

Interoperability in Project-Based Industries: Learnings and Challenges

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Abstract: The paper reviews the ongoing issue of interoperability at an organizational level and its importance in the context of Industry 5.0, focusing on the building and maritime industries. The paper explores the potential for cross-industry learning between the two industries, highlighting data domains that can improve project flow while analyzing lessons learned and challenges in the adoption of modern tools for data sharing and management. Findings suggest that establishing clear legal frameworks, adaptable work processes, and cultural dynamics are necessary for improving interoperability. Furthermore, the paper supports a holistic approach that considers human, organizational, and legal dimensions, highlighting guidelines from the European Interoperability Framework (EIF) to improve collaboration across these industries.

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1. INTRODUCTION

As we move towards the fifth industrial era, the concept of interoperability becomes more critical for reaching the main goals of Industry 5.0: human-centricity, resilience, and sustainability (European Commission. Directorate General for Research and Innovation., 2021). One of the main focuses of Industry 5.0 is the prevention of systemic waste (Maddikunta et al., 2022), with time waste being one of the identified types. Time waste can be minimized by improving organizational interoperability in project-based industries by enabling better collaboration and ensuring that relevant information is effectively exchanged.

This paper focuses on the challenges of organizational interoperability in the building and maritime industries, investigating on the utilization of modern tools such as Building Information Modeling (BIM) in the building industry and Product Lifecycle Management (PLM) in manufacturing. Both industries share similar project-based processes and encounter challenges due to fast technological changes, competitive pressures, and project complexity. This paper compares the two industries to discover interdisciplinary insights, highlighting common project delivery tools and the importance of data sharing for better decision-making and collaboration in light of traditional practices and fragmented data sources.

2. INTEROPERABILITY IN INDUSTRY 5.0

The Institute of Electrical and Electronics Engineers (IEEE) defines interoperability as the ability of multiple systems or components to share and use information effectively (*IEEE Standard Computer Dictionary*, 1991). European Interoperability Framework (EIF) provides a comprehensive approach to achieving interoperability through defining different interoperability layers such as legal, organizational, technical, and semantic levels (Ganck, 2017). Research by Turk (2020) highlights that while much of the construction information technology sector has focused on semantic interoperability, there is still the need to explore legal and

organizational aspects to achieve better integration. EIF presents twelve principles such as user-centricity and data portability that serve as a practical checklist for ensuring interoperability among public administration systems within the EU and that resonate with the objectives of Industry 5.0.

Organizational and legal interoperability, beyond technical and data-focused interoperability, is primarily examined within the healthcare sector but can be applied in other industries such as construction (Turk, 2020) where diverse software systems are increasingly interconnected. As in the case of project-based industries, multiple data domains are often coupled together throughout a product's lifecycle. Figure 1 presents six data domains identified and supported by the research of Bronson, Fonseca, & Gaspar (2024b). These domains spring from how different product and enterprise meta-data are generated throughout a product's development, incorporating project management practices such as planning.

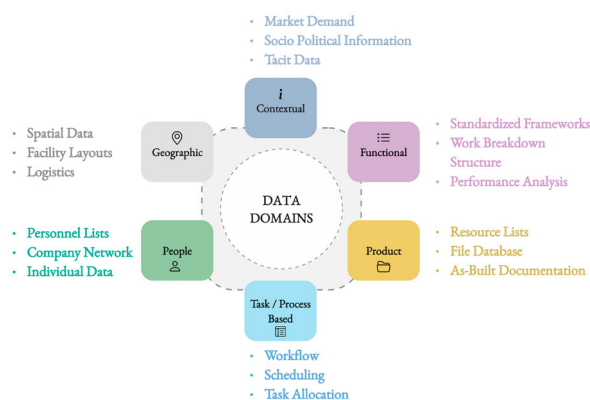


Figure 1: Multi-Data Domain Specifications (Based on Bronson, Fonseca, & Gaspar, 2024b)

With the complexity of large projects today, the more integrated the data is, the more effectively it is possible to track project progress and understand connections throughout its entire lifecycle, thus supporting decision-making by more

consistent information, and clearer communication among stakeholders.

While the mapping of these data domains is not yet fully understood, modern interoperable systems, especially those aligned with open standards like IFC (Industry Foundation Classes) in the building industry, provide sufficient flexibility to integrate the domains into a cohesive environment. Furthermore, in the context of Industry 5.0, where the collaboration between people and technology is necessary (Maddikunta et al., 2022), connectivity across these domains can enable industries to adjust their projects and operations quickly to adapt to changing conditions and stakeholder needs by minimizing communication silos.

3. PROJECT-BASED INDUSTRIES

3.1 Concept of Project-Based Industries

Project-based industries involve stakeholders, including project-based firms, suppliers, clients, owners, users, technology support infrastructure, and regulatory bodies (Gann & Salter, 2000). Within project-based industries, firms' design and production processes are organized around projects; they usually deliver highly customized solutions; and they operate with various stakeholders in their value chain (Gann & Salter, 2000). To define the characteristics of project-based industries, Erikstad (1996) identified seven aspects of the maritime industry that can also be extended to other project-based industries, such as construction, which share similar complexities.

These aspects include; (1) One of kind: Each project is unique and not simply a repeat of a standard product; (2) Multi-dimensional performance evaluation: Project performance has multiple dimensions such as cost, scope, quality, time; (3) High cost of error: Mistakes such as construction defects can be expensive to fix; (4) Shallow knowledge structure: There is no single right solution; instead, solutions evolve and remain open to interpretation; (5) Strong domain tradition: Projects are shaped by established practices specific to the people, context, geography, product, tasks, and processes involved; (6) Complex mapping between form and function: The connection between project design (form) and its purpose (function) is complex and often requires specialized expertise; (7) Stricted time resources and constraints: Projects are almost always bound by strict deadlines and schedules, whether set by contracts, funding availability, seasonal constraints, or market demands (Erikstad, 1996).

3.2 Importance of Building & Maritime Industries

These two industries present most of the aspects of project-based industries mentioned in the work of Erikstad (1996). Both industries are essential contributors to the global economy. The building industry is responsible for creating and maintaining the infrastructure that supports daily life (Tran et al, 2024) and its contribution to the global GDP is substantial, around 6% worldwide, with projections to reach 14.7% by 2030 (Tunji-Olayeni et al., 2024). The maritime industry is a globally competitive field that involves various sectors, including shipbuilding and repair, shipping and transportation, port operations, and offshore activities. The maritime industry is the backbone of international trade and transports around

90% of world trade, facilitating the movement of goods across the globe and contributing to economic growth (Bruce, 2021).

Research of Emblemvåg (2014) mentions that both industries manage large projects that require careful planning, thoughtful design, and collaboration among diverse teams. Despite the similarities, particularly in the need to adapt tools, methods, and strategies, each industry also has different challenges. Shipbuilding is more complex in terms of planning and scheduling than construction due to its unique challenges. These challenges include dependence on a global network of suppliers who must adhere to strict standards and effectively manage complicated supply chains (Emblemvåg, 2014)

4. TOOLS FOR DATA EXCHANGE IN BUILDING & MARITIME INDUSTRIES

By the early 2000s, increasing project complexity necessitated integrated solutions that incorporated lifecycle data for improved efficiency and control (Ghaffarianhoseini et al., 2017). This project complexity led to the introduction of tools like PLM and BIM, which aimed to improve data traceability, collaboration, and project management practices. The current solutions highlighted in Figure 2 are important to achieve the main infrastructure that supports modern, interconnected business operations within an organization.

	MARITIME	BUILDING
Technologies	Computer-Aided Ship Design Tools & PLM (Gaspar, 2019)	Building Information Modelling (BIM) Tools (Azhar, 2011)
Open Data Standards	STEP (ISO 10303), XML (Bronson, Fonseca, Gaspar, et al., 2024), OCX (Astrup et al., 2022)	Industry Foundation Classes (IFC) (ISO 16739-1, 2024)
Data Environment	Lacks a common data environment but solutions exists such as PLM adoption	Common data environment for collaboration (ISO 19650-1, 2018)
Supply Chain	Outsourcing enables access to a wide range of resources and specialized skills (Mello & Strandhagen, 2011)	Fragmented supply chains, studies explore how to transfer knowledge from the manufacturing industry (Ikudayisi et al., 2023)
Regulatory Environment	Classification societies such as DNV, Lloyd's Register, etc. (Bruce, 2021)	State governments, county/city levels, referral agencies (Glick & Guggemos, 2009)

Figure 2: Current Solutions for Organizational Interoperability

4.1 Established Solutions in the Building Industry

Today, BIM has an important role in the construction industry by supporting collaboration and decision-making, and it is considered more than just a technological answer. It has been proven that BIM helps reduce project completion time and save contract value (Azhar, 2011; Papadonikolaki et al., 2019) Furthermore, 74% of BIM users reported savings in operational and maintenance costs as well (NBS, 2020). As one of the key technologies of Industry 5.0, BIM provides the foundational data and model for creating a digital twin (Ikudayisi et al., 2023).

An important advancement is the concept of openBIM, introduced by buildingSMART, which enables standardized, transparent workflows and a new industry mindset. Even before openBIM, the need for more integrated systems in the construction industry was recognized as early as the 1970s (Miettinen and Paavola, 2014). A key component of OpenBIM is the IFC standard, an open data format that enables better

information exchange between different software platforms (Ghaffarianhoseini et al., 2017). The IFC standard, along with other standards from the OpenBIM family, provides a solid foundation for PLM systems in the construction industry (Turk, 2020) by integrating dimensions such as time (4D), cost (5D) and energy (6D) and more (Tran et al. 2024).

Additionally, the possibilities offered by BIM, such as Integrated Project Delivery (IPD), have increased the likelihood of adoption of BIM (Kent & Becerik-Gerber, 2010). The aim of IPD is to create a collaborative process that links stakeholders, systems, and organizational frameworks, aiming to reduce waste and improve coherence throughout the project lifecycle (Glick & Guggemos, 2009). However, there are additional factors that affect the collaboration between a project team. After the development of BIM, new BIM roles emerged, such as BIM managers or coordinators (Papadonikolaki et al., 2019), which have an impact on organizational interoperability by supporting better communication and collaboration among project teams. These roles require new approaches to design and project management, which support how project teams work together. Success in these positions depends on both technical skills and soft skills, which help resolve conflicts and align strategic objectives (Papadonikolaki et al., 2019).

The adoption of BIM is influenced by government mandates (Mitera-Kielbasa & Zima, 2024; Papadonikolaki et al., 2019). The UK required Level 2 BIM for public projects starting in 2016, which was inspired by the Norwegian 'BIM Manual' created in 2011 (Papadonikolaki et al., 2019), and the research by Mitera-Kielbasa and Zima, (2024) found that 35% of European countries plan to implement BIM mandates. Furthermore, there is also an increase in the private sector adopting BIM; 77% of firms used BIM for private projects, compared to 62% for public projects in the UK (NBS, 2020). This highlights that BIM adoption is not only driven by government requirements but also by the industry's recognition of its benefits, despite the slow pace of implementation.

4.2 Established Solutions in the Maritime Industry

Established solutions for improving data exchange in the maritime industry primarily revolve around two key approaches: implementing PLM systems and encouraging computer-aided ship design (CASD) software vendors to adopt open standards and improve compatibility with other tools (Nowacki, 2010; Gaspar, 2019). PLM systems enable the centralization of all ship-related data, from initial design and engineering to production and maintenance (Stark, 2020). The adoption of PLM in shipbuilding paves the way to address many of the interoperability challenges arising from the use of disparate CASD tools (Nowacki, 2010).

Shipbuilding is a highly customized process, especially when compared to the mass production industries like the automobile and aerospace industries. While PLM systems are effective in mass production environments, adapting them for unique shipbuilding projects can be challenging (Tulk et al., 2024). However, today, PLM tools for shipbuilding exist, such as the ShipbuildingPLM tool (Tulk et al., 2024).

Additionally, similar to the building industry, the maritime industry is researching ways to improve digitalization. However, challenges exist, primarily due to information silos that arise from inadequate protocols for information sharing and data transfer between ship designers and shipbuilders. The use of multiple specialized software packages complicates the synchronization of design changes, making the process difficult and time-consuming (Agis & Brett, 2024). As a result, more projects today are working to create integrated design platforms, such as the Smart European Shipbuilding (SEUS) project, which is working to create a PLM-like platform to develop shipbuilding by combining CAE, CAD, CAM, and PDM software. Hopefully, this integrated platform will improve digitalization in shipbuilding by (1) saving time in engineering, assembly, and construction processes, (2) improving design quality and data management, and (3) enhancing collaboration among ship designers and builders (Gaspar et al., 2023).

Furthermore, the maritime industry operates on a global supply chain that allows businesses to function across various markets. For example, in the context of European shipyards approximately 60% to 80% of a ship's value is outsourced to external suppliers or subcontractors, which can help to reduce costs and provide flexibility to adapt to market changes (Mello & Strandhagen, 2011). In this context, the maritime industry depends on regulatory bodies, called classification societies, such as DNV and Lloyd's Register (Bruce, 2021). These enforcement bodies are currently encouraging digital approaches to expedite the design verification of vessels and ensure they are seaworthy. Current practices for class approval rely heavily on 2D drawings and data (Astrup et al., 2022), exacerbating manual efforts for conversion and developing more design copies in different formats.

5. LEARNINGS & CHALLENGES

5.1 Learnings

Based on the previous section, four areas have been identified that could be improved to achieve better organizational interoperability. These areas include *open data standards*, *integrated project delivery*, *model ownership*, and a *shared data environment*.

Open Data Standards: The IFC standard in the building industry is a mature and cohesive data format, which improves data exchange in the building industry (Ghaffarianhoseini et al., 2017; Papadonikolaki et al., 2019). However, several challenges still persist while using it including (1) maintaining and updating IFC schemas to keep pace with evolving industry practices and technological advancements can be complex and time-consuming; (2) the richer nature of proprietary schemas used by software vendors thus creating additional complications; (3) the fact of industry leaning towards more loosely-coupled systems rather than rigid and predefined solutions (Turk, 2016).

The absence of a ship-specific standard in the maritime industry results in data fragmentation and decision-making based on incomplete information due to the lack of a comprehensive and standardized data model that can integrate multi-domain ship data, including both temporal and process-

related aspects (Bronson et al., 2024a). In the past, data formats such as ISO-STEP have been attempted for implementation, but their adoption has been slow due to their complexity, the time required for adequate implementation, and the varying levels of detail (LoDs) involved (Bronson et al., 2024a). Other neutral formats, like XML, present structured data exchange but come with great storage requirements (Rando, 2001). Since 2016, there has been growing interest and research in an open-source solution named Open Class 3D Exchange (OCX) standard, which targets to improve collaboration and data exchange by being flexible, vendor-neutral, and adaptable to various workflows in exchanging design information between shipyards and classification societies (Astrup et al., 2022).

Integrated Project Delivery: Integrated practices are becoming increasingly important based on current insights from the maritime and building industries. Moreover, in Industry 5.0, the need for integrated practices is becoming widely needed in order to overcome fragmented supply chains that cause delays and cost overruns. (Ikudayisi et al., 2023). One key aspect of these integrated practices is effective project delivery methods. While there are collaborative project delivery models in the building industry such as Design-Build or Construction Manager at Risk (CMAR), IPD stands out as unique due to it requiring a multiparty agreement that specifies the distribution of profits and the sharing of risks and rewards (Ikudayisi et al., 2023). The concept of IPD enables early stakeholder involvement and can deliver projects more quickly and at a lower cost in the construction industry (Glick & Guggemos, 2009), and could represent a solution for the maritime industry (Bronson et al., 2024a).

However, according to the research of Miettinen and Paavola, (2014) the idealistic and rigid nature of IPD contributes to uncertainty and as an alternative, more adaptable approaches to BIM implementation should be considered. Even though IPD seems to be presented as an ideal solution, it increases expectations that do not fully align with everyday realities in the building industry. Therefore, the centralized IPD approach may not suit the often disconnected nature of the construction industry, and users find it risky due to the current legal and contractual frameworks (Kent & Becerik-Gerber, 2010; Miettinen & Paavola, 2014; Turk, 2020).

Model Ownership: OpenBIM addresses collaboration and data sharing in construction through open standards for interoperability among software platforms, it does not exactly resolve data ownership issues, which need to be clarified through clear contracts (Azhar, 2011; Turk, 2020). Efforts like BIM Execution Plans (BEPs) and master information delivery plans provide rules for data sharing and responsibilities (ISO 19650-1, 2018), but they primarily focus on technical aspects rather than ownership issues (Turk, 2020).

Right now, most legal systems are designed for traditional paper-based processes and find it challenging to handle the complexities that come with sharing digital information through BIM (Tran et al., 2024). To effectively manage who owns these digital models, there is a need for a comprehensive strategy that blends the right technology with clear legal guidelines. Additionally, it is important to encourage the

industry to adopt OpenBIM principles, which promote openness and collaboration, while making sure that intellectual property rights are protected.

Shared Data Environment: In the building industry, according to ISO 19650-1 (2018), all information exchange in construction projects should be enabled by a Common Data Environment (CDE). CDEs are particularly useful for BIM-based project delivery methods to centralize project-related information, thus aiming to reduce data silos and improve communication among all organizations involved in a project (ISO 19650-1, 2018). According to the research of Bronson et al. (2024a), the maritime industry faces more limitations in data management due to the absence of a standardized CDE. Tools such as Cadmatic Wave and Siemens Teamcenter provide data management capabilities. However, besides these tools, the lack of a centralized database for all ship design data usually leads to fragmentation in shipbuilding information. Although, Gaspar (2018) indicates that engineers in the maritime industry spend much of their time converting and reusing old models instead of focusing on creating new and innovative designs despite the promises of data management offered by PLM solutions.

However, this does not mean that CDEs in the building industry are a substantial fix either. What has been learned so far indicates that the transition to CDEs presents challenges on its own, including existing interoperability issues as the exchange of information is often executed poorly despite advancements in standards like ISO 19650, and keeping the information safe and secure (Miettinen and Paavola, 2014; Tran et al. 2024). That said, implementing CDE-like solutions without addressing interoperability challenges, data security concerns, and establishing comprehensive workflows might not realize the full advantages of CDEs.

5.2 Common Challenges

Both industries face shared challenges, particularly concerning organizational culture and tool implementation. The literature identifies some of the key issues and comparisons between these industries.

Economic Barrier: Investing in new technologies usually requires substantial investments (Agis & Brett, 2024). These costs include software, hardware, training, and the potential need for organizational changes. Smaller companies often struggle to achieve a satisfactory return on investment (ROI) due to these high initial expenses (Ghaffarianhoseini et al., 2017; Messaadia et al., 2016; Park & Kim, 2017). This economic responsibility can interfere with the adoption of modern technologies and slow innovation, especially for those with limited engagement in advanced tools.

Change Resistance: Both industries face resistance when adopting new methods (Agis & Brett, 2024; Tunji-Olayeni et al., 2024). The reasons apart from economic conditions include (1) a strong preference for traditional methods over structured processes (Miettinen & Paavola, 2014) (2) a lack of awareness about the full potential and benefits of the new technologies (Ghaffarianhoseini et al., 2017) and many employees in doubt about whether the change is worth the effort, (3) as workers are already busy with current projects, adding training for new

technologies can be overwhelming, (4) legacy systems and outdated data also create problems, since older infrastructure often does not integrate smoothly with modern tools (Park & Kim, 2017; Stark, 2020). In the context of shipbuilding, there are additional challenges when it comes to adopting PLM systems, such as the need to customize the software to fit specific terminology and regulations, as well as the inability to incorporate commonly used ship design files (Gaspar, 2019). However, well-integrated PLM tools specifically designed for shipbuilding are practical to shipyards as they handle the distinctive challenges and complexities of the industry (Tulk et al., 2024).

Lack of Knowledge & Training: In the building industry, it is mentioned that BIM is not always used in the building lifecycle but rather used only in 3D modeling tools, like traditional CAD software, focusing on some capabilities for visualization, clash detection, and basic documentation. This limited perception can be due to the factors of lacking resources to invest in advanced BIM training and implementation. There are different data proven supporting this by a survey sponsored by Autodesk that the respondents identified the main difficulty factor as the ease of using the software was 70%, followed by 52% citing a lack of skills, and 31% indicating insufficient hardware (Ghaffarianhoseini et al., 2017). There is a similar landscape adopting more advanced tools in the maritime industry too, specifically for PLM tools, and additional concerns of fear of losing information and productivity when using a new tool, and high costs to train employees (Gaspar, 2019) besides its technical challenges.

6. CONSIDERATIONS FOR INDUSTRY 5.0

This paper contributed a comparative evaluation of two industries, identifying existing knowledge and gaps that can improve organizational interoperability. It highlighted that even viable solutions have their challenges. The focus was on current strategies for improving project management and reducing time waste, while also recognizing that a more high-level review could benefit future research. Although these industries have traditionally been conservative in adopting new solutions, the emergence of Industry 5.0 demands a change in business mindset. This change is necessary not just to stay competitive but also for people to be engaged in non-repetitive and more creative work.

To address these issues, embracing principles from Industry 5.0 can present valuable strategies for improving organizational interoperability and creating more collaborative work environments that encourage:

- utilizing scenario planning and agile development, so organizations can build systems that are flexible and capable of evolving to meet shifting requirements (Tran et al., 2024)
- utilizing user-preferred tools that support collaboration across specialized fields (Maddikunta et al., 2022)
- considering legal and organizational frameworks that establish clear rules regarding data ownership, and intellectual property rights, aiming to build trust and encourage collaboration among project stakeholders (Azhar, 2011; Park and Kim, 2017; Turk, 2020)

- developing adaptable architectures, such as federated systems for data exchange (Turk, 2016) and
- investing in employee training and growth, such that the workforce is skilled and motivated to utilize new technologies (Miettinen & Paavola, 2014; Tran et al., 2024)

Furthermore, the EIF can also be a valuable resource for project-based industries beyond just the healthcare sector. Its 12 principles present a structured approach to improve alignment in business processes, enhancing interoperability in an organization and supporting a human-centered transition that aligns with the goals of Industry 5.0.

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