It uses 360-degree photos as an input and creates a walkthrough virtual environment to visualize the digital copy of physical assets.
- **O&M Tasks Visualization:** This module is used to visualize the list of O&M tasks and the status of each specific WTG component. This module can import data from external maintenance management software and integrates it into the digital twin 3D model.
- **Link Technical Documents:** Through this module, the user can easily link technical documents with the specific component of the digital twin model. This function can be helpful for the user to find a specific document more efficiently.
- **Live Weather Data:** Weather module gives live update information of the wind and wave data of the wind farm site. This module imports real-time weather data from integrated weather forecasting platforms like Windly [29] or data from on-site weather stations.
- **GIS Mapping:** Global Information System mapping is used to map the location of the assets. This technology allows linking different data points with the geographical location. E.g. soil modelling, water depth for each WTG, etc.

- **Feedback Channel:** This channel provides the end-to-end communication between technician and expert by providing a comment and image capture functionality.

Physical assets of the offshore wind farm can be mapped with the use of LiDAR/laser scanning technology, if the detailed CAD model is unavailable. As shown in Figure 11, LiDAR/Laser scanning generates the point cloud data, which will convert into a 3D model for digital twin technology after processing. A cloud-based data storage platform is used to store collected data from scanning, sensors, etc. for RamView360. This storage platform is the backbone of the RamView360 software modules. Sensor technology is used to continuously monitor the behaviour of the physical assets and implement those scenarios into the Digital Twin model. SCADA statistics can be linked with RamView360 as per use case. This data can help the user to visualize specific KPIs with integrated 3D Digital Twin model and customized RamView360 panels. A continuous improvement process is established to enhance the smooth operation and health of the assets. With the use of API connections, RamView360 can be easily interlinked with Ramboll's web interface (a web-based interface to connect Ramboll's internal software applications) and/or any external software platform like Uptime Harvest (refer to Chapter 5). Due to the advanced functionalities of the RamView360 tool, it has a high potential to implement Digital Twin concepts for wind energy assets.

4.2.3 Demonstration of BIM method for RamView360

In this section, a detailed description of the building information modelling (BIM) approach is provided. This approach assists to derive Digital Twin model for the RamView360 tool. BIM is widely accepted in many industries like civil engineering, plant technology, architecture, energy sector, railway construction, etc. BIM ensures key changes in modern industries, transforming their approach to maintain and operate assets more digitally.

4.2.4 What is BIM?

BIM (**B**uilding **I**nformation **M**odelling) is a process for generating and operating the digital 3D model with overlaid information of a physical asset/system. According to the ISO 19650 standard described in the British Standards Institution (BSI), BIM can be defined as the following:

> "*Building information modelling (BIM) is about getting benefit through better specification and delivery of just the right amount of information concerning the design, construction, operation and maintenance of buildings and infrastructure, using appropriate technologies.*" [15]

In simple terms, BIM is an approach to present assets information integrated with the 3D visualization model. A BIM example is shown in Figure 12. This figure shows how BIM models are different from generic 2D or 3D CAD models. 2D models are a traditional way of working on paper-based communication, where the 3D model provides more user interactive functionalities. While BIM model display more sophisticated 3D model with overlaid asset information. So, that user can easily access and track information with BIM model than traditional 2D and 3D modelling. This BIM approach can be used to generate a Digital Twin model.

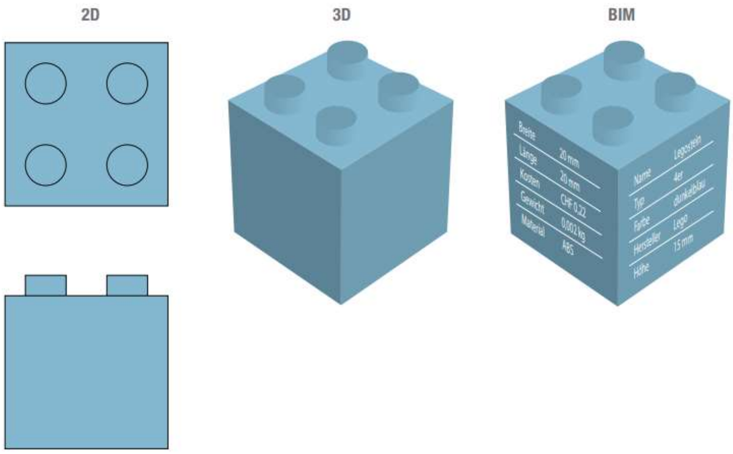


Figure 12 The Lego analogy: from 2D CAD to object-oriented Modelling with BIM [16]

As mentioned by Zita Sampaio, A. [17] that BIM methodology can be implemented with VR to visualize the Digital Twin model on a more realistic scale. The 4D level BIM model provides the visual stimulation of the building simulation or workflow process. This simulation process can be used with VR to observe the real work planning approach. Advanced BIM model incorporates information data like economical evaluation, material requirement, sustainability studies, maintenance activities, etc. The BIM model is compatible to be used during all phases of the asset life cycle from development, commissioning & Installation, operation until the decommissioning phase.

4.2.5 Current state of BIM visualization in the offshore Wind Industry

BIM visualization is prevalent in the building and construction industry due to the complexity of service providers and contractors in the same projects. The BIM methodology is new to the wind energy sector, having a higher potential to solve several challenges in the wind industry.

As mentioned by Johansson, M. [18], a real-time rendering process can reduce the time to generate and update the BIM model. This allows the offshore wind industry to visualize DT model effectively. Currently, OFW industry uses file-based collaboration like 2D CAD drawings, documents, datasheet and in some cases 3D models to share asset information. This process can be improved with the use of BIM methodology to collect, store & share information between stakeholders.

BIM application can be extended for the life cycle management of the offshore wind farm. Jia, J.; et. al.; [19] describe that BIM application frameworks can allow optimizing the workflow in the virtual environment with the implementation of real scenarios, which lead to an improvement in safety standard, cost optimization, automatic monitoring, better decision-making process, etc. Thus, BIM implementation can digitalize the working process and establish a fully digital system.

4.2.6 Advantages of BIM in the offshore wind industry

Early adoption of BIM methodology is beneficial for organisations to overcome hidden problems by tracking high-level data usability. BIM can be implemented from the beginning of the development phase until the decommissioning phase of an offshore wind farm. Advantages that can be implemented in OFW industries are listed below:

- Better 3D visualization with integrated GIS mapping function (chapter 4.2.2),
- During the construction phase, material & logistic planning can be optimized,
- Support of O&M activities like structure monitoring, O&M workflow optimization, maintenance training [20],
- Efficient document management system with integrated 3D model,
- Simple data sharing between different stakeholder or service providers,
- Real-time data update in the DT model,
- Easy tracking of the KPIs with the integrated 3D model environment,
- Pre-training in VSL to improve the HSE standard on-site,
- Optimization of material required during the manufacturing of WTG components or fabrication of the foundation structure [21].

As mentioned in BSI standard PAS:1192-3 [22] that the principal advantage of BIM is to collect and utilize the asset data throughout the life cycle of the asset. But the O&M phase has the highest potential economic saving compared to other phases, especially in the offshore wind industry. Because OFW assets typically have a longer (average 25 years) lifespan and high OPEX to CAPEX ratio proportion than other industry application. Therefore O&M task can be optimized through high-value data and a better understanding of how assets are behaving.

4.2.7 Hierarchy of BIM Users

The BIM pyramid is shown in Figure 13. It gives an overview of the level of information involved during the visualization of the BIM model according to the type of user/authors. On the lowest level of the system, information users have a right to only view and review the model. These users can provide comments and approval of specific tasks.

Figure 13 The BIM Pyramid [23]

At mid-level of the pyramid, process model authors are responsible to update the information of schedule management, cost estimation, maintenance tasks, logistic requirements, safety standards, etc. in the BIM model. This information will be resented on lower level visualization as per the user requirements.

At the top of the pyramid physical model authors are involved to update the component-specific information like 3D models, layout, technical information, geometry, etc. This BIM pyramid help to define the level of information need by each user.

4.2.8 Maturity Levels of BIM

BIM model can be classified according to the level of detail it contained. The maturity level is defined from level 0 to 3 because it shows the type of technical and collaborative working processes, tools and technologies to be used. The BIM maturity level is firstly introduced by the British Standard Institute (BSI) in PAS 1192-3:2014 standard report [22] for asset information management of building & infrastructure projects. But this can be also implemented on OFW assets. Figure 14 shows the generic graph of BIM maturity levels. These maturity levels are defined as the following:

- **Level 0:** This is the basic level to exchange assets information between project stakeholders. All the paper-based unmanaged tools like 2D CAD drawings, text documents, tabular form, etc. can be shared through a tool.
- **Level 1:** At this maturity level, most of the documents are properly managed with a digital copy. Information is transferred through 2D CAD digital drawings, 3D Modelling software, etc., with some standard data structure. This data structure platform supports file-based collaboration without any library management software. This level follows the standards like CPIC (Construction Project Information Committee), Avanti, etc.

- **Level 2:** In this maturity level all documents formats are managed through the library management platform and information stored in as the 3D model with integrated information model BIMs. BIM models can be further classified as AIM (asset information model), SIM (Structure Information Model), etc. according to their application. This level follows primarily the BIS 1192:2007 and CPIC, Avanti standards as secondary guideline standards.
- **Level 3:** This is the advanced level of BIM with integrated web services. iBIM can be integrated with any external or internal software platform through a BIM Hub. This level follows ISO BIM standards. Scope of Level 3 BIM model can be extended to the whole lifecycle of the assets.

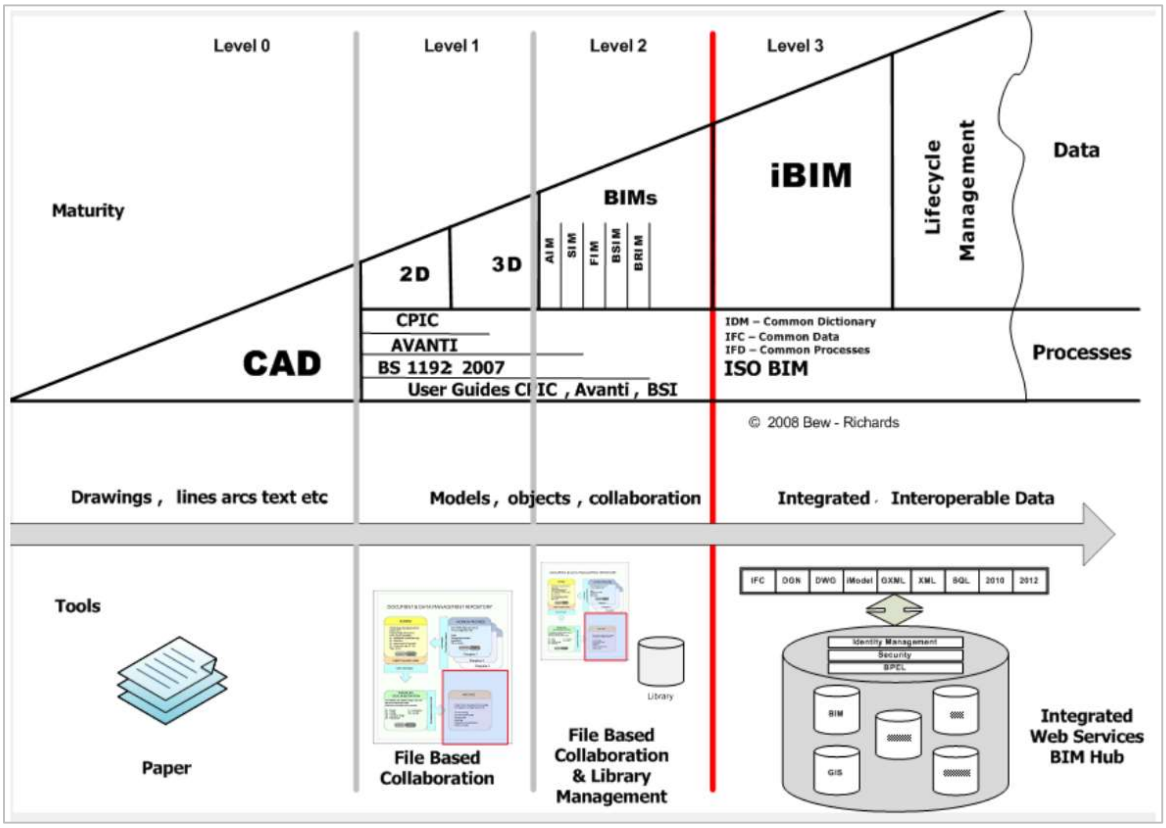


Figure 14 Level of BIM [24]

At the moment the OFW industry is following Level 1 guideline to exchange the information, where the building & architecture industry has achieved level 2/3 maturity. With the help of RamView360, OFW industry can be improved to level 2 and further develop to achieve level 3 maturity by following BIM methodology. This BIM maturity level can be used as a reference to define the level of detail of the Digital Twin model.

4.2.9 Level of Detail (LoD) of Digital Twin Model

To identify the development approach of the DT model, it is necessary to specify the different levels of detail in development activities. As shown in Figure 15, different levels of DT model are mentioned concerning the maturity level of the user/developer (green boxes). This project considers that the maturity level of users/developers is a beginner level, which will improve step-by-step with development activities. The final goal of this development exercise is to achieve the "Best in Class Solution – RamView360" for the DT model.

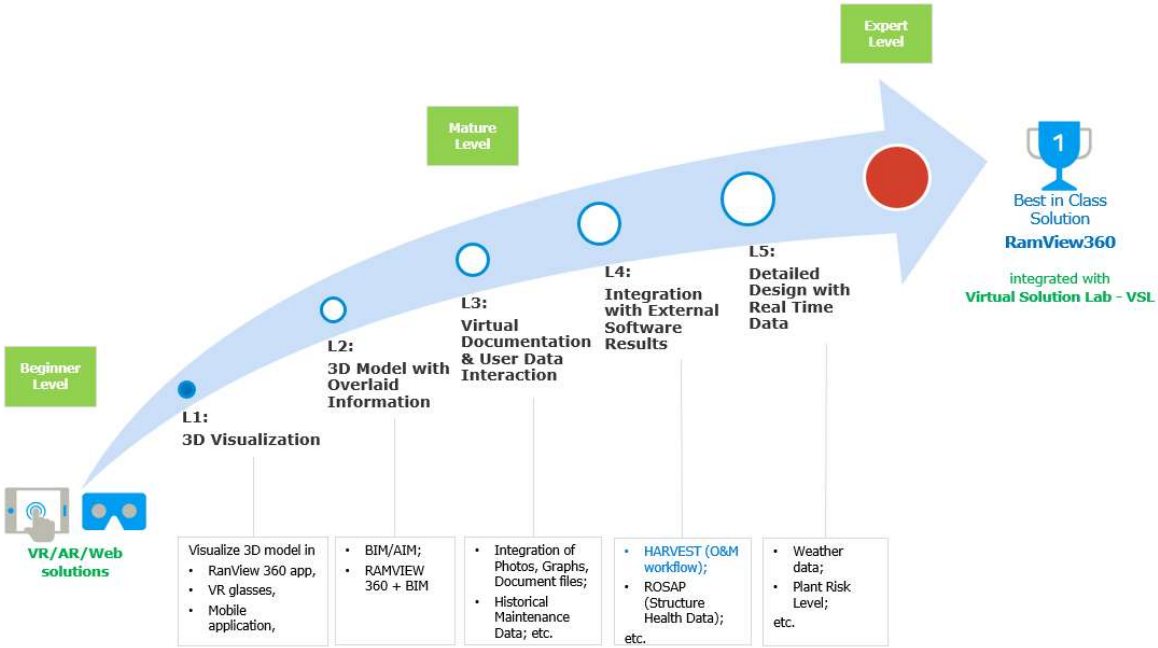


Figure 15. Levels of detail of the digital twin model

Level L1 is considered as a beginner level of the development cycle. The first step of development is to visualize the 3D exemplary model in different VR devices like VR glasses and mobile devices. This basic step helps to transform CAD model from design software as Ansys/Solidworks, etc. to DT modelling development software as RamView360. This 3D exemplary model will further develop as a Building Information Model (BIM) in level L2: 3D Model with Overlaid Information. In level L2 structure & asset information are linked with the 3D CAD model to generate the BIM model.

Level L3 is considered as a mature level, which is equitant to level 2 BIM maturity level (chapter 4.2.8). At this level, the user has an advanced understanding of the BIM model and integrated data structure. At this level, the user can link the document with a specific component of the system. Any type of document format (photos, graphs, file, drawings, etc.) can be uploaded into the system. At this development level, RamView360 model can integrate historical O&M information from the maintenance management system.

At Level 4, RamView360 can import results and data from Ramboll's web interface platform and/or any external software tool (e.g. Uptime Harvest) through a shared API connection. In this development phase, structural simulation results from ROSAP is integrated with the DT model. (ROSAP is a Ramboll's internal software to analyse offshore structure [30]). Uptime Harvest software will be linked with RamView360 by shared URLs of the DT model. Through this integration, Harvest user can directly visualize the O&M issue into the DT model.

Level 5 is the final RamView360 development level. DT model will be integrated with the real-time weather data and plant risk level. This allows RamView360 user to monitor weather updates and forecast from open source weather platform. This weather data can be used to define plant safety levels. It notifies the user if the safety level reduces due to bad weather conditions. After completing level 5 development process, RamView360 software could be become a best in class solution to visualize Digital Twin models through BIM methodology.

4.3 Interface Ramview360 – Uptime Solutions

In Chapter 4.2.2 "Features of RamView360 Tool", it is mentioned that Ramview360 has a URL sharing function that enables to connect easily with any external or internal software tool. In this research work, RamView360 is using the O&M issue list from an Uptime Harvest platform to integrate it with the DT model. The data-sharing interface between RamView360 and harvest can be automized by using a shared URL and/or API links. Those URL links are introduced into the harvest platform with related O&M issues. From there, a Harvest user can easily navigate to the RamView360 platform and visualize the detailed information with the integrated 3D environment.

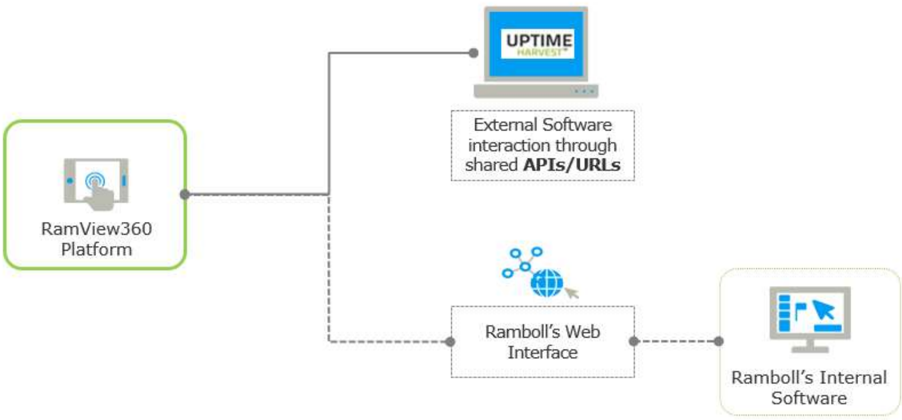


Figure 16 RamView360 data interface

As shown in Figure 16, the RamView360 platform can directly interact with any external software like Uptime Harvest and/or with Ramboll's internal web interface platform.

5 Use case demonstration

In this section several use cases and example applications for the Uptime Solutions visualization functionalities as well as the RamView360 technologies are shown and discussed.

5.1 Uptime Solutions use case

Fleet managers and technicians have to cope with growing fleets and technical complexity in terms of design and available information sources. Therefore, they are often overwhelmed by data information available for decision making. Furthermore, expert knowledge about failure modes, root causes and problem solving is usually distributed among the organization. The use case of Uptime Solutions within ROMEO project is therefore to facilitate seamless process from identification of abnormalities to continuous monitoring (Figure 17).

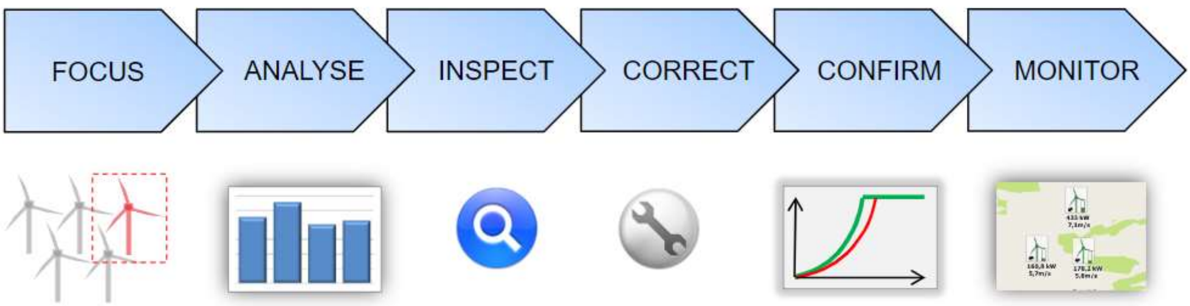


Figure 17: Uptime Solutions Use Case

The realized benefits of this process are:

- Cost effective performance checks of large fleets
- Benchmarking across several sites
- Benchmarking against manufacturer specification
- Comparison between expected and actual long-term energy yield
- Financial Assessment based on site performance
- Detailed failure diagnosis and prognosis
- Efficient support of service technicians
- Identification of Optimization potential
- Continuous learning to build up a corporate knowledge base

The functionalities developed for efficient inspection and support of service technicians including the Uptime Knowledgebase are described in detail in D6.4. In this deliverable we focus on visualization of generated information about the site, the turbines condition and the turbines history. The developed interface to external Business Intelligence Tools allows for use case specific depiction of different information types.

5.1.1 KPI Visualization

In the scope of ROMEO Project, the calculation of several important KPIs such as Capacity Factor, Time and Production based Availablity and Perfomance Ratio has been configured and implemented for the demonstrator wind farms. Figure 18 shows the depiction of averaged capacity factors for monitored turbines. This visualization allows a quick performance overview and identification of underperforming turbines.

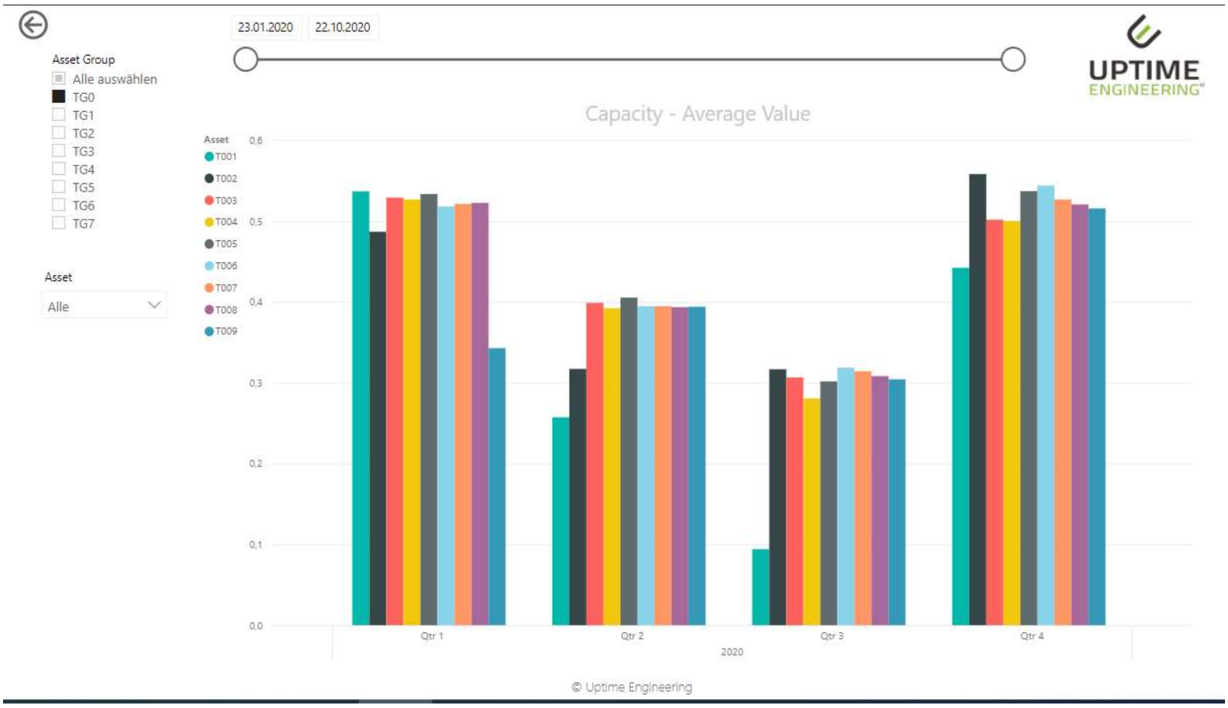
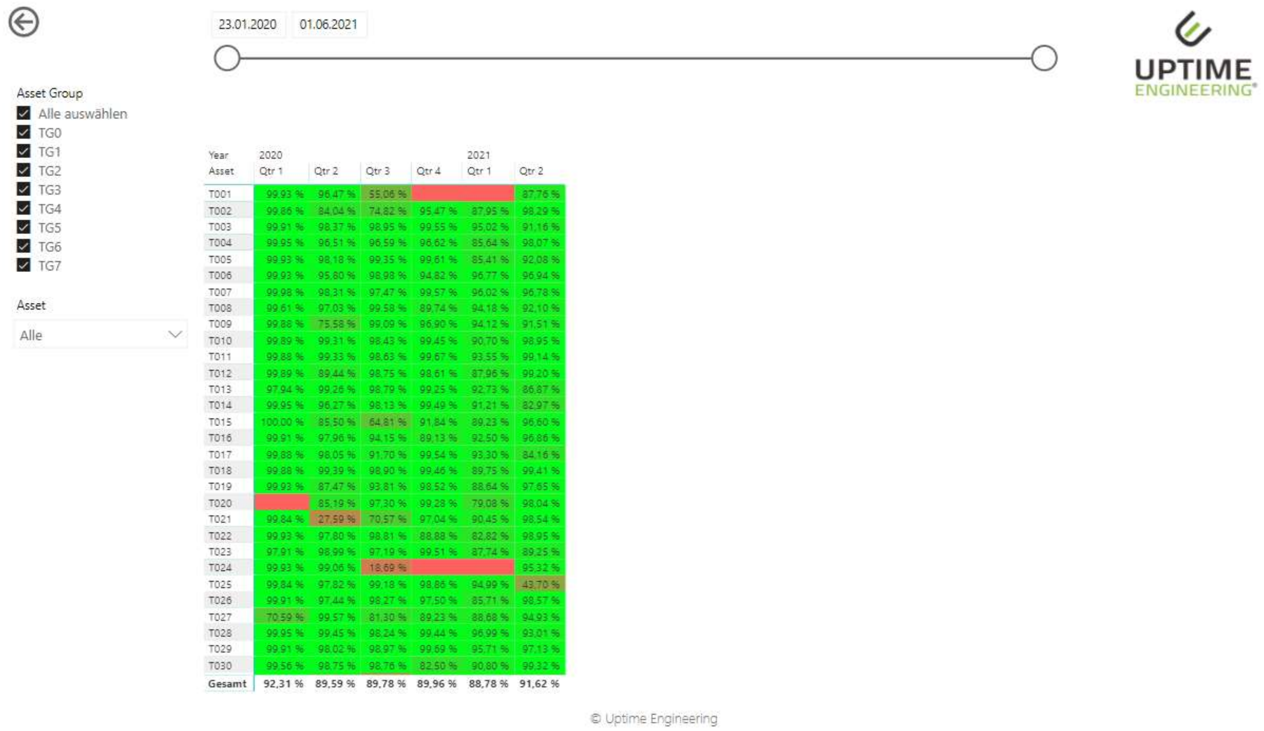


Figure 18: Capacity factor absolute

Another useful way of KPI visualization is the relative deviation from the wind farms mean value (Figure 19), which shows the deviation of each single turbines averaged Capacity factor from the wind farm mean capacity factor in the same time window. While absolute values cannot be seen from this plot, it is easy to identify underperforming turbines.

Figure 19: Capacity factor relative

A heat map of KPI values is a useful way to represent real values while also providing a visualization which allows for a quick overview of a large number of assets and identification of abnormalities. Figure 20 shows this representation for availability values of all Wikinger wind farm turbines.



Year	2020				2021	
Asset	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2
T001	99,93 %	96,47 %	55,06 %			87,76 %
T002	99,86 %	84,04 %	74,82 %	95,47 %	87,95 %	98,29 %
T003	99,91 %	98,37 %	98,95 %	99,55 %	95,02 %	91,16 %
T004	99,95 %	96,51 %	96,59 %	98,62 %	85,64 %	98,07 %
T005	99,93 %	98,18 %	99,35 %	99,61 %	85,41 %	92,08 %
T006	99,93 %	95,80 %	98,98 %	94,82 %	96,77 %	96,94 %
T007	99,98 %	98,31 %	97,47 %	99,57 %	96,02 %	96,78 %
T008	99,61 %	97,03 %	99,58 %	89,74 %	94,18 %	92,10 %
T009	99,88 %	75,58 %	99,09 %	96,90 %	94,12 %	91,51 %
T010	99,89 %	99,31 %	98,43 %	99,45 %	90,70 %	98,95 %
T011	99,88 %	99,33 %	98,63 %	99,67 %	93,55 %	99,14 %
T012	99,89 %	89,44 %	98,75 %	98,61 %	87,96 %	99,20 %
T013	97,94 %	99,26 %	98,79 %	99,25 %	92,73 %	86,87 %
T014	99,95 %	96,27 %	98,13 %	99,49 %	91,21 %	82,97 %
T015	100,00 %	85,50 %	64,81 %	91,84 %	89,23 %	96,60 %
T016	99,91 %	97,96 %	94,15 %	89,13 %	92,50 %	96,86 %
T017	99,88 %	98,05 %	91,70 %	99,54 %	93,30 %	84,16 %
T018	99,88 %	99,39 %	98,90 %	99,46 %	89,75 %	99,41 %
T019	99,93 %	87,47 %	93,81 %	98,52 %	88,64 %	97,65 %
T020		85,19 %	97,30 %	99,28 %	79,08 %	98,04 %
T021	99,84 %	27,59 %	70,57 %	97,04 %	90,45 %	98,54 %
T022	99,93 %	97,80 %	98,81 %	88,88 %	82,82 %	98,95 %
T023	97,91 %	98,99 %	97,19 %	99,51 %	87,74 %	89,25 %
T024	99,93 %	99,06 %	18,69 %			95,32 %
T025	99,84 %	97,82 %	99,18 %	98,86 %	94,99 %	43,70 %
T026	99,91 %	97,44 %	98,27 %	97,50 %	85,71 %	98,57 %
T027	70,59 %	99,57 %	81,30 %	89,23 %	88,68 %	94,93 %
T028	99,95 %	99,45 %	98,24 %	99,44 %	96,99 %	93,01 %
T029	99,91 %	98,02 %	98,97 %	99,69 %	95,71 %	97,13 %
T030	99,56 %	98,75 %	98,76 %	82,50 %	90,80 %	99,32 %
Gesamt	92,31 %	89,59 %	89,78 %	89,96 %	88,78 %	91,62 %

Figure 20: Availability heat map

5.1.2 Load history and damage quantification

Besides the representation of standardized KPIs, the evaluation of individual turbine load situation is useful to detect abnormalities and understand damage promoting boundary and operating conditions which eventually lead to failures. Typical observables are:

- Wind Speed
- Temperature measurements (Bearings, Gearbox, Generator, Power Electronics, Transformer)
- Pitch activity
- Yaw activity
- Currents / Voltage relationships
- Relationships between correlated observables (e.g.: Temperature/Power)

As an example, Figure 21 shows the individual average wind speed in a specified time range and the plants average value for each month. Besides the information about the site condition this also allows to identify outliers or accuracy problems with individual anemometers.

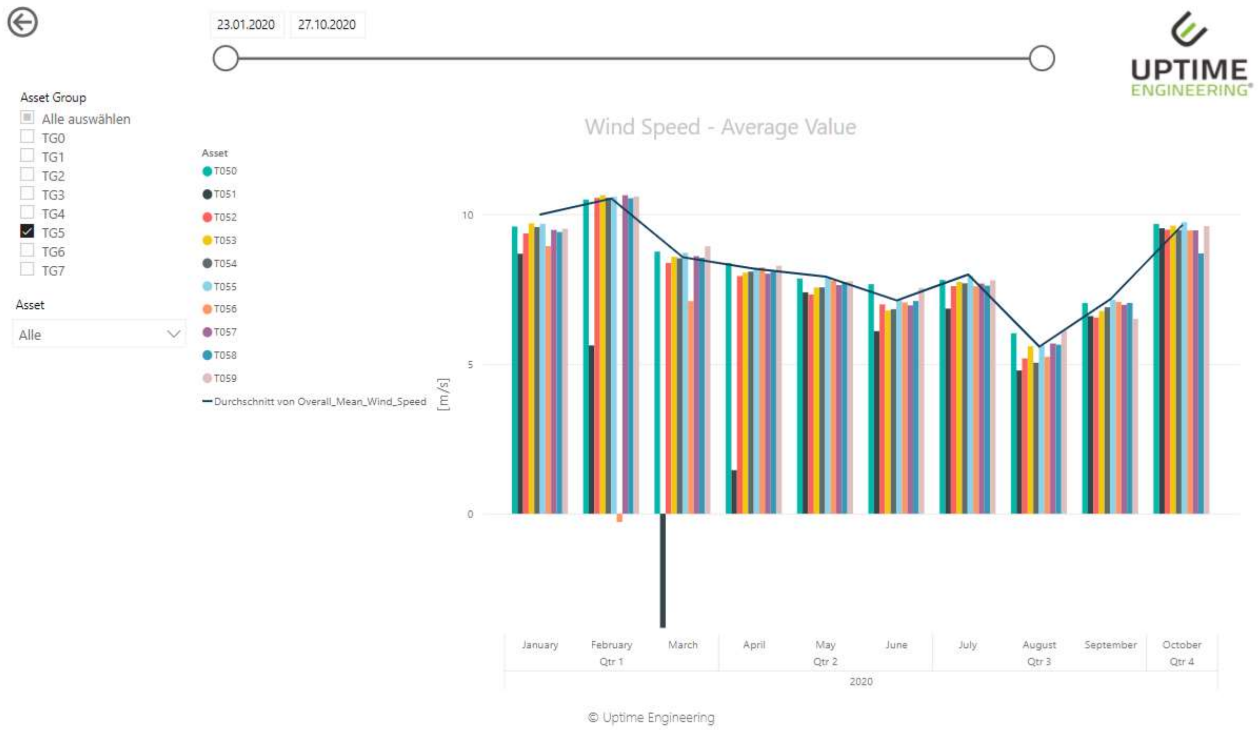


Figure 21: Averaged Wind Speed

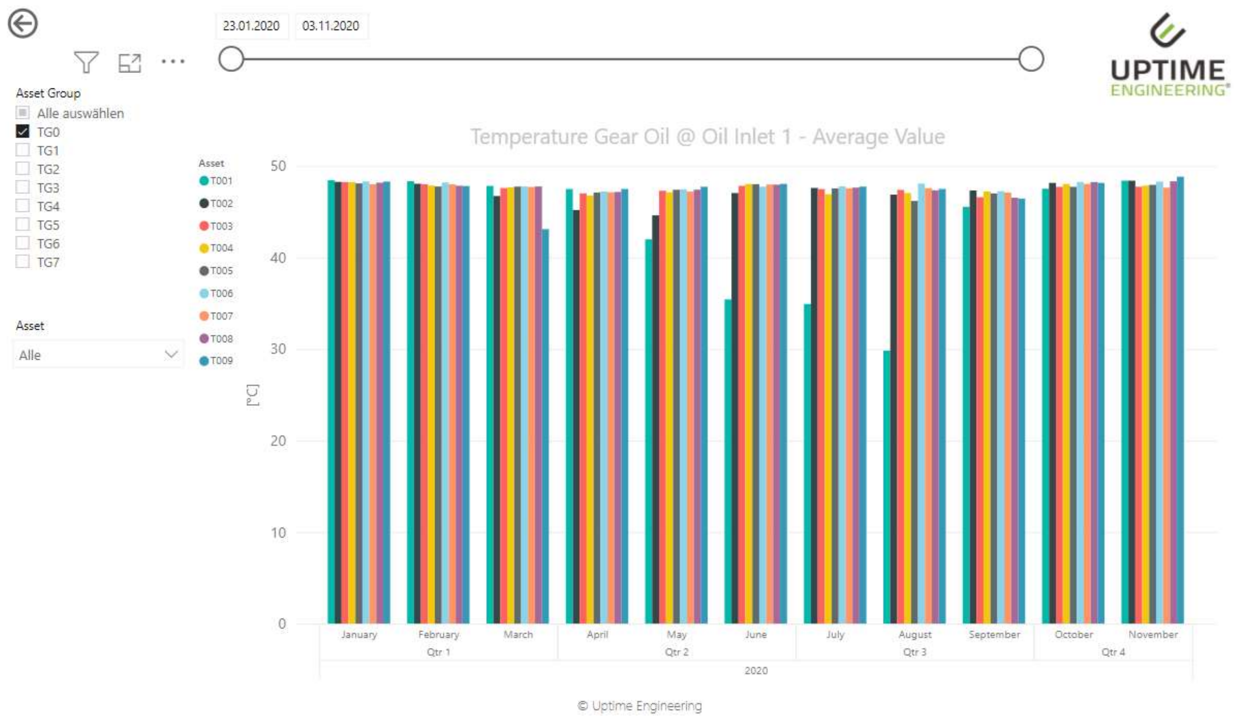


Figure 22: Gear Oil Temperature Monitoring

Figure 23: Failure Mode Specific load Situation

5.2 Use cases of RamView360 in the offshore wind energy industry

The RamView360 tool has the potential to prove itself a key changemaker for all types of project stakeholders. This tool can be used for the whole lifecycle of an asset. In this chapter, different use cases are described according to wind farm stakeholders. The RamView360 tool has high flexibility to modify its DT model functions (chapter 4.2.2) as per the user's requirements.

The DT model can be implemented from the development phase until the decommissioning phase of the project. During the development of the OFW project, RamView360 can be utilized to review the drafted design of the foundation models in a 3D environment. While during construction & installation phase it can help to stimulate the logistic process and material requirements, in the O&M phase RamView360 can be used to visualize sub-component information, O&M tasks, HSE documents, etc. [25]. The DT concept can also be applied to optimized maintenance activities though an asset information model [26] and help to reduce material required during the fabrication/manufacturing phase by an improved product design [27]. The decommissioning process can be simulated and performed in VSL.

These use cases can be transformed according to the current challenges & requirements of OFW industry. The list of the RamView360 use-cases is mentioned in Table 1 concerning the stakeholder groups.

Colour code for Table 1:

(green)	This use-case **is relevant** to the specific stakeholder(s),
ABC (green)	This use-case **is relevant** to only "ABC" stakeholder(s),
(yellow)	This use-case is **might be relevant** for specific stakeholder(s),
(red)	This use-case is **not relevant/suitable** for specific stakeholder(s).

Table 1 Different use cases of RamView360

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(1)	Development	DRA (Design Risk Assessment) – WTG structure model is updated and can be visualized continuously during the designing phase of the project. This model can be integrated with stress deformation data to analyse any design error.						
(2)		OFW foundation design can be reviewed and modified according to future O&M strategy & requirements.		**O&M service provider**				
(3)		Quantity of material required for WTG components manufacturing and/or substructure fabrication can be optimized through the BIM approach e.g. hybrid tower design through BIM [21].						
(4)		Wind farm Layout can be optimized with the use of integrating GIS mapping platform with BIM – Wind farm overview, potentially on 2D map.		**O&M service provider**				
(5)		Soil profiles within the wind farm site can be generated and visualised through GIS mapping in RamView360, this soil modelling profile can be used to derive WTG foundation type and clusters.		**O&M service provider**				

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(6)		Early engagement with WF developer and sub-contractors to create a CDE (Common Data Environment) for digital design basis can lead to cost reduction in design and O&M phases. This design data can be used as a reference for future development projects.		**O&M service provider**				
(7)	**Construction & Installation**	Based on visualization in RamView, During the installation phase, the working space area at the site can be pre-planned and divided between different party/contractors.						
(8)		A risk information model can be created from the high-level BIM model in RamView to visualize hazard area at the construction zone and safety equipment location. HSE documents can also be attached to this risk information model. This risk information model could be useful for HSE training/briefing before the installation is executed.						
(9)		HSE Pre-Training can be simulated for the Installation phase through VSL. In this training, different simulation scenarios can be performed. e.g. Transfer to Boat Landing Platform, Boat collision, etc.		**Construction service provider**				
(10)		The WTG components logistic process can be optimized by visualizing workflow in VSL (Virtual Solutions Lab). The Logistic process can be pre-planned and scheduled through the 3D simulator.						

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(11)		BIM Model of high voltage submerged cable connection can generate to visualize underwater cable layout and optimized cable length.						
(12)	Operation & Maintenance	O&M tasks, historical maintenance record, O&M manual, documents, photos, graphs etc. can be organized, archived and visualized through Ramview360						
(13)		The O&M work process can be optimized with the use of BIM-based visualizing workflow in VSL (Virtual Solutions Lab). The O&M activities can be pre-planned and & scheduled through RamView360.						
(14)		Structure monitoring data and results can be integrated with the digital twin model and sensor status can be analysed in a 3D virtual environment.						
(15)		Time-based structure degradation model can be generated to simulate the DT model with the real environment scenarios.						

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(16)	Operation & Maintenance	BIM integrated GIS mapping along with design information can be used to find the best suitable WTG locations for monitoring purposes. This can reduce the number of monitoring systems needed to be installed.						
(17)		Virtual Inspection can be carried out through True Digital Twin technology. This can reduce onsite workload and improve O&M decision by a predictive maintenance approach.						
(18)		OFW assets can be managed by a smart asset management approach (BSI PAS-1192.3:2014 Standards for O&M) through an AIM (Asset Information Model) integrated with BIM.						
(19)		Complex structures like substation, WTG sub-components can be mapped in 3D model with the use of Laser/LiDAR scanning technology, if the CAD/3D detailed model is unavailable.						
(20)		O&M process-related risks can be identified through FMECA methodology in risk assessment tools like RamRisk & RiskBIM [31]. Those risks can be mapped in the DT model by integrating RamRisk & RiskBIM tools to RamView360.						

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(21)	Operation & Maintenance	Maintenance Pre-Training can be simulated through VSL (Virtual Solution Lab) to mitigate failure due to human error.						
(22)		During O&M activities, the technician can get remote expert support through fully virtualized communication gateways like video calls, comments, uploading photos, etc.						
(23)		Live weather forecast can be indicated in the DT model. Which can be used to give the real-time plant safety level and an update of HSE conditions.						
(24)		Advanced document management systems can be built by linking documents with the DT 3D model. This will improve the high level of information allocated with each component and the documents can easily be managed and shared with stakeholders.						
(25)	Decommis sioning	BIM can be used to pre-plan the decommissioning process by simulating different scenarios.						

Nr	Project Phase	RamView360 Use Cases	WF Owner/ Developer	Individual Service Providers (ISPs)	Substructure/ Foundation Designer	WTG Manufacturer	Transmission System Operators (TSOs)	External Advisories/ Consultancy/ Government
(26)	Decommissioning	With the used of BIM, remaining component life and damage can be assessed. Which helps to estimate decommissioning cost.						
(27)		With the use of an “8D” BIM approach, Sustainability and environmental evaluation can be tracked during the decommissioning phase.						

5.3 RamView360 Demo

A proof of concept of the DT model is developed in RamView360. The Wikinger WF is considered as a reference wind farm and “WTG–64” is used as a reference WTG in this demo. In Figure 24, the desk panel of RamView360 is shown.

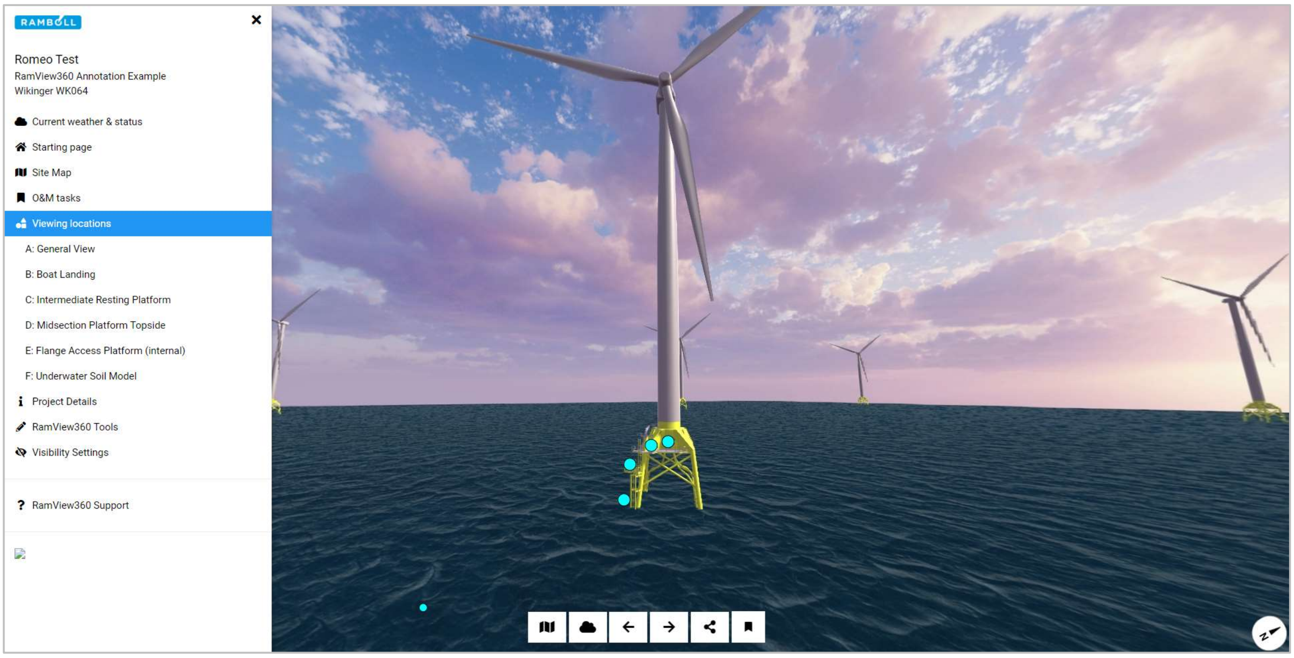


Figure 24 RamView360 desk panel

This demo contents five different use-case example as mentioned in the following:

- HSE Training on boat landing ladder,
- Structure inspection of K-joint of Jacket structure,
- Maintenance example of davit crane component,
- Inspection example of J-tube cable connection,
- Inspection example of scour protection,

An example of the inspection of a Jacket structure is shown in Figure 25. In this figure, it is shown that the user can easily visualize the inspection information by clicking on the annotation point integrated into the RamView360 model. An annotation point is a point which is marked in the 3D model to link additional information,e.g. O&M issues, documents, graphs etc., with the 3D model. This annotation point is marked in blue colour in Figure 25. In the demo model, 5 annotation points are mentioned - each point for a specific use-case example mentioned above.

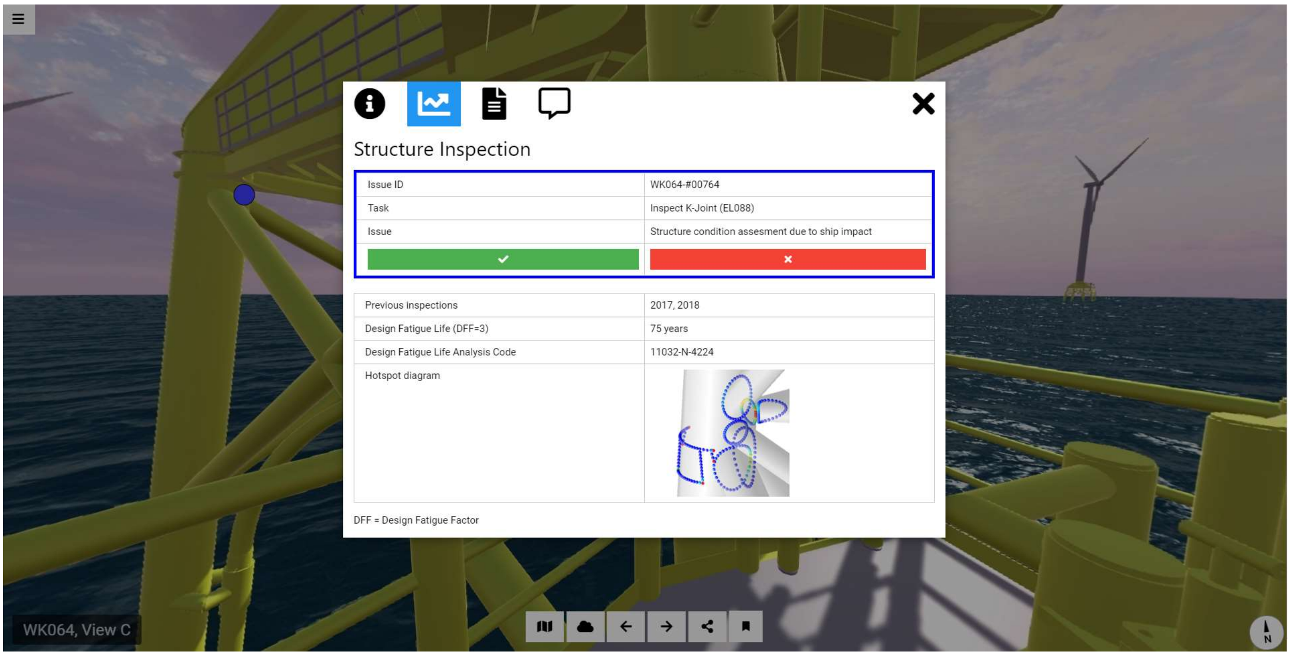


Figure 25 Structure inspection example in RamView360

6 Conclusions and Future Development

In this deliverable the visualization concepts for the Ramboll Digital Twin technology as well as the information management and analytics platform Uptime Solutions are discussed.

The basic concept of RamView360 is shown and several use-cases are derived and assigned to key stakeholders. As the demo version is only limited to the O&M activities, it can further develop for other phases of the project like the development, construction & installation-phase, etc. This RamView360 demo is limited to the WTG level asset information model and can be extended to a WF level model. Furthermore, the RamView360 tool can be linked with other digital twin enabling technologies, mentioned in Chapter 3.2. This allows the user to also visualize real-time monitoring results in RamView360. An advanced level BIM-model in RamView360 can be used as a pre-training simulator to reduce accidents due to human error. In this research work, a detailed model of the foundation is used to generate the BIM model. This BIM modelling approach can be extended to map the wind turbine sub-components like gearbox, transformer, etc. as well as substation equipment in addition to the substructure.

Nevertheless, there is an extensive list of possible further development, but it is essential to identify the potential use-cases for RamView360 based on the different stakeholders. The RamView360 tool application can be expanded to other energy business areas e.g. onshore wind farms, HV transmission structures, etc. Thus, the presented use-cases show that RamView360 has the potential to be an effective communication solution of the digital twin methodology for offshore wind assets.

For Uptime Solutions a powerful timeseries visualization tool for large time series has been developed, implemented and successfully tested in multiple use cases. For further visualization of generated Information such as KPIs, a standardized interface for the integration of external Business Intelligence tools has been developed and implemented. For the use case of the ROMEO demonstrator wind farms, several useful visualization approaches have been tested in MS Power BI Future work will focus on the continuous testing of developed functionalities in operational environments. This work will be documented within the scope of WP7.

7 Appendix

7.1 Appendix A

The minimum technical requirement for the RamView360 tool is the version of the web-browser. RamView360 can work with the oldest web-browser version mentioned in Table 2 or the latest released version.

Table 2 Web-browser version requirement for RamView360

Desktop Browsers	**Mobile Browsers**
Google Chrome v74+	Google Chrome for Android v74+
Apple Safari (Mac only) v11+	Apple Safari for iPhone and iPad v11+
Microsoft Edge v12+	Microsoft Edge for tablets v12+
Mozilla Firefox v66+	
Microsoft Internet Explorer v11+	

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