Digital Transformation of Marinas through BIM-Based Lifecycle Management

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Abstract

Building Information Modeling (BIM) has revolutionized building projects, yet its application in marine and port infrastructure remains scarce—particularly when it comes to lifecycle management and sustainability. This study addresses this gap by introducing an integrated BIM-based approach for the Chios Marina, a project of strategic importance for maritime tourism and coastal development. The methodology combines 3D parametric modeling in Autodesk Revit with 4D scheduling and 5D cost simulations in Navisworks, ensuring accurate quantity take-offs, transparent budget control, and real-time visualization of construction progress. Beyond the design and construction phases, the study advances BIM into the operation and maintenance stage by embedding inspection and replacement cycles into the digital model. This enables condition-based monitoring of structural components, preventive interventions, and extension of service life. The results demonstrate not only improved accuracy and efficiency, but also a pathway toward smarter, more sustainable management of port infrastructure. By showcasing how BIM can evolve into a practical facility management system, the study highlights its potential to enhance decision-making, reduce costs, and support long-term resilience. This work offers original insights into the digital transformation of maritime infrastructure, positioning BIM as a key enabler of efficiency, transparency, and sustainability in coastal engineering projects.

Keywords
Building Information Modeling (BIM), Port infrastructure, 4D/5D simulation, Facility management, Lifecycle management.

1. Introduction

Sailing and maritime tourism represent activities of high cultural and economic importance for countries with extensive coastlines, such as Greece. Beyond their recreational value, marinas function as critical infrastructures that support vessel accommodation, supply services, and contribute to local and national economies through tourism, employment, and business activities. Their proper design and operation directly influence safety at sea, the attractiveness of destinations, and the competitiveness of coastal regions.

Despite their significance, many port and marina facilities were constructed decades ago, often with outdated methods and under limited regulatory frameworks. In several cases, the original construction documentation is incomplete or no longer available, making adaptation, expansion, and maintenance particularly challenging. These limitations hinder accurate assessment of current conditions and complicate long-term planning, especially under the growing demands for sustainability, resilience, and environmental protection.

The design, construction, and management of port infrastructure are complex processes that require the integration of technical, financial, and environmental considerations. Marinas are not merely berthing facilities; they must ensure functionality, safety, durability, and optimal use of resources, while also aligning with modern sustainability objectives. Traditional management approaches, based on fragmented information and static documentation, often fall short of meeting these requirements. In this context, digital technologies provide a new framework for efficient and transparent infrastructure management.

Building Information Modeling (BIM) has emerged as a transformative methodology and fundamental tool in the construction industry. By integrating geometric, technical, scheduling, and financial data into a unified digital model, BIM improves accuracy in quantity estimation, enhances transparency in budget control, and facilitates collaboration among stakeholders. Although primarily associated with building projects (Baik, 2025), its application extends to a wide range of infrastructures such as roads, bridges, and large-scale construction works (Bradley, 2016). By combining three-dimensional visualization with reliable information for each element, BIM functions not merely as a digital representation but as an integrated management framework. It supports analysis, decision-making, and coordinated data flow across all stages of a project's lifecycle. While BIM is now well established in the building sector, its application to marine and port infrastructure remains limited.

The existing literature highlights promising results. Studies have demonstrated BIM's capacity to improve cost estimation and resource allocation (Li & Li, 2020; Nsimbe & Di, 2023), optimize maintenance scheduling (Valdepeñas et al., 2020), and accelerate parametric modeling of marina and coastal structures (Balku, 2021; Hua, 2020; Lee et al., 2012). More recently, Digital Twin approaches have been proposed as complementary tools, combining BIM with IoT sensors and simulation environments to enable real-time monitoring and predictive maintenance in ports (Yao et al., 2021; Homayouni et al., 2025). These advances confirm BIM's potential but also underline persistent challenges, such as high implementation costs, interoperability issues, and the need for specialized training of technical staff.

Despite these developments, there remains a research gap in the comprehensive lifecycle application of BIM to marine infrastructures. Most existing studies focus on design or construction phases, with limited attention to the operational stage where maintenance and asset management are critical for ensuring long-term functionality and sustainability. The present study addresses this gap by applying a holistic BIM methodology to the case of Chios Marina. The objective is to demonstrate how BIM can support the entire lifecycle of a port facility—from detailed design and construction scheduling to cost simulation and preventive maintenance management. By showcasing this integrated workflow, the study aims to highlight BIM's capacity to improve efficiency, transparency, and sustainability, and to contribute to the digital transformation of maritime infrastructures.

2. Methodology

The proposed methodology follows a lifecycle-oriented framework for the digital management of marine infrastructure projects. It consists of four sequential stages, each supported by BIM tools and processes:

1. 3D Parametric Modeling
    - Development of a comprehensive BIM model of the port and related facilities in Autodesk Revit.
    - Representation of both existing and new structures, including complex geometries such as breakwaters, caissons, and superstructures.
    - Organization of model elements into phases (existing, demolished, new) to enable comparative analysis and clear visualization of interventions.
2. 4D Construction Scheduling
    - Integration of time as a fourth dimension through Autodesk Navisworks.
    - Linking model components to construction activities and simulating project sequencing using Gantt charts.
    - Support for monitoring progress and identifying delays or rescheduling needs.
3. 5D Cost Simulation
    - Addition of cost parameters into the BIM environment.
    - Automatic extraction of quantities and dynamic monitoring of financial evolution across construction phases.
    - Evaluation of alternative scenarios with respect to resource allocation and budget constraints.
4. Operation and Maintenance Management
    - Embedding inspection, replacement, and deterioration parameters within the BIM model.
    - Use of color-coded filters and schedules for condition-based monitoring of structural elements.
    - Establishment of a digital facility management system that supports preventive maintenance and extends service life.

This stepwise methodology transforms BIM from a design-focused tool into a lifecycle management system for marine infrastructure. Its application to an actual marina project demonstrates how the approach can be practically implemented and adapted to the specific needs of port facilities.

3. Case Study: Chios Marina

The Chios Marina was selected as a case study due to its strategic importance for the local community and the development of maritime tourism, as well as the need to modernize its existing facilities. As shown in Figure 1, there are currently no building infrastructures on site. The project represents a typical example of port infrastructure with strong potential for applying Building Information Modeling (BIM) technologies. The implementation of the BIM methodology enables three-dimensional digital representation, 4D scheduling analysis, as well as the organization and monitoring of maintenance activities through integration with the digital model

3. 1 Project Overview

The upgrading of Chios Marina comprises a set of interventions on both existing and new facilities, aiming to enhance safety, functionality, and service capacity. The planned works include the widening of the head of the windward breakwater, as well as the demolition and reconstruction of the end section of the leeward breakwater in an expanded form. At the same time, extensive repairs and resurfacing with fiber-reinforced concrete will be carried out on the breakwaters, the inner piers, and the waterfront quays. Additional improvements concern the construction of a slipway for vessel hauling-in and launching, which entails the demolition of the existing quay at the same location, and the installation of a toe protection system at the floating dock caisson. The project also foresees the installation of new fenders and high-capacity mooring bollards (10–20 tons) across the main port structures to meet increased berthing demands, along with the provision of mechanical and electrical utilities in the main operational areas. Finally, a new seasonal pier will be constructed south of the marina, outside the leeward breakwater. Overall, these interventions aim to modernize the marina’s infrastructure and provide a representative case for demonstrating the applicability of BIM in complex marine works.

Fig. 1. Current state of Chios Marina (38°23'13"N 26°08'16"E)

3.2 3D BIM Modeling

The three-dimensional modeling of the Chios Marina was developed in Autodesk Revit, enabling an integrated digital representation of both port and building infrastructures (Figures 2 and 3). Parametric elements were employed to capture the complex geometries of the marine works, including rock armors, artificial concrete units, and reinforced concrete cross-sections, while the building facilities were modeled at a basic level of detail, covering their main structural and morphological features. The model was organized through the Phases function, distinguishing existing, demolished, and new elements, which facilitated comparison between the initial and upgraded configurations of the marina. This classification also supported clear visualization of the interventions through color-coded differentiation, enhancing communication among stakeholders. Overall, the 3D model established a unified digital database that could be directly linked with scheduling and cost estimation processes, thereby forming the foundation for the subsequent 4D and 5D BIM analyses.

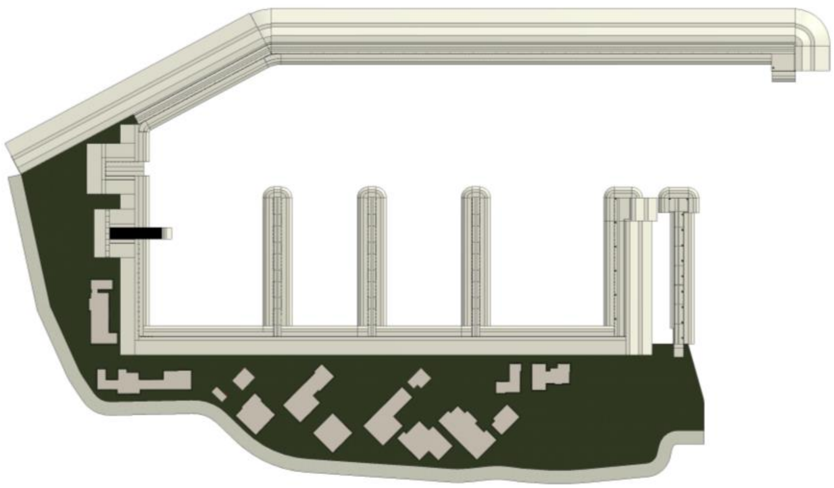


Fig. 2. Masterplan layout of the new Chios Marina developed with BIM modeling

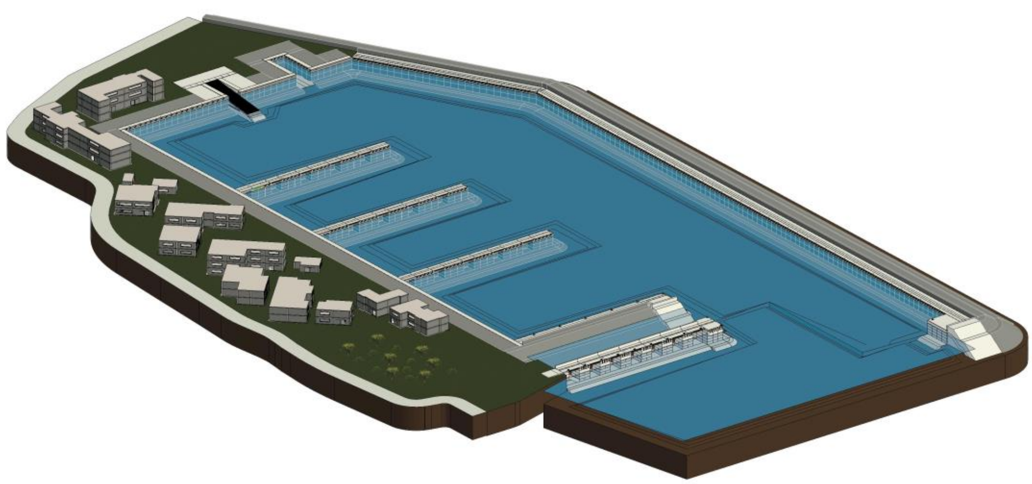


Fig. 3. 3D view of the new Chios Marina Masterplan

3.3 Construction Scheduling (4D BIM)

The 3D BIM model was extended with a time dimension to create a 4D simulation of the construction works using Autodesk Navisworks (Figure 4). Further, Figure 5 illustrates a key phase of the construction process, documenting the evolution of the slipway works. Each structural element was linked to the corresponding activity, allowing the generation of a detailed Gantt chart and a visual sequence of the construction phases. The integration of demolition, rehabilitation, and new construction enabled a step-by-step visualization of the project timeline, supported by color coding to distinguish between existing, removed, and new components. This dynamic representation enhanced the monitoring of progress, facilitated the identification of potential delays, and provided a flexible tool for adjusting the construction schedule in real time. Overall, the 4D model demonstrated how BIM can support transparent planning, efficient coordination among stakeholders, and proactive decision-making during the execution of complex marine works.

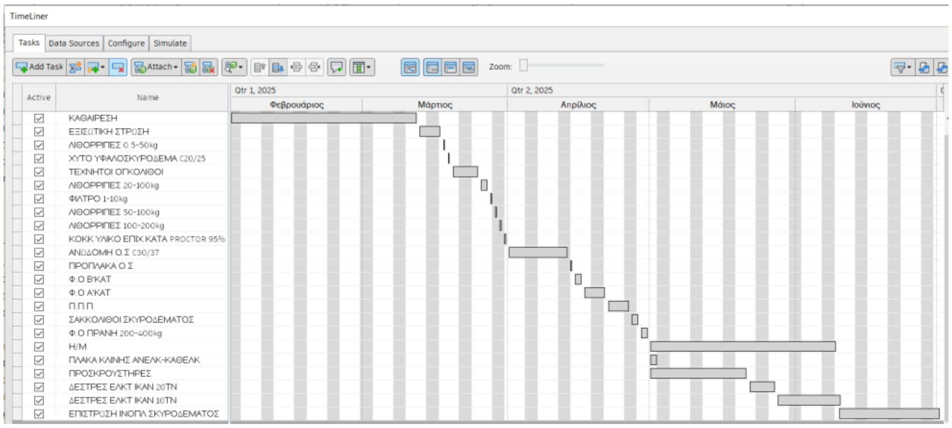


Fig. 4. Gantt chart of the timeline and sequencing of port infrastructure works for the Chios Marina project,

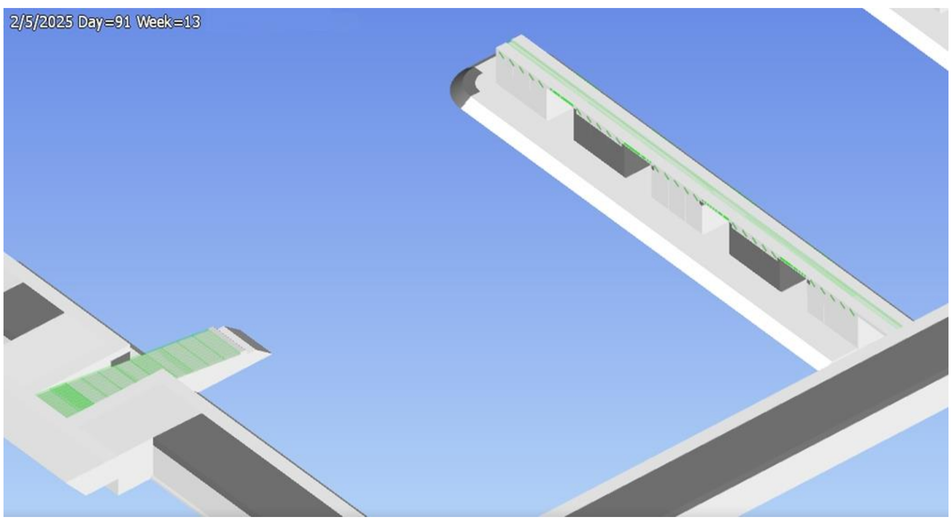
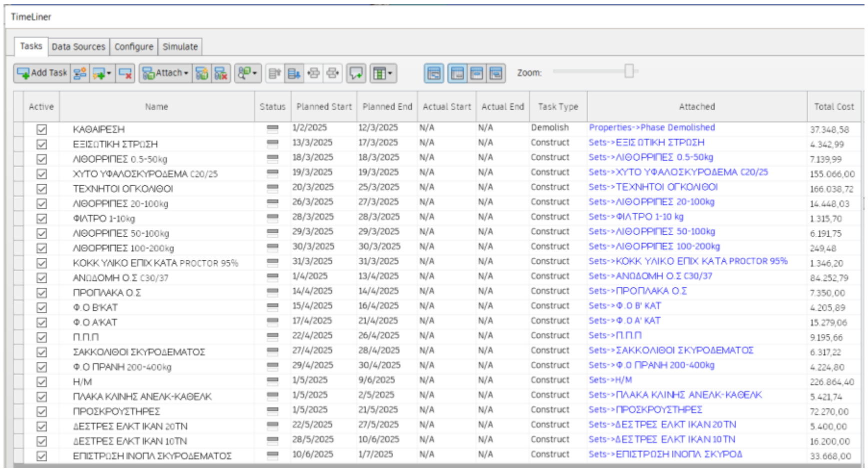


Fig. 5. Time -lapse snapshot of slipway slab concrete casting and installation of fenders and MEP channels

3.4 Cost Simulation (5D BIM)

The integration of cost parameters into the digital model resulted in a 5D BIM environment, where construction activities were directly linked to financial data. (Figures 6 and 7). Using Autodesk Navisworks, material quantities extracted from the 3D model were combined with unit prices and execution rates to simulate the project cost evolution across different phases. Figure 6 illustrates part of the activity cost estimation, while Figure 7 shows the cost evolution over time. This process enables dynamic monitoring of budget progression in parallel with construction scheduling, providing early insight into financial risks and allowing timely adjustments in resource allocation. The 5D model offered transparency in cost estimation, improved the evaluation of alternative design scenarios, and supported more accurate decision-making by connecting technical, temporal, and financial dimensions within a unified digital workflow.



TimeLiner

Tasks | Data Sources | Configure | Simulate

Add Task | Attach | Zoom:

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	Attached	Total Cost
☑	ΚΑΘΑΙΡΕΣΗ		1/2/2025	12/3/2025	N/A	N/A	Demolish	Properties->Phase Demolished	37.348,58
☑	ΕΞΙΣΩΤΙΚΗ ΣΤΡΩΣΗ		13/3/2025	17/3/2025	N/A	N/A	Construct	Sets->ΕΞΙΣ ΩΤΙΚΗ ΣΤΡΩΣΗ	4.342,99
☑	ΛΙΘΟΡΡΙΠΕΣ 0.5-50kg		18/3/2025	18/3/2025	N/A	N/A	Construct	Sets->ΛΙΘΟΡΡΙΠΕΣ 0.5-50kg	7.139,99
☑	ΧΥΤΟ ΥΦΑΛΟΣΚΥΡΟΔΕΜΑ C20/25		19/3/2025	19/3/2025	N/A	N/A	Construct	Sets->ΧΥΤΟ ΥΦΑΛΟΣΚΥΡΟΔΕΜΑ C20/25	155.066,00
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☑	ΦΙΛΤΡΟ 1-10kg		28/3/2025	28/3/2025	N/A	N/A	Construct	Sets->ΦΙΛΤΡΟ 1-10 kg	1.315,70
☑	ΛΙΘΟΡΡΙΠΕΣ 50-100kg		29/3/2025	29/3/2025	N/A	N/A	Construct	Sets->ΛΙΘΟΡΡΙΠΕΣ 50-100kg	6.191,75
☑	ΛΙΘΟΡΡΙΠΕΣ 100-200kg		30/3/2025	30/3/2025	N/A	N/A	Construct	Sets->ΛΙΘΟΡΡΙΠΕΣ 100-200kg	249,48
☑	ΚΟΚΚ ΥΛΙΚΟ ΕΠΙΧ ΚΑΤΑ PROCTOR 95%		31/3/2025	31/3/2025	N/A	N/A	Construct	Sets->ΚΟΚΚ ΥΛΙΚΟ ΕΠΙΧ ΚΑΤΑ PROCTOR 95%	1.346,20
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☑	ΔΕΣΤΡΕΣ ΕΛΚΤ ΙΚΑΝ 20ΤΝ		22/5/2025	27/5/2025	N/A	N/A	Construct	Sets->ΔΕΣΤΡΕΣ ΕΛΚΤ ΙΚΑΝ 20ΤΝ	5.400,00
☑	ΔΕΣΤΡΕΣ ΕΛΚΤ ΙΚΑΝ 10ΤΝ		28/5/2025	10/6/2025	N/A	N/A	Construct	Sets->ΔΕΣΤΡΕΣ ΕΛΚΤ ΙΚΑΝ 10ΤΝ	16.200,00
☑	ΕΠΙΣΤΡΩΣΗ ΙΝΟΠΛ ΣΚΥΡΟΔΕΜΑΤΟΣ		10/6/2025	1/7/2025	N/A	N/A	Construct	Sets->ΕΠΙΣΤΡΩΣΗ ΙΝΟΠΛ ΣΚΥΡΟΔ	33.668,00

Fig. 6. Detailed cost estimation for port infrastructure works

Fig. 7. Cost evolution during the placement of artificial armour units in the breakwater construction process

4. Facility Management

While BIM applications traditionally focus on design and construction, their extension into operation and maintenance remains at an early stage. Nevertheless, BIM offers the ability to consolidate inspection and maintenance data in a unified digital environment, supporting continuous monitoring throughout the lifecycle of infrastructure.

In the Chios Marina case, the Revit model was enriched with parameters that allow the systematic tracking of key elements such as bollards, cleats, dock bumpers, slipway slabs, and fiber-reinforced concrete superstructures. The attributes include "***Current Condition***", "***Last/Next Inspection***", "***Last/Next Replacement***", and "***Replacement Cycle***", all of which can be easily managed through Schedule tables. This structured dataset provides a clear overview of the current and future state of assets, facilitating preventive planning and maintenance prioritization.

For visualization, the *Condition* parameter was linked to color filters—**green** for good, **orange** for satisfactory, and **red** for critical—allowing immediate recognition of deteriorated components. Maintenance personnel can update these fields during inspections, turning the model into a living database that reflects the evolving condition of the marina. Figures 8 and 9 illustrate long-term performance projections of the port infrastructure. Figure 8 presents the simulated condition of the windward breakwater head after a decade of service, while Figure 9 focuses on the slipway zone, showing the estimated deterioration of structural elements derived from maintenance and aging analyses. Overall, this integration transforms BIM into a practical facility management system, improving transparency, enabling rational planning of interventions, reducing risks of failure, and ensuring the sustainable functionality of port infrastructure.

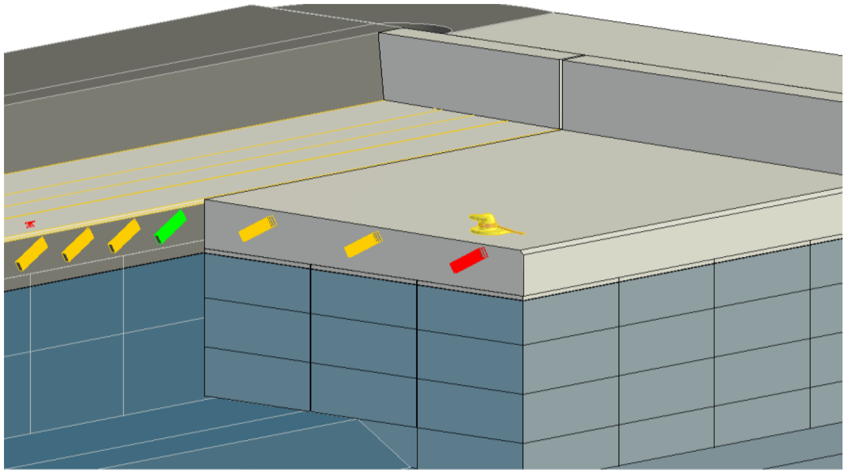

Fig. 8. Simulation of the expected condition and structural representation of the windward breakwater head after 10 years of service

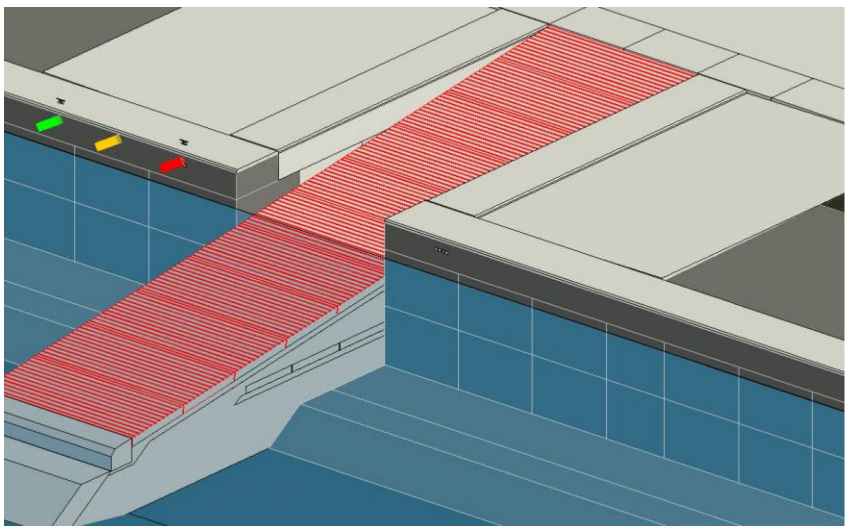

Fig. 9. Estimated condition of slipway structural elements after 10 years of operation

5. Discussion

The application of BIM to the lifecycle management of the Chios Marina illustrates both the potential and the challenges of digital transformation in marine infrastructure. The study shows that BIM can unify geometric, scheduling, and financial information in a single environment, supporting transparent planning, accurate cost estimation, and dynamic visualization of construction processes. By extending BIM into the operation and maintenance stage, the model demonstrated how inspection cycles and replacement planning can be embedded into a digital workflow, thus contributing to preventive maintenance and longer service life.

Compared with previous BIM applications in buildings and large-scale infrastructure, this case highlights two important contributions. First, it demonstrates that marinas and regional port facilities—projects often characterized by fragmented documentation and limited digital records—can also benefit from a BIM-based lifecycle approach. Second, the integration of 4D and 5D simulations with facility management features illustrates the versatility of BIM, showing that the methodology can evolve from a design and construction tool into a comprehensive asset management system. This expands beyond earlier works that primarily focused on cost control or parametric design automation.

At the same time, the case study underlines challenges for broader adoption. Interoperability and open standards (e.g., IFC) remain barriers to seamless data exchange between software platforms. Implementation costs and the need for specialized training may discourage stakeholders, particularly in smaller port projects. Moreover, while BIM enables structured maintenance planning, its long-term value depends on the consistent updating of the model by facility managers, which requires organizational commitment and resources.

While the findings are promising, certain boundaries of the present study should be acknowledged. The methodology was applied to a single case study, which restricts the extent to which results can be generalized to other types of marine or port infrastructures. The assessment did not include a quantitative evaluation of efficiency gains; therefore, while the benefits are evident qualitatively, their measurable magnitude remains to be validated. Nevertheless, previous studies in infrastructure have reported improvements in cost accuracy, error reduction, and maintenance planning through BIM (Li & Li, 2020; Nsimbe & Di, 2023; Valdepeñas et al., 2020), suggesting that similar outcomes can be anticipated in marine contexts. Finally, the model's effectiveness in the operation phase is conditional on systematic updates and the active involvement of facility management teams—an organizational factor that lies beyond the scope of this research but is essential for successful real-world implementation.

6. Conclusions

This study demonstrated the application of a BIM-based methodology for the lifecycle management of port marine structures, with the Chios Marina serving as a representative case. The development of a 3D parametric model, combined with 4D scheduling and 5D cost simulation, enabled accurate quantity take-offs, transparent cost monitoring, and dynamic visualization of construction phases. By embedding inspection and replacement cycles into the model, BIM was further extended into the operation and maintenance stage, evolving into a practical facility management tool.

The results confirm that BIM can support efficiency, transparency, and informed decision-making across all project stages, from design to long-term maintenance. The originality of this work lies in adapting BIM to marine infrastructure, an area where applications remain limited, and in demonstrating how digital workflows can modernize and sustain port facilities. Future work could explore the integration of BIM with Digital Twin and IoT technologies to enhance real-time monitoring and predictive maintenance in complex maritime environments.

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