International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 12 | Dec 2025 www.irjet.net p-ISSN: 2395-0072

Evaluation of a Framework for Integrated Web Services Using Simulation-as-a-Service and Cloud-Native Virtualization for Academic and Industrial Applications

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Abstract - *The growing transition from traditional stand-alone simulation tools to cloud-based simulation services has created an increasing demand for cloud-based Simulation-as-a-Service (SMaaS). Therefore this research provides an evaluation of a new cloud based platform which combines web-based simulation, training and analytical services in one cloud native platform by utilizing micro services and containerized orchestration technology. In addition, it provides resource utilization through the use of automated provisioning, dynamic pricing (adaptive licensing), and hybrid virtual machine (VM)-containerized deployment; it also supports the ability to scale performance in real-time across various types of academic and commercial users. An example case study using Polymer Portal and Manifold Flow Predictor showed that the proposed model is able to provide improvements in efficiency, reductions in operational costs, as well as higher levels of user satisfaction. Results from benchmarking studies demonstrated that the hybrid approach significantly reduces response times and computational overhead when compared to previous VM-based models. Finally, evaluations of user acceptance were completed using both TAM and UTAUT methods, which demonstrate that the proposed model is more usable and will be adopted at a greater rate than prior models. Therefore, the proposed model provides a base for further extension, including the use of AI-assisted prediction, collaboration between edge-clouds, and block chain enabled license transparencies.*

Key Words: **Simulation-as-a-Service (SMaaS), Web Services Integration, Micro services Architecture, Cloud Computing, High Performance Computing (HPC), Adaptive Licensing and Billing.**

1. INTRODUCTION

Simulation technology has traditionally been a vital component of research, design of engineering products and production in the industrial sector. Historically, nearly all simulation programs were standalone desktop applications that required special computer hardware configurations and considerable investment for license fees. In recent years with the pursuit by industry of the digital transformation of business, the delivery platform for simulation systems has undergone a dramatic shift from independent computing environment models to a distributed (cloud) based model. With this shift has come the opportunity for greater remote collaboration, lower costs and more accessible, and powerful, High Performance Computing (HPC) capabilities along with sophisticated analytical tools.

1.1 Evolution from Traditional Standalone Simulation Software to Cloud-Delivered Services

Simulation technology has traditionally been a vital component of research, design of engineering products and production in the industrial sector. Historically, nearly all simulation programs were standalone desktop applications that required special computer hardware configurations and considerable investment for license fees. In recent years with the pursuit by industry of the digital transformation of business, the delivery platform for simulation systems has undergone a dramatic shift from independent computing environment models to a distributed (cloud) based model. With this shift has come the opportunity for greater remote collaboration, lower costs and more accessible, and powerful, High Performance Computing (HPC) capabilities along with sophisticated analytical tools.

1.2 Rise of Micro services and Container Orchestration Transforming Cloud-Based Service Integration

From 2020 through 2024, modern cloud services have utilized micro-service architecture, and containerized services such as Docker and Kubernetes. Micro-services and containerized services enable the decomposition of large complex simulation systems into small, independent services which can be scaled up, updated, or independently deployed. In contrast to large monolithic systems, the use of micro-service systems decreases the operational overhead and increases the overall reliability of systems.

Orchestration of containers enables additional efficiencies in automation for resources, load balancing, and fault tolerance. Cloud service providers utilize orchestration of containers to provide seamless performance, increased availability, and faster time-to-deploy to SMaaS platforms which support multiple users running different simulation tasks with variable computational requirements.

1.3 Increasing Industrial Demand for Real-Time Simulation, Lightweight Licensing Models, and Remote Access

Manufacturing, Automotive, Aerospace, Polymer, and Materials Engineering industries rely on Real-Time Analysis and Simulation-Driven Decision Making. With shorter Product Development Timelines, it is necessary to receive faster Feedback with Reduced Reliance on Physical Prototypes. The need for Online Simulation Platforms that enable Users to Rent Computational Power instead of Purchasing Perpetual Licenses has increased due to this.

Subscription-Based Licensing and Pay-Per-Use Billing allows users to have access to Professional Simulation Tools, eliminating the need to purchase a Long-Term Perpetual License. Also, Remote Access through Web Portals and Virtual Environments, enable Teams from various Geographical Locations to Collaborate Effectively, thus Improving Productivity and Reducing Operational Delays.

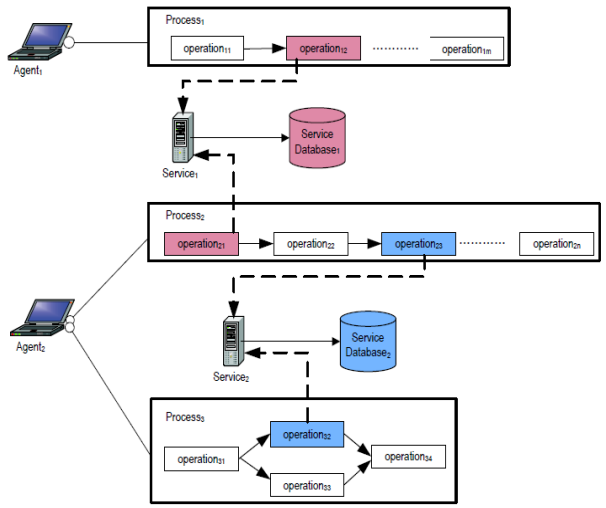

Figure 1: Process Execution in an SOA

1.4 Research Gap between Monolithic Simulation Deployment and Distributed SMaaS Models

Even though the use of cloud computing is expanding, many current simulation systems continue to be built on tight, monolithic deployment architectures that have difficulty with scalability, cost of maintenance, and can't accommodate a wide variety of user needs due to a rigid design. As simulations in real-world settings are evaluated, monolithic simulation environments are shown to have great difficulties in handling fluctuation in workload (i.e., when the demand for a simulation increases such as at an academic peak time, or when a continuous high volume of requests are generated in an industry), and therefore may require a distributed, service-oriented architecture that will allow the integration of simulation tools through web services and scalable resource management. The proposed model would also provide users with multi-tenant access, distribute the load across all available processors to increase system performance, and simplify the process of managing software licenses and user authentication.

1.5 Contributions of the Study

This research introduces an integrated framework that enables simulation services to be delivered through a scalable cloud-based architecture. The key contributions include:

1.5.1 A Scalable Service-Oriented Model

A framework that uses web services to integrate multiple simulation tools within a unified portal, allowing users to access resources through a common entry point with single sign-on capabilities.

1.5.2 Usability, Cost, and Performance Evaluation

A quantitative evaluation of the framework based on user experience, cost effectiveness, computation performance, and practical adoption in both industrial and academic settings.

1.5.3 Integration of Cloud Resource Automation

The incorporation of modern automation techniques such as virtualization, containerized deployment, and dynamic resource allocation to improve responsiveness and system efficiency.

2. LITERATURE REVIEW

Web service technology development and transition from traditional, self-contained applications to distributed Service Oriented Architecture (SOA), has had a significant impact on both design and delivery of simulation services. New Cloud Computing, Micro Services, High Performance Virtualization, Automated Resource Orchestration, Intelligent Licensing Frameworks, etc. are facilitating the development of scalable and accessible Simulation as a Service (SMaaS) platforms. This section will provide an overview of literature regarding Web Service Technologies, HPC Based Simulation Delivery, Evolving Billing Strategies, and End User Portal Evaluation Models.

2.1 Web Services, SOA and Micro-Service Trends

2.1.1 Traditional SOA vs. Micro services vs. Server less Frameworks

Service-Oriented Architecture (SOA) has become a common approach to integrate business process and software component in various locations. In traditional SOA, business processes are orchestrated through a central control point and communication between different system components is typically conducted with standard protocols. With increased scalability of the systems, this architecture will increase both

complexity and performance bottleneck. Micro services, on the other hand, partition an application into many small, independent services, each capable of being independently deployed and scaled. Due to their ability to independently deploy and scale, micro services are more suited than traditional SOA for cloud-native simulation services that have to deal with a variety of workloads and multiple user groups. Additionally, Server less Computing has emerged as an alternative to micro services due to its lack of requirement for management of the application server(s), and automatically scales depending on demand alone; therefore, suitable for unpredictable simulation workloads.

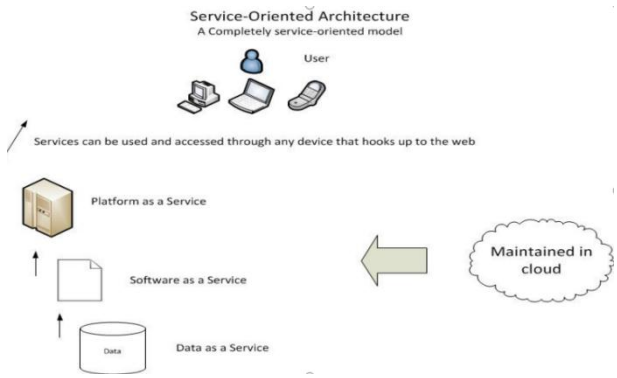

Figure 2: Web Service Models in a Service-Oriented Architecture [3].

2.1.2 Modern Service Dependency Handling Using Event-Driven Orchestration

Orchestration models based on event triggers have developed as a method of controlling dependency relationships between large-scale distributed services. Compared to the traditional use of workflow management to control the flow of data between services, event-triggered systems create new flows of activity by triggering the execution of a service (or set of services) upon occurrence of an event that has been identified as relevant to that activity. By creating these flows of activity at the time of the event occurrence, this model provides improved performance responsiveness, better fault isolation and higher throughput in real-time environments. As such, event-triggered orchestration models are being widely adopted within the design of newer SMaaS platforms to manage the task of coordinating simulation processes, scheduling jobs, and executing result processing pipelines.

2.1.3 Updated Approaches for API Standardization

While previous generations of web service technology commonly utilized SOAP/WSDL based communications, today a significant number of Web Service developers utilize REST full APIs, Open API Specifications as well as emerging Graph QL based interfaces due to their flexible nature, lower communication overheads and easier integration across cloud computing platforms. This newer generation of API technologies will provide better interoperability among simulation services, e-commerce components and resource provisioning layers within an integrated framework for web services.

2.2 Simulation-as-a-Service and High-Performance Computing

2.2.1 Container-Based HPC Simulation vs. VM-Based Deployment

In traditional Cloud Simulation Systems, virtual machines (VMs), have been used to create a "sandbox" environment for each user. VMs provide a level of isolation that allows developers to configure their applications in the same way across different platforms, but at the cost of increased resources and longer deployment times. A new type of virtualization tool is container-based virtualization, with tools such as Docker, which provides lightweight, portable and fast execution environments. This has made it an attractive option for use in High Performance Computing (HPC)-based simulation workflows. Containers allow users to scale up/down with ease and make efficient use of system resources when performing repeated simulation jobs.

2.2.2 Use of Kubernetes and Docker for Runtime Automation

Kubernetes has become an industry standard for automation of distributed orchestration for containerized applications. In addition to providing automation for resource provisioning, job scheduling, fail-over and scaling of simulation workloads, integration of Kubernetes with Docker-based simulation services provides SMaaS (Simulation-as-a-Service) providers the ability to dynamically allocate computing resources in response to real-time usage of the service, allowing for reduced costs while maintaining high levels of performance reliability.

2.2.3 Edge-Cloud Collaborative Simulation for Low-Latency Computation

Research studies have recently investigated hybrid computing models that combine both cloud based processing and edge-based processing. In automated manufacturing and other industrial applications which are time sensitive, to achieve timely (real-time) process monitoring and optimization is critical and will require a minimum amount of latency. A method for collaborative simulation between edge and cloud is edge-cloud collaborative simulation. This method involves pre-processing or partial model execution at the physical location of the sensor(s) or device (edge), and the remaining and/or complex calculations will be executed on the cloud. Therefore, edge-cloud collaborative simulation improves the speed and reliability of the overall system, reduces its dependency on the network, and maintains the required level of system stability.

2.3 Licensing & Cloud Billing Models

2.3.1 Usage-Based Licensing in Commercial Simulation Platforms

Simulation engineering software licensing is moving from a perpetual or extended subscription license model to a "pay-per-use" model where engineers are charged only by their actual use of the software (by computation time, or frequency of use), this will dramatically lower the economic barrier for academics as well as smaller industry organizations in utilizing high-end simulation software.

2.3.2 Block chain-Enabled Transparent Software Licensing

Recently, block chain based smart contracts have been proposed as a way to improve software license verification, license usage tracking and billing transparency. The use of a distributed ledger that is immutable allows the transactions associated with licensing to be recorded securely so that unauthorized access can be prevented, license distribution among multiple tenants can be ensured fairly and secure audit trail records can be created for both service providers and customers.

3. PROBLEM DEFINITION

The need to provide flexibility, scalability, and cost-effective access to high-performance computing resources has led to significant advancements in computational engineering and industrial simulation. Nevertheless, there is a large number of the currently used simulation environments based on the so-called "legacy" systems, where these legacy systems work as isolated monolithic structures, thus limiting the availability, performance, and affordability of these systems. The aforementioned limitations represent a hindrance for both industrial customers that use continuous simulations to develop products and academic customers that have limited access to the system with fluctuating usage demands. This section will identify the primary challenges that are motivating the development of an SMaaS framework as a service integration model.

3.1 Cost and Scalability Limitations of Legacy Simulation Systems

The majority of traditional simulation software applications require significant investments in expensive perpetual licenses, specialized hardware configurations as well as continuing support and maintenance. Consequently, the investment cost is elevated (especially for small-to-medium enterprises and education-based institutions) since they are unable to afford a large initial expenditure. In addition to being costly, legacy simulation deployment methodologies lack flexibility — resources do not scale with demand; therefore, if utilization is low then computational capability remains idle while during high demand there may be insufficient computational capability. The limitations imposed by the above constraints limit both the wider use of simulations and innovation.

3.2 Performance Bottlenecks during Usage Spikes in Academic Environments

Usage of academic environment's simulation tools varies significantly based on an academic setting's schedule (lab sessions, due dates for assignments and group projects), which can cause a surge in demand for these types of software tools at various times. However, legacy systems fail to adapt to dynamic requests for more computing power, as such, students experience slow responses, job queue backlogs, and failed access when multiple users attempt to use them simultaneously. These system performance limitations negatively impact student learning experiences and prevent timely running of critical simulations. Therefore, a scalable architecture is required to ensure that the services continue to operate reliably while the load on those services changes throughout the day.

3.3 Need for Intelligent Resource Adaptation Instead of Fixed Configuration

Traditional simulation frameworks provide a static amount of computing power to an individual application or user community (not dynamically based on current workload or priority). Static provisioning can result in wasted computing power and is inefficient in both academic and business settings. The ability to manage computing resources through intelligent means (through dynamic scaling and runtime allocation) has become critical to meet demand as it relates to simulation applications. The need for resource flexibility will be critical in modern cloud-based simulations as they will require continuous adaptation to meet changing simulation demands with optimal costs and performance.

4. PROPOSED FRAMEWORK

The proposed framework provides a scalable, service-based solution for offering simulation software as part of a cloud-integrated platform; it offers a modern alternative to traditional simulation systems that are limited in their ability to take advantage of cloud-based computing resources (i.e., cloud-native virtualization, micro-services, adaptive resource utilization). The proposed framework utilizes cloud-based services to provide streamlined access to software, improved computational performance, flexible licensing options and enhanced user experience via a single service catalog.

4.1 System Architecture

The system architecture is based on a multi-layer design that enables seamless integration of simulation services, training modules, and analytical tools within a unified portal. The framework is constructed using three core modern

computing approaches: cloud-native virtualization, micro service deployment, and federated identity management.

4.1.1 Cloud-Native Virtualization

The ability to scale and dynamically allocate computing resources is a key benefit of using cloud-based virtualization for running simulation software in a cloud-native environment. Simulation software can run either as a virtual machine (VM) or a containerized instance as needed and therefore does not require a fixed amount of compute resources prior to running. As a result, cloud-based virtualization also offers scalability which allows for high-performance computing during peak workload conditions that would otherwise limit traditional static configurations. Therefore, it provides a common platform for both academia and industry to utilize simulation tools with less concern for hardware limitations or the complexity associated with configuring systems.

4.1.2 Micro service Deployment Model

A micro service based architecture is utilized in order to create a larger simulation system from multiple smaller services which are able to operate independently, to be deployed separately, to be updated individually and/or to scale each service independently; this will allow for greater reliability, enhanced ability to perform maintenance and faster deployment times for simulation services that are being used in an integrated manner.

4.1.3 Identity Federation Using SSO, OAuth2, and OpenID Connect

The use of federated identity management with Single Sign-On (SSO), along with modern authentication methods like OAuth2 and Open ID Connect, has made it easier for users to sign-in one time and then be able to access all authorized tools and systems through the portal, therefore no longer having to sign into each system separately. Federated identity management with SSO increases the user's ability to produce work while also increasing the ease of use by decreasing the number of times that a user must sign-in.

4.2 Service Delivery Workflow

The framework provides a workflow that is completely automated and for delivering services related to simulations; the framework can manage all aspects of a simulation service request's lifecycle from the time the user logs into the system until they have access to results of their computation. The framework also provides a self-service model where users select a service from the catalog and then the system will automatically provision all resources required for the selected service as needed, including virtual machines and/or containerized instances based on real-time demand. The provisioning process has all aspects of automation, which include resource allocations (compute, memory, and storage), license validations, load balancing, and monitoring to ensure that the service provided is consistent and stable.

An additional function of the framework's workflow is the scheduling of container-based workloads for the purpose of optimizing workload distribution. As part of this process, the framework utilizes Kubernetes to orchestrate the launching of simulation-based workloads. By utilizing Kubernetes, the framework ensures that the containers are launched on available compute nodes with no conflicts regarding the use of those resources. The optimized workload distribution reduces waiting time for both the user and the system, eliminates resource contentions, and allows for continuous service availability for large numbers of users.

5. IMPLEMENTATION

The deployment of the proposed SMaaS framework shows an example of how to integrate cloud-based simulation and web services into real world environments. To demonstrate the SMaaS framework's feasibility, two case studies were developed as cloud-native virtualized, web-integrated applications — Polymer Portal and Manifold Flow Predictor — which demonstrated the ability to test the performance of the system; the user experience; and the adaptive management of resources for both academic and industrial users. This project demonstrates that Simulation-as-a-Service (SMaaS), with features including automated computing resource allocation, dynamic licensing, and central access via a web interface, is viable.

5.1 Case Study Applications

Two of the most commonly used simulation tools in both materials science and engineering were incorporated into this framework for purposes of demonstrating the feasibility of the proposed architecture. The two tool examples were selected based on their ability to provide differing types of simulation workload that could potentially be executed by a distributed cloud computing environment, with the potential benefits of providing real-time performance and user interface enhancements.

5.1.1 Polymer Portal

The Polymer Portal is a comprehensive simulation-based application that is intended for use in the evaluation of materials, product development and process selection for polymers. This portal provides access to a variety of different simulation services as well as several training tools which are used by both industrial personnel and research academics to predict how a polymer behaves when subjected to varying forms of processing. A major advantage of the Polymer Portal's cloud-based architecture is the ability to remotely run complex simulations without having to acquire expensive local computer systems capable of running these applications. The Polymer Portal uses high-performance virtual computing nodes which are allocated dynamically to

meet current workload demands. Integration of the Polymer Portal into the framework also results in faster computation times and cost effective licensing options; both of which reduce operational costs and encourage greater utilization of this technology within engineering firms.

5.1.2 Manifold Flow Predictor

The Manifold Flow Predictor tool is a valuable asset for analyzing flow behavior and evaluating performance of multi-branch manifold systems. The predictor is utilized across a variety of applications within both mechanical and fluid dynamics engineering to assess the flow behaviors, pressure losses and overall efficiency of the system. As part of the overall framework of the implementation, the application utilizes container-orchestration based execution environment to enable fast start-up times, allow for concurrent job execution and to control the resources allocated for each job. This method allows numerous users to execute their own simulation at the same time and avoids slowing down the computer system by having all jobs executed one after another. Data obtained as a result of the case study indicate that the cloud managed version of the configuration allows for faster job execution than when the user installs the application themselves using local software.

5.2 Research Extension: Integration of AI-Based Prediction Models

The implementation framework will create opportunities for integration of artificial intelligence and machine learning modeling in simulation workflows. Artificial Intelligence (AI) based prediction can improve the accuracy of simulation results while decreasing computation time by predicting near optimal results before complex simulations are executed. The ability to provide early feedback to both engineers and students will help to reduce the amount of iterative work and improve the speed of decision making. Future plans to extend this system include incorporation of Predictive Analytics modules that use historical simulation data to suggest the best initial configuration for a simulation, predict the outcome(s) of the simulation, and/or determine the optimal parameter(s) for material or design. Positioning AI within the Service Catalog will position the framework for Real-Time Intelligent Simulation Environments that utilize hybrid models combining Physics-Based Simulations with Data-Driven Predictions of Performance.

6. EVALUATION & RESULTS

User feedback was utilized as part of an evaluation to determine if the proposed architecture can be used efficiently and effectively by users, at a reasonable cost, and in a real-world setting for both educational and industry applications. User studies were conducted to evaluate the usability of the architecture, benchmarking performance studies were also conducted to compare performance of the proposed architecture to current architectures in the field of simulation, and various configurations of the architecture were tested against one another in a comparative study format. These studies provided insight into how cloud-based simulation service improves access to simulations, speed of computation, and usage of resources compared to locally installed and expensive equipment.

6.1 User Study

A user evaluation study was conducted to understand the acceptance, usability perception, and practical benefits of the implemented Simulation-as-a-Service framework. The study included participants from both academic institutions and industry organizations with varying levels of simulation expertise.

6.1.1 Incorporation of Technology Acceptance Model (TAM/UTAUT) Questionnaires

User satisfaction and willingness to utilize the platform was measured by using TAM and UTAUT standardized surveys, as both models evaluate perceived usefulness, perceived ease of use, behavioral intention, and actual system utilization. In addition to these metrics, participant feedback showed that users felt a high level of confidence regarding their ability to easily access the system; especially appreciated by the users were the unified portal feature of the system which provided one-stop shopping for all simulations, and a simple sign-on process. Users also appreciated being able to access several simulation services through the system with little or no need to configure each service individually.

6.1.2 Performance Metrics Measurement

More metrics were collected to determine technical efficiency in addition to the performance evaluation parameters. These included: Response time of systems while performing tasks with multiple users at the same time; Resource usage optimization during peak simulation tasks; Cost reductions in comparison to locally installed simulation environments. The data showed that the automated method of allocating resources to simulations resulted in significant decreases in wait times for users and increases in simulation processing rates, as well as overall cost reductions using a "pay-as-you-go" model of utilizing shared resources.

7. CONCLUSION

The proposed framework for integrated web-based simulation services demonstrates a viable solution to the challenges associated with traditional standalone simulation systems. By incorporating cloud-native virtualization, micro services architecture, and automated resource provisioning, the system successfully delivers scalable, cost-efficient, and user-friendly access to simulation tools. The implementation of case study applications such as the Polymer Portal and the Manifold Flow Predictor validates the effectiveness of the model in both academic and industrial settings. Evaluation

results indicate significant performance improvement, reduced operational cost, and enhanced usability through unified service access and dynamic pay-per-use licensing. Overall, the study confirms that Simulation-as-a-Service (SMaaS) can substantially improve productivity, accelerate engineering workflows, and expand accessibility to advanced computational resources.

8. LIMITATION

Although the proposed framework appears to have a number of positive results, there are several constraints that should be acknowledged. Cloud based simulation services (performance & accessibility) will depend on a reliable high speed internet connection; therefore, this may pose a challenge for regions with minimal or no internet infrastructure available. Many commercially developed simulation programs require proprietary hardware support, which could limit them from being directly deployed as a container application and could necessitate a hybrid configuration approach. Interoperability issues may develop with third party tools if they use varying data formats or licensing agreements. Although users provide an overwhelming level of acceptance with respect to using the platform, additional research is required to assess the platforms' impact over time as well as its ability to assist industry's and other large groups of users.

9. FUTURE SCOPE

The future development of this framework offers numerous enhancements that can help expand its use, as well as the intelligence of the framework. Future enhancements include using artificial intelligence (AI)-based predictive modeling to enhance the accuracy of simulations and to accelerate computation cycles by generating a near-optimal result prior to executing the simulation; expanding the capabilities of hybrid cloud and edge computing so that simulations are executed in real-time for time sensitive industrial applications; and integration of block chain based licensing and data protection to provide additional transparency in billing and access controls. Additional areas of study that could be researched include automated workload forecasting, zero trust security authentications, and the expansion of service catalog offerings with additional domain specific simulation tools, interactive training modules, and enhanced analytics. The ongoing development of the framework, if it continues to evolve, has the potential to become an intelligent autonomous simulation environment that supports wide spread digital transformation across the disciplines of engineering, manufacturing, and education.

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