Simulation-supported decision-making in the design of volatile, uncertain, complex, and ambiguous (VUCA) systems: a research agenda

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Abstract: Manufacturing industries increasingly operate in VUCA (Volatile, Uncertain, Complex, Ambiguous) environments, requiring new approaches to decision-making. This paper examines how digital and simulation-supported tools can help organizations navigate uncertainty and complexity, outlining key approaches and technologies for VUCA decision-making, including digital twins, scenario simulation, and immersive visualization. The study categorizes major research challenges and proposes a research agenda structured upon a layered capability framework for the use of simulation models in VUCA environments. The agenda supports the future development of collaborative digital decision-support tools that strengthen resilience, adaptability, and transformative innovation in rapidly changing industrial contexts.

Keywords: VUCA; Decision Making; System Design; Simulation; Value Exploration; Digital Twins; Visualization

1. INTRODUCTION

The acronym VUCA was introduced by Warren Bennis and Burt Nanus (1985) as a framework for describing the volatile, uncertain, complex, and ambiguous post–Cold War military environment. VUCA has since been widely adopted to characterize today's technological, business, and societal landscape, which is increasingly shaped by unpredictability (Baran and Woznyj, 2020). Against this backdrop, manufacturing industries and public sector organizations are under increasing pressure to remain competitive and increase public value while responding to volatile customer demand, globally interconnected operations, geopolitical and industrial disruptions, raw material shortages, and uncertain technology readiness. Traditional decision-making approaches are often inadequate in VUCA environments (Tuyen, 2025) because they rely on stable assumptions, complete information, and predictable system behavior. As a result, decision-makers require tools that can evaluate alternative scenarios, anticipate disruptions, and support robust decisions under uncertainty (Carayannis et al., 2025). Simulation tools and digital twins are often discussed as critical enablers in this regard, enabling the analysis of complex systems, testing responses to changing conditions, and generating data-driven insights without disrupting real operations (Toller Melén et al., 2025). The objective of this paper is therefore to examine how simulation-supported decision-making can enhance decision-making in VUCA environments by improving organizational resilience, adaptability, and competitiveness.

2. RESEARCH APPROACH

This paper is grounded in both a literature review and empirical insights generated through multiple projects across industrial and public-sector contexts focused on simulation-driven decision support and Digital Twins (DT) for value creation. The literature review establishes the theoretical foundation and positions the study within existing research on VUCA environments, decision support, and socio-technical transformation. Empirically, the research is informed by participatory action research (Cornish et al. 2023) conducted in collaboration with industrial partners, companies, and public-sector organizations. The empirical work is based on iterative development and testing of demos and digital twin 'sandboxes', used as boundary objects for exploring decision-making under uncertainty (Ruvald et al. 2024). These prototypes were developed and refined through workshops, presentations, and semi-structured interviews, enabling continuous feedback loops between researchers and practitioners and supporting co-creation of knowledge across contexts. Participating organizations span several industrial domains, including construction equipment, shipbuilding, and electrical infrastructure, as well as public-sector entities such as municipalities, regional administrations, and public safety and emergency management. Despite differences in sector, mission, and technological maturity, they shared key characteristics relevant to this study: all operated in highly VUCA environments, many had established experience with cross-functional collaboration, and most engaged in participatory, iterative development practices. They were also undergoing rapid transformation driven by broader macro-level trends, which heightened uncertainty and underscored the need for exploratory, simulation-based decision-making.

3. LITERATURE OVERVIEW

Lechner and Schlüter (2023) recently highlight the lack of a comprehensive approach that integrates systems engineering, project management, and VUCA thinking into a unified decision-making framework for system design. While DT, process simulations, and model-based representations are widely known and acknowledged as critical decision-making enablers, they are seldom addressed as part of an integrated decision methodology. Similarly, immersive visualizations are increasingly employed to support understanding of complex

systems, yet they are not fully embedded within broader project and uncertainty management structures.

3.1 Digital Twins and model-driven approaches

A key challenge in systems engineering is developing digital twins and shadows that can effectively support product and system design under VUCA conditions. This requires moving beyond fragmented solutions toward modular DT architectures that enable design space exploration, together with interoperable standards that support integration, scalability, and reuse across systems (Panarotto et al., 2023; Machchhar et al., 2024a). At the same time, resilience must be embedded as a non-functional requirement, with twins and shadows supporting continuous monitoring, availability assurance, early detection of misalignments, and robust decision-making under uncertainty (Campanile et al., 2023). Yet, current research provides only partial solutions. Resilience is often modeled using stochastic approaches and cost-based adaptation measures (Alexopoulos et al., 2022), while more sophisticated causal-loop dynamics are proposed to capture DT behavior for resilience analysis (Sanchez et al., 2024).

The notion of Cognitive Digital Twins further extends this direction by introducing perception, reasoning, and learning capabilities to better handle complexity and uncertainty (Eirinakis et al., 2022). Synthetic Training Environments offer a complementary approach by enabling realistic simulation for training, testing, and design exploration. They support iterative prototyping, stakeholder collaboration, and behavioral analysis through metrics such as user experience and frustration (Spicer et al., 2015). When combined with DTs and digital shadows, they can strengthen resilience engineering by enabling safe exploration of failure modes and adaptation strategies. However, these approaches remain difficult to integrate and scale in practice. Overall, three main gaps persist. First, resilience is inherently multifaceted and stochastic, requiring models that capture both internal dynamics and external disruptions (Eirinakis et al., 2022). Second, limitations in data quality, availability, and volume constrain DT accuracy and usefulness (Alexopoulos et al., 2022). Third, most existing approaches focus on supply chains rather than product and production system resilience.

3.2 Process Simulations

VUCA contexts call for a flexible, fact-based exploration of multiple system-of-systems alternatives to enable informed decisions under uncertainty (Toller et al., 2025). Yet, existing simulation approaches often lack the adaptability needed to address evolving operational conditions, real-time complexity, and strategic insights across different levels of granularity (Hernandez et al., 2018). A key gap concerns the generation and management of simulation scenarios, which remains highly time-consuming despite its importance for uncertainty exploration. While automation techniques have been proposed (Hernandez et al., 2018), challenges persist in interoperability, data exchange, and communication during large-scale simulations. Methods such as the Extensible Scenario Modelling Method (ESMM) aim to address these issues through ontology-based scenario specification (Baek et al., 2024). In parallel, AI-based approaches have shown potential for anomaly detection and automated response support (Biroslavo et al., 2024), but remain limited and insufficiently validated (Spaniol and Rowland, 2023). Hybrid simulations that combine a discrete-event and agent-based logic are alos proposed to capture emergent behaviors in uncertain environments (Rondini et al., 2017). However, their adoption remains constrained by challenges related to scalability, flexibility, precision, and model validation and verification (Brailsford et al., 2019; Machchhar et al., 2024b), despite emerging examples in areas such as resilient cities and mining systems (Carramiñana et al., 2024; Toller et al., 2024).

3.3 Immersive data visualizations

Recent research explores the integration of Artificial Intelligence (AI) and Extended Reality (XR) (Xi et al., 2024), showing how AI-enhanced dashboards can improve the efficiency, accuracy, and interactivity of data analysis (Kumar et al., 2024; García-Peñalvo et al., 2022). Immersive visualization combined with real-time monitoring is also observed to enhance spatial understanding and support more intuitive interpretation of complex data (Sharma et al., 2024; Sivakumar et al., 2024). At the same time, multi-sensory XR environments (Karunanayaka et al. 2021) have demonstrated potential to improve immersion, situational awareness, and exploration of heterogeneous datasets through natural interactions such as gestures and gaze-based interfaces (Bordegoni et al., 2023; Zhang et al., 2023). These approaches may also support the identification of unexpected patterns and "unknown unknowns" in complex systems. Yet, the adoption of these tools is constrained by the high cost and complexity of sensory technologies, limited understanding of multi-sensory perception, and the lack of mature interaction patterns and interface designs (Zhang et al., 2023). As a result, the integration of simulation support with AI-enabled dashboards and XR remains underdeveloped.

4. RESEARCH CHALLENGES AND AGENDA

Building on insights from the literature review and empirical evidence collected across research partners, this section proposes a layered capability framework for the use of simulation support in VUCA environments (Figure 1). Each layer is further detailed in the form of key research questions that need to be investigated for the future development of collaborative digital decision-support tools that strengthen resilience, adaptability, and transformative innovation in rapidly changing industrial contexts.

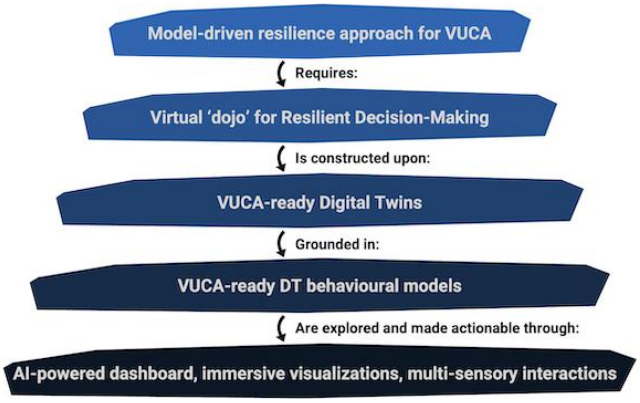

Figure 1: Layered capability framework for the use of simulation models in VUCA environments.

4.1 Toward a model-driven resilience approach for VUCA

In VUCA environments, the ability of a system to anticipate, absorb, recover from, and adapt to disruptions is critical. Firstly, one of the key challenges in designing a resilient system is determining the priorities and relevances of different resilience metrics to be considered. Traditional KPIs often fail to capture the full spectrum of resilience, especially when systems operate under uncertainty and unexpected disturbances. Secondly, the human factor is a critical aspect that often influences systems' behavior and performance, for instance, by detecting anomalies, making strategic decisions, or responding to unforeseen disruptions. The concept of human-in-the-loop underscores the need to seamlessly integrate human decision-making into digital models while maintaining situational awareness and decision support. Thirdly, as for any other model seeking to predict future behavior, even DT in VUCA environments must account for stochastic variations, incomplete data, and dynamic system behaviors. While uncertainty is ingrained in resilience modeling, there is a need to quantify, represent, and incorporate it in models to enhance decision-makers' awareness.

Such reflections lead to the formulation of the following research questions:

- What key resilience metrics shall be considered during system design in a VUCA environment?
- How can human-in-the-loop features be included in the modeling to enable real-time interventions?
- How can the ingrained uncertainty in resilience modeling be effectively and reliably quantified, represented, and incorporated?

4.2 Toward a Virtual Dojo for Resilient Decision-Making

In VUCA environments, effective decision-making under pressure depends not only on technical expertise, but also on the ability to interpret evolving situations, anticipate cascading effects, and respond to disruptions in a timely and coordinated manner. In this context, simulation-based and synthetic training environments can serve as a "virtual dojo" where decision-makers continuously train and strengthen their resilience during periods of relative stability, preparing them to better manage future crises and disruptions.

By integrating DT data, real-time system behavior, and evolving operational scenarios, such environments can support immersive and experiential learning. These simulation-driven environments enable decision-makers to safely explore complex situations, test alternative strategies, and improve situational awareness in realistic yet controlled settings. A further challenge concerns enabling collaborative, distributed training sessions in which multiple actors located across different geographic areas can interact simultaneously within the same virtual environment. Addressing this issue requires robust networked simulation architectures, real-time synchronization mechanisms, and low-latency interactions to ensure coherent and immersive shared experiences.

These considerations lead to the following research questions:

- How can simulation-based training environments integrate DT data and evolving operational scenarios to create realistic and situationally relevant VUCA training experiences?
- How can distributed and collaborative training sessions be supported through synchronized real-time interaction with shared virtual environments across multiple locations?

4.3 Toward VUCA-ready Digital Twins

DT are often positioned as a backbone for developing simulation-based training environments, such as ‘war rooms’ for VUCA contexts, enabling monitoring, simulation, and, ultimately, decision-making under conditions of high volatility, uncertainty, complexity, and ambiguity. The study, however, highlights that current applications and design approaches for DTs are constrained by limitations in interoperability, modularity, adaptability, and scalability, which, in turn, restrict their effective deployment in dynamic and uncertain operational environments. The integration and interoperability of heterogeneous data sources—including Internet of Things (IoT) sensors, Enterprise Resource Planning (ERP) systems, Manufacturing Execution Systems (MES), Product Lifecycle Management (PLM) platforms, and contextual environmental data—remain significant challenges.

Findings from the empirical study indicate that existing DT implementations often struggle to ensure consistent, reliable, and real-time data exchange across distributed systems, thereby limiting the accuracy and effectiveness of DT-based decision support. In addition, both industrial and public-sector stakeholders raised concerns about the modularity of current DT architectures. As systems become increasingly interconnected, existing DT solutions still provide limited support for modular aggregation, filtering, and fusion of heterogeneous data while maintaining the flexibility, scalability, and reusability required across multiple applications and operational contexts.

Scalability also emerged as a major research challenge. DT architectures must operate coherently across multiple levels of granularity—from individual components and machines to production systems and supply chains—while maintaining computational efficiency and consistency across interconnected models. At the same time, VUCA environments are characterized by rapidly evolving systems and operational conditions, requiring DTs to continuously adapt to new interactions, incoming data, changing behaviors, and emerging system configurations. However, current approaches still provide limited support for continuous learning, automated model evolution, and long-term synchronization between physical and digital systems. These considerations are synthesized into the following three research agenda questions:

- How can modular DT architectures enable flexible aggregation, filtering, and fusion of multi-source data while ensuring reusability and adaptability?
- How can DT architectures scale coherently across multiple levels, from components to system-of-systems?

- How can DT models continuously evolve and self-adapt to changing operational conditions without compromising reliability and performance?

4.4 Toward VUCA-ready DT behavioral models

The VUCA-readiness of DT behavioral models, which are process simulations that reveal emergent behaviors when a system responds to changing conditions, interactions, events, and external disturbances, was extensively discussed with the research partners. The development and test of sandboxes and demonstrators at varying levels of granularity was one of the major means of investigation aimed at revealing significant how such models should be designed and operated in VUCA contexts. These discussions consistently pointed to the need for a hybrid approach in developing simulation environments that integrates quantitative forecasting techniques, qualitative expert knowledge, and dynamic simulation models. This need arises from the frequent observation that such tools are developed and used in isolation—either to support strategic-level decision-making or technical engineering analysis—and are rarely treated as boundary objects capable of bridging these domains and enabling the co-design of resilient solutions.

DT behavioural models have been observed to span multiple scales, ranging from physics-based representations of molecular or mechanical interactions in operational assets (e.g., an excavator removing sand in a mine), to system-level dynamics involving coordinated assets and human operators in complex environments (e.g., fleets of vehicles and work crews in mining operations), and further to infrastructure-level interactions such as energy or resource systems (e.g., real-time load balancing in electrical networks supporting parallel vehicle charging). Integrating these heterogeneous modeling layers—along with associated decision points and stakeholder perspectives—enables hybrid simulation approaches that can identify bottlenecks, enhance system resilience, and support efficiency optimization and trade-off analysis.

A further key advantage of hybrid simulation is its ability to provide near real-time feedback by updating simulation outcomes as new data becomes available. When linked with digital twin architectures, this capability enables decision-makers to conduct virtual experiments in a risk-free environment, test alternative strategies, anticipate potential failures, and assess the effectiveness of mitigation measures. In summary, three research questions can be identified regarding the use of hybrid simulations in VUCA environments:

- How should DT behavioral models be designed to provide insight at both macro and micro system levels?
- How can DT behavioral models be designed to function as boundary objects between management and engineering teams?
- How can hybrid simulation be integrated into behavioral DTs to enable virtual experimentation of evolving scenarios across multiple decision-making levels?

4.5 Toward enhanced scenario exploration and sensemaking under VUCA conditions

The role of immersive visualizations and AI, in combination with digital twins and simulation-driven scenario exploration, has been discussed with research partners, primarily with the aim of strengthening sensemaking under VUCA conditions. These approaches are often viewed as mutually reinforcing, with the potential to enhance situational awareness within simulation environments, surface elements of tacit knowledge, and deepen understanding of both tangible and intangible emergent system behaviors under varying conditions, strategic choices, and alternative design configurations.

A growing body of research positions immersive technologies such as virtual and augmented reality as enablers of seamless collaboration within distributed teams and networks. Virtual collaboration environments are increasingly proposed as spaces where decision-makers can engage in complex analytical and deliberative processes independent of geographical constraints, while benefiting from varying degrees of sensory immersion and diverse visualization modalities. However, several open questions remain regarding their effectiveness, particularly regarding usability, cognitive load, and integration into existing operational workflows, prompting further inquiry in this area.

At the same time, complex simulation environments often involve heterogeneous data streams originating from multiple sources and formats. Integrating these into a coherent, unified view—potentially enriched with real-time updates—represents a significant challenge. For decision-making to be robust, such data must be aggregated with both accuracy and consistency. One promising direction to address this challenge is the use of AI-driven analytics and dashboard systems capable of processing large-scale datasets, identifying patterns, and generating predictive insights, while remaining intuitive, transparent, and accessible to human decision-makers. This requires the development of clear, interpretable, and user-centered interfaces that support effective human–AI interaction. To further explore the potential of AI-enabled and immersive technologies in VUCA contexts, the following research questions are identified:

- How can immersive technologies be maximized to support remote and multidisciplinary collaboration?
- How can multi-sensory interaction enhance the effectiveness of immersive environments for decision-making under VUCA conditions?
- How can AI-powered dashboards integrate data and deliver reliable predictive insights in VUCA environments?

Another important aspect of scenario exploration and sensemaking concerns the need to refine techniques for analyzing environmental signals in VUCA contexts and for balancing exploration and exploitation in innovation engineering. Second, challenges persist in integrating multidimensional value dimensions into decision-making processes. Moreover, methodological support is insufficient for predicting the future value of solutions in dynamically changing environments. In particular, greater emphasis is required on ensuring adaptability and maintainability of system functionalities under uncertain conditions (Machchhar et al., 2024). Existing processes for technical change management in systems engineering also require further development (Lechner et al., 2024), as they are not adequately designed to address VUCA-related factors. This includes

improving methods for assessing the value and resilience of design concepts under dynamic conditions (Specking et al., 2021) and for supporting the negotiation of value-added features across design alternatives. These challenges align with the perspective highlighted by Shet (2024), who emphasizes the importance of preparing individuals to navigate VUCA environments by strengthening cognitive flexibility, fostering an agile mindset, and cultivating personal ambidexterity, i.e., the ability to balance the exploration of new ideas with the effective exploitation of existing resources.

In such a context, sensing and analyzing weak signals, i.e., subtle, early indicators of potential trends or disruptions, can become critical to navigating complexities and ensuring resilience and agility. Weak signals often precede significant changes, allowing organizations to anticipate and respond proactively. However, traditional methods and tools are frequently insufficient to capture these nuanced indicators effectively, leaving open research possibilities investigating:

- How can we enhance the sensing, analysis, and utilization of weak signals for improved decision-making and value creation in design and manufacturing operations?
- How can we integrate weak signals consideration in established design methodologies to rapidly simulate alternative scenarios?

5. CONCLUDING REMARKS

This paper pinpoints the main challenges and required capabilities for designing simulation-driven decision-making environments in increasingly VUCA settings. The study points to the need for further research into the development of virtual "dojos" and synthetic training environments that enable resilient decision-making through simulation-based learning, allowing organizations to anticipate, act, and adapt effectively under conditions of volatility, uncertainty, complexity, and ambiguity. Such environments are envisioned as being built upon VUCA-ready Digital Twins, grounded in adaptive DT behavioural models, and operationalized through AI-powered dashboards and immersive visualizations. The proposed research agenda, composed of 14 research questions across 5 layers, emphasizes the importance of sustained investment to advance the maturity of digital tools and simulation-enabled decision-support capabilities capable of addressing both operational and systemic complexities. More broadly, the agenda aspires to provide a roadmap for the development of more robust, adaptive, and insightful simulation-supported decision-making methods and technologies suited to highly complex and unpredictable environments.

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REFERENCES

Alexopoulos, K., Anagiannis, I., Nikolakis, N. and Chryssolouris, G., 2022. A quantitative approach to resilience in manufacturing systems. International Journal of Production Research, 60(24), pp.7178-7193.

Baek, Y.M., Cho, E., Shin, D. and Bae, D.H., 2024. An Extensible Modeling Method Supporting Ontology-Based Scenario Specification and Domain-Specific Extension. International Journal of Software Engineering and Knowledge Engineering, 34(01), pp.91-162.

Baran, B.E. and Woznyj, H.M., 2020, "Managing VUCA: the human dynamics of agility", Organizational Dynamics, Vol. 50 No. 2, 100787, doi: 10.1016/j.orgdyn.2020.100787.

Bennis, W., & Nanus, B., 1985. The strategies for taking charge. Leaders, New York: Harper. Row, 41.

Biloslavo, R., Edgar, D., Aydin, E., & Bulut, C., 2024. Artificial intelligence (AI) and strategic planning process within VUCA environments: a research agenda and guidelines. Management Decision.

Bordegoni, M., Carulli, M., & Spadoni, E., 2023. Multi-sensory Interaction in eXtended Reality. In Prototyping User eXperience in eXtended Reality (pp. 49-63). Cham: Springer Nature Switzerland.

Brailsford, S.C., Eldabi, T., Kunc, M., Mustafee, N. and Osorio, A.F., 2019. Hybrid simulation modelling in operational research: A state-of-the-art review. European Journal of Operational Research, 278(3), pp.721-737.

Campanile, L., de Biase, M. S., De Fazio, R., Di Giovanni, M., Marulli, F., & Verde, L., 2023. Merging Model-Based and Data-Driven Approaches for Resilient Systems Digital Twins Design. In 2023 IEEE International Conference on Cyber Security and Resilience (CSR) (pp. 301-306). IEEE.

Carayannis, E.G., Papamichail, G., Zotas, N., & Askounis, D., 2025. Corporate foresight: navigating uncertainty in a VUCA world. Journal of the Knowledge Economy, 16(6), pp. 17494-17515.

Carramiñana, D., Bernardos, A.M., Besada, J.A. and Casar, J.R., 2024. Towards resilient cities: A hybrid simulation framework for risk mitigation through data-driven decision making. Simulation Modelling Practice and Theory, 133, p.102924.

Cornish, F., Breton, N., Moreno-Tabarez, U., Delgado, J., Rua, M., de-Graft Aikins, A., & Hodgetts, D., 2023. Participatory action research. Nature Reviews Methods Primers, 3(1), 34p.

Eirinakis, P., Lounis, S., Plitsos, S., Arampatzis, G., Kalaboukas, K., Kenda, K., Lu, J., Rožanec, J.M. and Stojanovic, N., 2022. Cognitive digital twins for resilience in production: A conceptual framework. Information, 13(1), p.33.

García-Peñalvo, F.J., Vázquez-Ingelmo, A. and García-Holgado, A., 2022, June. Fostering Decision-Making processes in Health Ecosystems Through Visual Analytics and Machine Learning. In International Conference on Human-Computer Interaction. Cham: Springer International Publishing, pp. 262-273

Hernandez, A.S., Hatch, W.D., Pollman, A.G. and Upton, S.C., 2018, December. Computer experimentation and scenario methodologies to support integration and operations phases of mission engineering and analysis. In 2018 Winter Simulation Conference (WSC) (pp. 3765-3776). IEEE.

Karunanayaka, K., Nijholt, A., Halloluwa, T., Ranasinghe, N., Wickramasinghe, M. and Vyas, D., 2021, August. Multi-sensory augmented reality. In IFIP Conference on Human-Computer Interaction. Cham: Springer International Publishing, pp. 558-563

Kumar, Y., Marchena, J., Awlla, A. H., Li, J. J., & Abdalla, H. B., 2024. The AI-Powered Evolution of Big Data. Applied Sciences, 14(22), 10176.

Lechner, J., & Schlüter, N., 2023. Sustainable and Resilient System Development in a VUCA-World: An Empirical Study to Develop a Process Orientated Method of Risk and Technical Change Management in Automotive Industry. Proceedings of the Design Society, 3, pp. 3255-3264.

Lechner, J., Schlüter, N., & Fahrner, A., 2024. Sustainable Design Process Management in a VUCA-World–A Survey on Risk and Technical Change Management in Automotive Industry. Procedia CIRP, 128, pp. 333-338.

Machchhar, R. J., Melén, C. N. K. T., & Bertoni, A., 2024a. A tradespace exploration approach for changeability assessment from a system-of-systems perspective: application from the construction machinery industry. Proceedings of the Design Society, 4, pp. 2655-2664.

Machchhar, R.J., Bertoni, A., Wall, J. and Larsson, T., 2024b. Incorporating changeability for value-robust productservice systems: an integrative review. Design Science, 10, p.e8.

Panarotto, M., Isaksson, O., & Vial, V., 2023. Cost-efficient digital twins for design space exploration: A modular platform approach. Computers in industry, 145, 103813.

Rondini, A., Tornese, F., Gnoni, M.G., Pezzotta, G. and Pinto, R., 2017. Hybrid simulation modelling as a supporting tool for sustainable product service systems: a critical analysis. International Journal of Production Research, 55(23), pp.6932-6945.

Ruvald, R., Cockayne, W., & Carleton, T., 2024. How teams use tangible prototypes to move from future speculation to Decisions When Developing Resilient Product-Service Systems. Smart Services Summit: Building Resilience in a Changing World, p. 195.

Sanchez, M.A., Rossit, D. and Tohmé, F., 2024. Enhancing production system resilience with digital twin-driven management. International Journal of Computer Integrated Manufacturing, pp.1-20.

Sharma, M., Puri, C. and Kumar, P., 2024, October. A Review: Transformative Impact of Data Visualization Across Various Industries. In 2024 8th International Conference on I-SMAC, pp. 799-804. IEEE.

Shet, S.V., 2024. A VUCA-ready workforce: exploring employee competencies and learning and development implications. Personnel Review, 53(3), 674-703.Balling, R. Design by Shopping: A New Paradigm. In Proceedings of the Third World Congress of Structural and Multidisciplinary Optimization, Buffalo, NY, USA, 17–21 May; pp. 295–297. 1999.

Sivakumar, M., Maranco, M., Krishnaraj, N., & Reddy, U.S., 2024. Data Analytics and Visualization in Smart Manufacturing Using AI-Based Digital Twins. Artificial Intelligence-Enabled Digital Twin for Smart Manufacturing, pp. 249-277.

Spaniol, M. J., & Rowland, N.J., 2023. AI-assisted scenario generation for strategic planning. Futures & Foresight Science, 5(2), e148.

Specking, E., Parnell, G.S., Pohl, E. and Buchanan, R., 2021. Engineering resilient systems: achieving stakeholder value through design principles and system operations. IEEE Transactions on Engineering Management, 69(6), pp. 3982-3993.

Spicer, R. et al., 2015. "Innovation and rapid evolutionary design by virtual doing: Understanding Early Synthetic Prototyping (ESP)". 2015 Fall Simulation Interoperability Workshop, SIW 2015

Toller, C.N.K, Machchhar, R.J., Wendin, C. and Bertoni, M. (2025) An integrated simulation framework for System-of-System value exploration, Design Science, In press.

Toller, C.N.K., Machchhar, R.J. and Bertoni, A., 2024. Merging agent-based simulation and vehicle dynamics: a hybrid approach for value exploration in the mining industry. Proceedings of the Design Society, 4, pp.2755-2764.

Toller Melén, C.N.K.T., Bertoni, M., & Askling, C.J., 2025. Effective system-of-systems simulation in a VUCA world: lessons learned for design decision-makers. Proceedings of the Design Society, 5, pp. 1435-1444.

Tuyen, N.C.B., 2025. Transformation of traditional to modern leaderships in the vuca environment. International Journal of Professional Business Review, 10(3), 7p.

Xi, M., Perera, M., Matthews, B., Wang, R., Weiley, V., Somarathna, R., & Thomas, B.H., 2024. Towards Immersive AI. In 2024 IEEE International Symposium on Mixed and Augmented Reality Adjunct ISMAR) (pp. 260-264). IEEE.

Zhang, Y., Wang, Z., Zhang, J., Shan, G. and Tian, D., 2023. A survey of immersive visualization: Focus on perception and interaction. Visual Informatics, 7(4), pp. 22-35.