SUSTAINABLE TECHNOLOGY AND BUSINESS DEVELOPMENT: APPLICATION OF SIMULATION PLATFORMS IN NORWEGIAN MARINE INDUSTRIES

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KEYWORDS

Simulation platforms, innovation projects, technology readiness level, business readiness level, industrial applications

ABSTRACT

This article delves into the pivotal role of simulation platforms in efficiently advancing innovation projects, drawing insights from a case study involving Manulab, the Manufacturing Laboratory at the Norwegian University of Science and Technology, and regional fish industry companies. The utilization of simulation platforms emerges as a cornerstone for project success, notably in expediting the development of cutting-edge technologies and seamlessly integrating research findings into industrial practices. The study underscores how simulation platforms not only propel technology readiness level progression but also facilitate concurrent advancement along the business readiness level. This holds particularly true for simulation platforms like Unity and Omniverse by Nvidia, equipped with physics engines that meticulously simulate interactions within virtual environments.

Several factors contribute to this success, including sustained engagement among stakeholders and the fostering of spin-off initiatives, which catalyze collaborative innovation. By nurturing a holistic and collaborative approach, simulation platforms serve as catalysts for translating research outcomes into tangible applications within the industrial sector. This underscores their indispensable role in propelling industrial innovation forward.

INTRODUCTION

The commercialization of research results presents a recurring challenge in numerous innovation projects involving industry and research partners. While companies acknowledge the value of these results, they do not always deem them sufficiently compelling to warrant immediate investment.

In research and innovation projects, the Technology Readiness Level (TRL) framework plays a crucial role in assessing the technological maturity of innovations. By providing a structured evaluation of readiness for practical application, TRL helps researchers and industry partners evaluate the progress of their developments. This assessment becomes particularly significant when navigating the challenging transition from the lab to the market, commonly referred to as the "technological valley of death." During this critical phase, innovations often face barriers to commercialization, stemming from technological uncertainties and market readiness.

To overcome these challenges, it's essential to integrate TRL assessment with considerations of Business Readiness Level (BRL). While TRL evaluates technological readiness, BRL evaluates the business's preparedness to successfully commercialize these innovations. This includes factors such as market analysis, business planning, regulatory compliance, and strategic partnerships. By aligning both TRL and BRL assessments, research and innovation projects can address not only the technical hurdles but also the business-related obstacles that may impede successful market entry.

This paper presents a compelling case study showcasing how the utilization of simulation platforms equipped with physics engines, notably Unity and Omniverse by Nvidia (*Isaac Sim NVIDIA*, 2023), can facilitate seamless transitions from conceptualization to market for the design and development of fish processing equipment. Leveraging such platforms enables the realistic simulation of interactions between objects within virtual environments, offering a near-real testing environment for the application of innovative solutions in the industry.

This case study is rooted in collaborative projects between the Manufacturing Laboratory, Manulab, at the Norwegian University of Science and Technology's Aalesund campus, and various Norwegian marine and maritime companies.

The case study delves into the intricate connections between the utilization of simulation platforms and the advancement of both technology and business readiness levels. Subsequent chapters will introduce the Manulab-industry competence-building process, providing a deeper understanding of the interplay between technology and business readiness levels. The article will then present the case study, followed by a comprehensive discussion, conclusion, and recommendations for future research.

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BACKGROUND AND THEORY

Manulab represents a technologically advanced small-scale factory, equipped with a diverse array of cutting-edge tools such as 3D printers, laser cutters and various types of robots. These technologies are interconnected through sophisticated sensor networks, cameras, and IoT technology. The core focus at Manulab lies in fostering competence within product and process development for flexible automated production. The utilization of simulation and modelling platforms is seamlessly integrated into the research and innovation activities within the lab, which primarily revolve around collaborative projects with industrial companies. While these collaborations foster a dynamic exchange of ideas and expertise, translating technological concepts from Manulab to practical industrial applications has posed challenges in certain instances.

To provide deeper understanding of the collaborative approach with companies, researchers at Manulab have developed a competence-building process inspired by Nonaka and Takeuchi's organizational knowledge creation model.

Manulab-Industry Competence Building Process

Informed by Nonaka and Takeuchi's model, researchers have delineated a six-phase competence building process within the Manulab industry projects, as depicted in Figure 1 (Hansen et al., 2023; Nonaka & Takeuchi, 1998). This process mirrors the organizational knowledge creation model but extends into specific phases unique to Manulab.

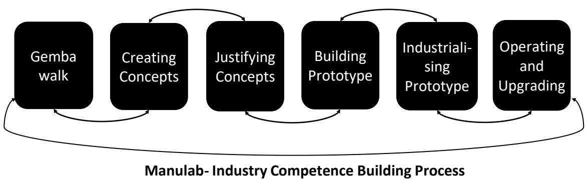

Figure 1: Manulab-Industry Competence Building Process (Hansen et al., 2023)

The initial phase involves a Gemba-walk, fostering socialization between the company and the Manulab team. Gemba-walks facilitate collaboration initiation through visits to factories and Manulab, fostering relationship-building, method understanding, and issue identification.

Subsequent phases, including “creating” and “justifying the concept”, and “building the prototype” are intricately interlinked, involving iterative modifications between concept and prototype development. This iterative process ensures alignment with the company's approval for industrialization.

The 'industrial installation' phase marks the implementation of the technology solution in the industrial company's facility. Typically undertaken by a system integrator, this phase demands meticulous planning, often causing production interruptions. The system integrator assumes responsibility for training operators and ensuring seamless integration into the existing manufacturing process.

The final phase, “operating and upgrading”, is a responsibility of industrial operators and engineers managing the system, while the system integrator focuses on servicing and enhancing the delivered solution. This iterative and collaborative process seeks to illustrate the dynamic evolution of competence within the Manulab-industry framework. Through industry-university projects, it attempts to bridge the divide between technological advancement and its practical application in industrial settings.

Previous research analysing this process has pinpointed a crucial challenge: while the technology readiness level progresses, the absence of key stakeholders impedes the project's business development (Hansen et al., 2023). Specifically, the limited involvement of decision makers, system integrators, and sales managers in the initial stages hampers the integration of Manulab results into factory operations. Moreover, the Manulab team's exclusion from later industrial phases diminishes their potential contribution to enhancing operational technology. Hence, it is imperative to involve personnel at all organizational levels—from operators and engineers to sales managers and decision-makers—in collaborative projects. Additionally, engineers who serve as technology integrators in manufacturing facilities play a pivotal role in ensuring the success of such initiatives. This inclusive engagement strategy is fundamental for maximizing the effectiveness and impact of collaborative endeavours. To explore further the collaborative landscape, understanding the significance of metrics like Technology Readiness Level (TRL) and Business Readiness Level (BRL) becomes crucial. These metrics serve as guiding lights, illuminating the path from conceptualization to implementation in both technological and commercial realms. The following paragraph will delve into how these metrics complement understanding of collaborative projects and their progression.

Technology Readiness Level (TRL) and Business Readiness Level (BRL)

Technology Readiness Level (TRL) is developed by NASA (Mankins, 1995). It is a systematic metric used to assess the maturity and readiness of a technology throughout its development stages. It consists of nine levels, ranging from TRL 1 (conceptualization) to TRL 9 (full-scale deployment and commercialization). The TRL framework helps in gauging the progress of a technology, ensuring a systematic transition from early-stage research to real-world applications. Stages of TRL:

TRL 1 - This level signifies that the technology is at the conceptual stage.

TRL 2 - Technology concept is formulated based on scientific principles.

TRL 3 - Experimental proof of concept to validate the feasibility of the concept in a laboratory environment.

TRL 4 - Technology is validated in lab to demonstrate its functionality and reliability under simulated conditions.

TRL 5 - Technology is validated in relevant environment that closely mimics real-world conditions.
TRL 6 – Technology is demonstrated in relevant operational environment to address user requirements.
TRL 7 - System prototype demonstration in operational environment to assess the system-level performance.
TRL 8 - Actual system is completed and qualified through testing and validation.
TRL 9 - Actual system proven in operational environment.

Business Readiness Level (BRL) is a complementary framework to TRL, focusing on assessing the readiness of a business venture (*Business Readiness Level (BRL) og Technology Readiness Level (TRL)*, 2023). It spans from BRL 1 (conceptualization and business planning) to BRL 9 (fully operational and sustainable business model). Stages of BRL:
BRL 1 - Business opportunity is identified based on market research or emerging trends.
BRL 2 - Value proposition for the technology is formulated, outlining its benefits and target market.
BRL 3 - The value proposition is validated through interactions with potential customers or stakeholders.
BRL 4 - Prototype or pilot is developed to demonstrate its functionality and gather feedback from early users.
BRL 5 - A scalable business model that outlines how the technology will generate revenue and scale is defined.
BRL 6 - The technology gains initial traction in the market.
BRL 7 - The scalability and sustainability of the business model are validated through continued growth.
BRL 8 - The technology is fully deployed and available for commercial use on a large scale.
BRL 9 - Increasing incoming orders.

Th seamless integration of mature technologies into well-planned business models is essential for achieving meaningful and lasting impact in the marketplace. TRL and BRL, when considered in tandem, provide a comprehensive framework for the successful development, integration, and commercialization of innovative technologies.

METHODOLOGY

This study has used the workshops as the main research method. The study-group consisting of three researchers and two engineers, all working in Manulab, conducted a series of workshops to analyse the industrial cases conducted in Manulab.

Workshops function as a research methodology designed to extract reliable and precise information on progressive strategies (Ørngreen & Levinsen, 2017). In addition to the workshops, the study-group investigated projects' documentation, such as project applications, meeting reports and final reports. The workshop centered on analyzing collaborative projects with industry, aligning with the Manulab-industry competence building process, and also advancing projects with regard to TRL and BRL.

CASE STUDY

The examination of projects during the workshops reveals a predominant emphasis on the technological aspects of collaborations between Manulab and industrial companies, often overshadowing potential challenges in industrial implementation. The analysis conducted in the workshops indicates that many projects have progressed to TRL levels 4-5, but show limited development along the BRL axis, typically falling within levels 1-3.

The Manulab industry competence-building process accurately adhered to the initial stages of the TRL scale. Commencing with the Gemba walk, the process saw engineers, production managers, and university researchers collaborating from the outset, fostering a profound understanding of each other's methodologies during the idea development phase. This collaborative effort led to the conceptualization of solutions addressing industrial technology challenges (TRL 1-3), subsequently progressing to prototype development in both virtual and physical environments within Manulab (TRL 4-6). Importantly, the product development and competence-building processes proved iterative, with phases alternating between concept refinement, alignment with stakeholder needs, and prototype construction. However, upon transitioning to TRL 7-8 - developing the industrial version and integrating it into the factory environment - a challenge emerged. Decision-makers from the companies hesitated to invest in the solutions, resulting in the failure of implementation in the industrial setting. Figure 2 illustrates this Manulab-industry competence process in orange, depicting development along the TRL scale up to TRL 7-8, but with no corresponding progress along the BRL axis.

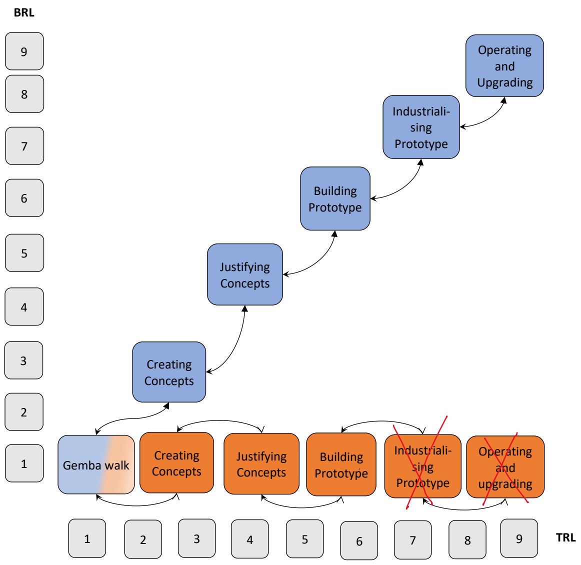

Figure 2: Manulab-Industry Competence Building Process in relation to TRL and BRL

A noteworthy revelation emerged through the comparison of projects that successfully integrated into industry or were on the verge of implementation. Figure 2 illustrates the parallel development of the Manulab-industry competence-building process in these projects along both the TRL and BRL axes, depicted in blue. Here the use of simulation programs facilitated continuous engagement of all the key stakeholders, including, engineers, sales managers, decision-makers, and operators throughout the Manulab-industry competence building process.

Another favourable result stemming from these projects was the emergence of spin-off initiatives, manifesting as new projects involving either the same and/or novel collaborative partners. The inception of these spin-off initiatives was driven by the opportunities unlocked through the applications of simulation platforms with physic engines. One notable case pertains to the projects for development of fish processing equipment in collaboration with a key industrial partner specializing in the design and production of such equipment. In the first project one used the simulation program Unity (*Unity Real Time Development Platform- 3D, 2D VR and AR engine*, 2023). The remarkable outcome of the simulation conducted in Unity spurred the initiation of two spin-offs initiatives. The first initiative, with the same partner, transitioned to the use of a more advanced simulation platform, Omniverse by Nvidia and its tool Isaac Sim. The second initiative involved the same partner along with two other industrial collaborators within the fish industry. While each partner has distinct needs and utilizes different simulation programs, the collective synergy of collaboration promises significant advancements for the fish industry. The subsequent paragraphs delve into the evolution of this case.

Case Start: Use of Unity

The utilization of simulation programs has proven highly effective for product and process development in manufacturing (Baizid et al., 2016; Ingalls, 2011). Traditional trial-and-error methods often involve making alterations to factory configurations in real-world settings, resulting in considerable expenses and operational disruptions. Simulation provides a cost-efficient and non-disruptive platform for experimenting with adjustments, refining processes, and proactively addressing challenges without impacting real-time production operations across various manufacturing industries.

While simulation programs have been utilized in the fish industry for some time, their current application typically involves modeling fish as rigid bodies, lacking consideration for their texture and flexibility. Factories designed around rigid fish bodies often necessitate significant adjustments during installation and are disposed to equipment errors upon initial use.

The Unity-project conducted at Manulab in collaboration with the company that designs and produces fish processing equipment, called further FPE-company, has presented a paradigm shift in fish factory design. Unity's reputation for ease of use and accessibility has made it a favorite among developers of all skill levels. Therefore, it was selected for this project to explore the feasibility of using programs with physics engines for the design of fish processing equipment. In Unity, the physics engine is built-in and includes features for simulating rigid body dynamics. It provides a range of settings and parameters to control the behavior of objects in the scene.

In this project the researchers used Unity to design the digital fish models that would closely resemble the behavior of real fish (Giske et al., 2023; Kleppe et al., 2023). Real fish specimens were instrumental in furnishing precise data regarding sizes and weights, facilitating the creation of accurate digital counterparts. As Figure 3 shows, the digital fish models were constructed from multiple rigid body pieces interconnected by rigid joints.

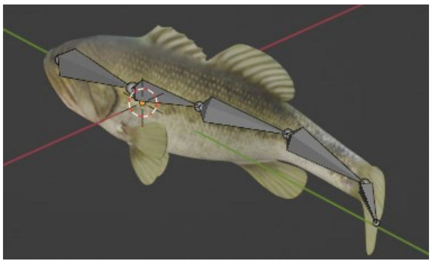

Figure 3: Digital Fish Models in Unity

This approach aimed to simulate the flexibility and movement of a fish's soft body within the constraints of the Unity physics engine. The Unity-project demonstrated the capability to create digital fish models that closely replicate natural fish behavior within factory environments. This breakthrough has paved the way for revolutionary advancements in the design and operation of fish processing equipment.

Findings from Use of Unity

The analysis of the Unity-project has showed the Manulab-industry competence building process development in tandem with the Technology Readiness Level framework. Initially, at TRL 1 and TRL 2, researchers conceptualized the utilization of a simulation program integrated with a physics engine to craft digital fish models that should mimic soft bodies.

As the digital fish models within the simulation program began to emulate real fish behavior closely, indicative of feasibility (TRL 3), researchers transitioned to testing functionality (TRL 4). Here, CAD models of actual fish processing lines were imported into Unity. The evaluation of virtual results was done by imitating the scenario in real physical facilities. Figure 4 shows the print screen of two videos. The upper part of Figure 4 displays the actual fish bodies in motion on the physical conveyor belt, while the lower section of the Figure 4 illustrates the digital flow of fish moving on the CAD model of the conveyor belt (Giske et al., 2023; Kleppe et al., 2023). A multidisciplinary team of industrial experts validated the reliability of the simulation program against real-world observations. Digital fish bodies interacted with one another and with conveyor similar in virtual in physical environment. The approved validation drove the project to the TRL 5 stage, affirming its readiness for testing in relevant operational environments.

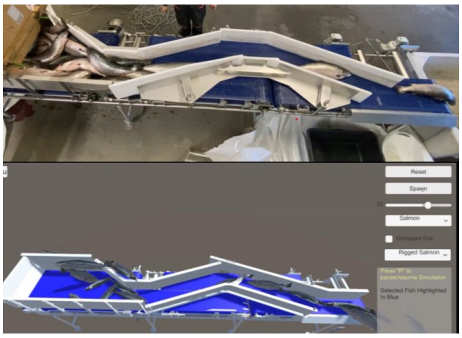

Figure 4: Comparison of Fish Movement on the Conveyer Belt in Unity and Real Setting (Giske et al., 2023; Kleppe et al., 2023)

Simultaneously, there was notable progress in the advancement of the Manulab-industry competence building process along the BRL axis. Figure 5 demonstrates the progresses along the TRL and BRL axes. The potential business opportunity and value of utilizing simulation platforms for designing fish processing equipment were recognized during the initial stages (BRL 1-2). Continuous validation of the concept occurred through engagement with project partners, including engineers and sales managers who interacted with customers (BRL 3). Subsequent verification of simulation program results through physical testing (BRL 4) showcased the versatility of simulation platforms in designing fishing equipment for various environments, whether on land-based fish factories or aboard fishing vessels, ultimately attaining BRL 5. Figure 5 illustrates the advancement of the Manulab-industry competence building process up to TRL 5 and BRL 5, achieved through the utilization of the Unity.

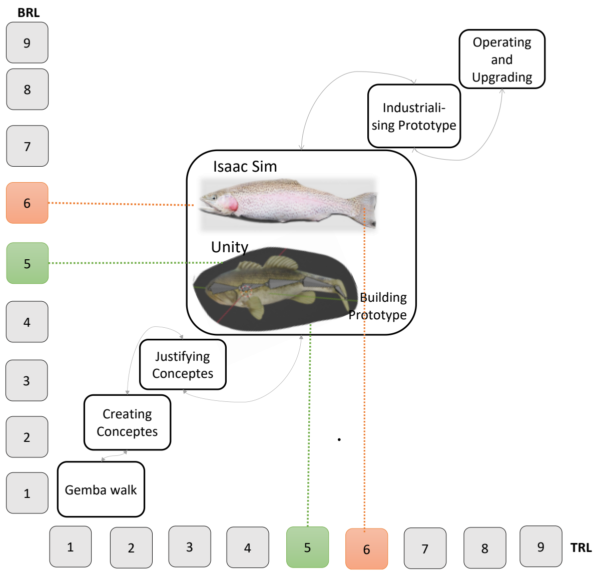

Figure 5: Manulab-Industry Competence Building Process: Progression from Unity to Isaac Sim

Case Evolution: Spin-off Initiatives based on Isaac Sim

Use of Unity demonstrated the advantages of applying simulation programs with physics engines in the fish industry's product development process. However, Unity primarily focuses on game development and interactive experiences. While the digital fish models in Unity closely mimicked real fish behavior in fish factories, they were still constructed from rigid pieces connected by rigid joints. To explore the simulation opportunities even further, the FPE- company initiated a new collaboration initiative with Manulab to leverage a more advanced simulation program: Omniverse by Nvidia and its tool, Isaac Sim. Isaac Sim is primarily intended for robotics and AI research and is tailored for professionals in industries requiring complex simulations and high-quality visuals.

The simulation of fish as soft bodies in Isaac Sim elevated the innovation project to the next level. This advancement stems from Omniverse's ability to provide more accurate and realistic simulations of soft-bodied organisms like fish, enhancing fidelity and precision in the developmental process. In the writing moment, the project is still in progress. However, the project develops quite fast. The digital prototypes have been developed, tested, and verified repeatedly. The verification of the movement of the digital fish bodies on the conveyer was done in the same way as in Unity -project. The videos of the real physical test and virtual test were compared and assessed by the experts in fish industry. The results showed that Isaac Sim allows accurate replicating the soft body dynamics, thereby facilitating a closer approximation to real-world conditions, which corresponds to TRL 6.

So far, Isaac Sim has shown itself to be much more effective tool for development of fish processing equipment, streamlining the design, prototyping, and installation processes in factories compared to traditional methods.

Moreover, Isaac Sim can potentially utilize real-time data from operational equipment in a factory to improve operational efficiency. Integrating real-time data from operational equipment into Isaac Sim could facilitate realistic simulations that closely resemble actual factory conditions. By doing so, researchers from Manulab and industrial engineers can analyze and optimize processes, test control algorithms, and assess the impact of different factors on efficiency and productivity. This integration could involve connecting sensors and other data-gathering devices from the factory floor to the simulation environment, allowing for the replication of real-world conditions within the virtual space. By running simulations with real-time data inputs, stakeholders can evaluate different scenarios, identify potential bottlenecks or inefficiencies, and implement improvements in a controlled and cost-effective manner before applying them to the actual factory floor. This not only can enhance operational efficiency but also pave the way for new revenue generation opportunities, supporting innovative business models and facilitating business expansion. Recognizing the potential benefits, the FEP-company has invested in engineering competence by allocating additional engineering staff to collaborate with Manulab on the project. Furthermore, the FEP have showcased the simulation capabilities to their customers—the owners of fishing boats with onboard fish factories. The prospect of more efficient factories that can utilize fish catch in a sustainable manner is paramount for the fish industry. In response to these needs, a collaboration has been initiated between FEP, Manulab, and the fishboat owner-company, called further Fishboat. The collaboration aims to leverage simulation programs to optimize production flows within the fish factories onboard. With several boats featuring diverse factory layouts and equipment configurations, the implementation of highly realistic simulations holds the promise of significantly enhancing operational efficiency for Fishboat.

At the same time, the researchers from Manulab demonstrated the results from the Unity-project on different industrial seminars and conferences related to fish industry topics. The interest from the industrial companies was huge. One company, further called AquaPipe, took contact with Manulab. The company designs piping systems for a well boats that retrieve salmon from fish farms in the sea. AquaPipe uses multiphysics computational fluid dynamics software, STAR-CCM, for designing systems that intend to work within real-world conditions. However, AquaPipe has a challenge with using fish models as rigid bodies in their software, and therefore the company has entered a partnership with Manulab.

The necessity of employing simulation platforms with physics engines was evident for FPE, Fishboat, and AquaPipe companies, leading to a new collaborative research project with Manulab, as illustrated in Figure 6. This joint effort signifies a shared dedication to enhancing sustainability and profitability in the fish processing industry, culminating in a BRL 6 investment for case development. At the time of writing, the project is in progress. So far, the companies exchange both practical knowledge from different sides of fish industry and software knowledge, including importing-exporting digital models between the different software. The intermediate results are very promising both regarding technical and business development.

Figure 6: Joined Research across the Fish Industry and Manulab

Findings from the Spin-off Initiatives

The evolution of the TRL and BRL within the collaborative project involving FPE, Fishboat, AquaPipe, and Manulab has been noteworthy.

The transition to Isaac Sim, specifically tailored for complex simulations in industries, marked a significant advancement, especially in simulating soft-bodied organisms like fish. This progression elevated the project to TRL 6, with the ability to accurately replicate soft body dynamics closely resembling real-world conditions.

The ongoing project has demonstrated Isaac Sim's effectiveness in streamlining the development of fish processing equipment, offering improvements in design, prototyping, and installation processes compared to traditional methods. Additionally, the integration of real-time data from operational equipment into Isaac Sim holds promise for further enhancing operational efficiency in factory settings.

The collaboration between FPE, Fishboat, AquaPipe and Manulab underscores the commitment to leveraging simulation programs to optimize production flows within fish factories onboard vessels. Meanwhile, AquaPipe's involvement highlights the broader applicability of simulation platforms with physics engines beyond fish processing, extending to designing piping systems for well boats. As the project progresses, the exchange of practical and software knowledge among the involved companies has been fruitful, showcasing promising results both technically and from a business perspective. This collective effort reflects a shared dedication to advancing sustainability and profitability in the fish processing industry, exemplified by the BRL 6 investment in case development.

DISCUSSION AND CONCLUSION

The findings from this case study underscore the critical role of simulation platforms in driving innovation projects forward efficiently. The collaborative effort involving Manulab, regional fish industry companies, and simulation platforms like Unity and Isaac Sim exemplifies how these tools serve as catalysts for technological advancement and seamless integration of research outcomes into industrial practices.

Simulation platforms play a pivotal role in expediting the development of cutting-edge technologies by providing a virtual environment where complex interactions can be meticulously simulated. The transition from Unity to Isaac Sim, particularly for soft-bodied organism simulations in fish processing, illustrates how advancements in simulation technology can significantly elevate project outcomes, advancing both technology readiness level and business readiness level simultaneously.

Moreover, sustained engagement among stakeholders and the fostering of spin-off initiatives are crucial factors contributing to the success of innovation projects. Collaborative efforts between research institutions like Manulab and industry players not only drive technological innovation but also facilitate knowledge exchange and the development of practical solutions tailored to industry needs.

Looking ahead, future research endeavors could explore the integration of artificial intelligence (AI) and machine learning (ML) algorithms into simulation platforms to enhance predictive capabilities and optimize decision-making processes. Additionally, investigating the scalability and interoperability of simulation platforms across different industries and domains could open new avenues for cross-disciplinary collaboration and innovation. Moreover, incorporating numerical indicators in the use of simulation platforms can provide tangible metrics for evaluating their impact on innovation projects. Parameters such as predictive accuracy, decision-making speed, and overall efficiency can lead to a better understanding of Technology Readiness Levels and Business Readiness Levels in collaborative projects between industries and universities, providing valuable insights into the progression of these projects and guiding their future development.

By nurturing a holistic and collaborative approach, simulation platforms enable the translation of research findings into tangible applications within the industrial sector. This underscores their indispensable role as enablers of industrial innovation, propelling industries forward and fostering sustainable growth.

In conclusion, the case study emphasizes the transformative impact of simulation platforms in advancing innovation projects efficiently. By leveraging these tools, stakeholders can accelerate the development of cutting-edge technologies, drive collaborative innovation, and seamlessly integrate research outcomes into industrial practices, ultimately contributing to the advancement of industries and fostering sustainable growth in the long term.

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