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LARGE LANGUAGE MODEL-DRIVEN WORKFLOW FOR REGULATORY REPORTING IN NUCLEAR CONSTRUCTION

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ABSTRACT

The nuclear construction industry is subject to strict regulatory requirements, which require extensive reporting to ensure compliance with safety and quality standards. Traditional regulatory reporting processes are labor-intensive and inefficient due to the vast volume of requirements data, including inspection records, quality and acceptance criteria, and regulatory codes. However, existing approaches cannot analyze unstructured text data or automate complex reporting tasks, leading to reliance on manual processes that are time-consuming and potentially inconsistent. This paper presents a Large Language Model (LLM)-driven workflow designed to address these challenges. The proposed workflow involves fine-tuning an LLM to understand and process complex regulatory requirements. LLMs are uniquely suited for this task due to their advanced capability to capture intricate patterns, context, and semantic nuances within large volumes of regulatory documents. The workflow then focuses on streamlining the preparation and submission of regulatory reports documentation by using the unique generative capabilities of LLM. Unlike traditional systems that only retrieve and match information, LLMs can generate contextually accurate and well-structured regulatory reporting content. This generative feature allows the LLM to suggest the most appropriate content, ensuring accuracy and consistency while reducing the time and effort needed by regulatory inspectors. The LLM-driven workflow can efficiently automate these regulatory reporting tasks, enhance compliance tracking, reduce manual workload, and improve documentation accuracy.

INTRODUCTION

Inefficiencies and delays in regulatory reporting cause significant disruptions in nuclear construction projects, leading to project slowdowns, increased costs, and potential regulatory penalties (World Nuclear News, 2022; U.S.NRC, 2022, 2024). The nuclear construction industry operates under strict regulatory oversight to ensure safety, reliability, and environmental compliance. Regulatory agencies such as the US Nuclear Regulatory Commission (NRC) require extensive reporting throughout the design, construction, and inspection phases to verify that projects meet safety and quality standards (U.S.NRC, 2025). The extensive manual effort required to compile, verify, and submit compliance documentation, which involves handling vast amounts of regulatory codes, design control documents, inspection records, testing reports, and acceptance criteria, contributes to prolonged approval processes, delaying project timelines and increasing administrative burdens (U.S.DOE, 2012).

Despite advances in digital documentation, regulatory reporting remains an inefficient and labor-intensive process, heavily reliant on manual review, data extraction, and cross-referencing. Engineers, compliance officers, and regulatory professionals must navigate complex, unstructured texts to interpret regulatory requirements and ensure alignment with federal codes and industry standards, a process that significantly slows down compliance verification and increases the risk of errors and inconsistencies.

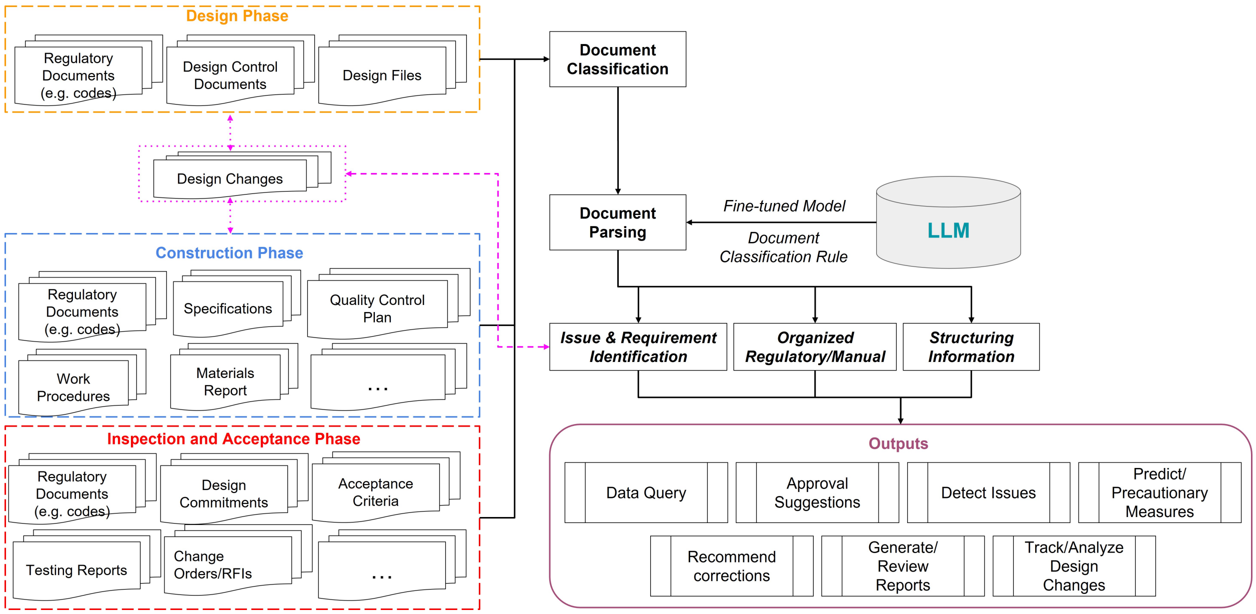

Figure 1. The LLM-driven workflow for regulatory reporting in nuclear construction.

To address these challenges, this study proposes a Large Language Model (LLM)-driven workflow to automate and streamline regulatory reporting in nuclear construction (Figure 1). The workflow begins by using the capabilities of LLMs to process and classify regulatory documents, specifically fine-tuning the model to extract target information nuclear-specific requirements successfully. It extracts compliance-related information from unstructured text to identify issues and discrepancies, thereby automating the generation of regulatory reports and notifications. This automation significantly reduces manual effort while ensuring accuracy and consistency. By adopting LLMs into compliance checking and document processing workflows, this approach improves efficiency, lessens the burden on regulatory professionals, and enhances the accuracy of regulatory reporting in nuclear construction.

This study introduces a conceptual LLM-driven regulatory reporting workflow, outlining its structure, methodological approach, potential applications, and anticipated benefits. As the research is ongoing, this paper focuses on presenting the workflow's design and theoretical foundation, highlighting key challenges and knowledge gaps that need to be addressed for its full implementation and validation in future studies.

BACKGROUND

Regulatory reporting in the Architecture, Engineering, and Construction (AEC) domain plays a critical role in ensuring that projects adhere to legal, safety, and quality standards imposed by governing bodies. It involves the systematic documentation, submission, and verification of compliance-related information throughout a project's lifecycle (McGibbney and Kumar, 2015). Regulatory reporting encompasses a wide range of documents, including design approvals, material compliance reports, safety inspections, environmental impact assessments, and final acceptance certifications (U.S.NRC, 2023). Traditionally, regulatory reporting in the AEC industry has relied on manual data collection, document review, and compliance verification (Zhang and El-Gohary, 2015; Zhang et al., 2023). Compliance officers, project managers, and engineers must compile information from drawings, contracts, inspection records, and construction logs, cross-reference them with relevant regulations, and prepare structured reports for submission to regulatory authorities. This process is often time-intensive and prone to human errors, leading to delays in project approvals and potential legal consequences in cases of non-compliance (Brogan et al., 2018; Macit İlal and Günaydın, 2017). To address these challenges, the industry has increasingly adopted digitalized regulatory reporting systems to streamline the regulatory reporting process, such as integrating Building Information Modeling (BIM)(Jiang et al., 2022), data management platforms (Jallow et al., 2017), or automated compliance checking tools (Zhang and El-Gohary, 2017).

Despite these advancements, existing regulatory reporting systems still face limitations, particularly in handling and interpreting unstructured regulatory texts, automating compliance checking, and report generation. To explore these challenges, the following sections examine each area's state of the art, highlighting recent developments and ongoing gaps in automating regulatory reporting within the AEC domain.

Information Extraction

Natural language processing (NLP)-based information extraction (IE) has been widely adopted in automated unstructured text extraction and analysis for its ability to analyze, interpret, and extract meaningful information from text-based data (Chung et al., 2023; Liu et al., 2023). Research on IE has primarily focused on two key areas: enhancing extraction performance and expanding its applications across different domains. To improve TE accuracy and efficiency, advanced computational techniques such as machine learning and deep learning models have been explored to recognize patterns, rules, and features that refine the extraction process (Chen and EI-Gohary, 2021; Wu et al., 2022; Zhang and El-Gohary, 2021). Beyond methodological improvements, IE has been widely applied to compliance checking and requirements documentation processing, addressing the labor-intensive nature of manual document review. By automating the extraction of construction documents, such as building codes, quality regulations, and safety requirements, IE techniques significantly reduce the effort required for regulatory verification (Xue and Zhang, 2022; Zhong et al., 2022). Despite these advancements, challenges remain in integrating IE into real-world regulatory workflows, particularly in handling complex, cross-referenced regulatory texts. Effective implementation requires significant manual effort in data preparation, rule definition, model development, and training, making it difficult to scale and adapt these solutions efficiently.

Automated Compliance Checking

Automated compliance checking (ACC) has emerged as a transformative approach to address the inefficiencies inherent in traditional manual regulatory reporting processes (Jiang et al., 2022; Saka et al., 2024). To address the inefficiencies associated with traditional compliance checking that relies heavily on human involvement, ACC integrates computational rule-checking frameworks (Jiang et al., 2022), natural language processing (Zhang and El-Gohary, 2016), machine learning (ML) (Wang and El-Gohary, 2023) and BIM (Nuyts et al., 2024) to automate the verification of design and construction documents against regulatory requirements. However, these ACC frameworks still rely on predefined rule sets, rigid ontologies, or static dictionaries, which limit their applicability to dynamic construction environments. Besides, recent advancements in generative AI (GenAI) have introduced new possibilities for automating regulatory report generation by enabling systems to synthesize compliance information, generate structured reports, and ensure consistency across regulatory submissions (Xiao et al., 2024).

THE PROPOSED WORKFLOW

As shown in Figure 1, the proposed LLM-driven workflow for regulatory reporting in nuclear construction projects consists of three modules: (1) Documents analysis, (2) Compliance checking, and (3) Automated report generation. Each module is designed to enhance the efficiency, accuracy, and automation of regulatory compliance checking and reporting by using a fine-tuned LLM. The workflow integrates document processing, compliance checking, and automated report generation, ensuring that design and construction activities align with regulatory requirements.

Documents Analysis

Each phase of the nuclear construction process requires comprehensive documentation to demonstrate compliance. In the design phase, regulatory requirements outlined in documents such as the Design Control Document (DCD) and American Society of Mechanical Engineers (ASME) codes must be meticulously followed. Any modifications to design specifications must be validated against these standards to ensure compliance before construction begins. During the construction phase, ongoing documentation, including material specifications, work procedures, and quality control reports, must be monitored for adherence to regulatory requirements.

This module integrates a hybrid requirements documents processing approach, where both document structure recognition and requirement classification occur simultaneously rather than in separate sequential steps. This hybrid workflow ensures efficient data extraction, filtering, and structuring before storage in a compliance database. The key objective is to convert raw regulatory documents into a structured format that facilitates downstream compliance checking and reporting.

To achieve this, the process first gathers a comprehensive dataset comprising regulatory codes, design documents, construction reports, and compliance records. These documents often contain both structured (e.g., tabular data) and unstructured (e.g., textual descriptions) information. Then, the workflow converts text-based nuclear requirement documents from PDF into a format that can be processed by LLMs (e.g., JSON). Given the complex layout of regulatory and project documents, PDF file parse solutions such as Donut (Kim et al., 2022) would be used to extract both textual content and document structure (e.g., tables, headings, sections, annotations) while preserving contextual relationships. This step ensures that compliance-critical information is accurately digitized without losing structural integrity. Once the document is in a processable format, the construction requirements ontology developed by Wang et al. (UnderReview) is a filtering mechanism to remove irrelevant content and ensure only requirement-related information is extracted and categorized. The ontology-driven filtering process maps extracted text to predefined regulatory categories, such as object, manner, and criteria, enabling the classification of regulatory clauses.

Simultaneously, the LLM structures and classifies extracted content before storing it in the database. Instead of relying solely on post-processing classification, the LLM processes text dynamically, applying Named Entity Recognition (NER), dependency parsing, and hierarchical text classification to assign compliance requirements to the correct ontology categories. The structured output is then stored in a knowledge graph or vectorized database, allowing for efficient retrieval, reasoning, and cross-referencing in later compliance checking stages. To ensure the LLM understands the domain-specific terminology and compliance requirements, the model undergoes fine-tuning using a curated dataset containing historical compliance reports, regulatory standards, and domain-specific glossaries. The fine-tuning process involves supervised learning techniques where labeled compliance-related text is used to refine the model's ability to classify, extract, and generate relevant regulatory content. Benchmark evaluations will be conducted to assess the model's accuracy in interpretation, cross-referencing, and compliance validation.

This hybrid approach ensures that regulatory content is accurately digitized, filtered, classified, and structured, significantly reducing manual preprocessing efforts while improving accuracy and compliance traceability.

Compliance Checking

This module assesses regulatory compliance in response to design changes and construction inspection-related concerns. In construction projects, design changes and on-site compliance issues frequently arise, necessitating real-time verification against applicable regulations. When a design change occurs, the system dynamically retrieves corresponding regulatory clauses from the ontology-driven compliance database. Similarly, if a compliance concern is raised during construction, the system references relevant work procedures, material standards, and quality control plans to assess alignment with regulatory requirements. The LLM-powered compliance checking engine, augmented with retrieval-augmented generation (RAG), ensures context-aware retrieval of relevant regulations based on the construction scenario. Using semantic similarity matching, the system identifies potential conflicts between design changes and regulatory guidelines. The workflow then generates automated compliance assessment reasoning output, outlining specific violations, recommended corrective actions, and necessary approvals to ensure compliance continuity. By automating compliance checking for design changes and construction inspection issues, this module minimizes the need for manual review and enhances real-time compliance monitoring.

Automated Report Generation

The nuclear construction inspections and acceptance processes require the submission of compliance reports such as ITAAC Closure Notifications (ICNs) under 10 CFR 52.99(c)(1). The proposed system automates the generation of these reports by integrating relevant data, thereby improving submission accuracy and reducing manual workload.

This module transforms compliance checking insights in the module of *Compliance checking* into structured regulatory reports and decision-support recommendations. This module facilitates efficient regulatory reporting and decision-making by integrating ontology-enhanced compliance data with identified compliance issues. The LLM applies template-based and AI-driven text synthesis to automatically generate compliance reports, including approval suggestions, issue detection summaries, and corrective action recommendations. These reports follow standardized regulatory formats, ensuring consistency and readability for compliance professionals. Additionally, LLM's predictive analytics ability can assess potential compliance risks and detect emerging non-compliance patterns. By providing proactive compliance risk mitigation strategies, such as real-time tracking of regulatory updates, impact analysis of design changes, and automated regulatory decision support, this module significantly enhances regulatory transparency and efficiency.

Potential Implementation of the Workflow

Welding is a critical process governed by strict quality and safety standards, and deviations, such as inconsistent welding parameters, interruptions in gas or electricity supply, or failure to track cross-sectional changes, can lead to non-compliance with regulatory requirements. This section presents a potential use case for implementing the LLM-driven regulatory reporting workflow in welding quality control (Figure 2). While this application has not yet been tested in a real-world scenario, it demonstrates how the proposed workflow could enhance automated compliance checking and regulatory reporting in welding-intensive nuclear construction projects.

The first step in implementing the workflow involves automated document classification and parsing to extract welding-related compliance requirements from regulatory codes and project specifications. Welding regulations contain detailed requirements on welding procedures, qualification tests, and process control parameters. The workflow will convert them into a structured, machine-readable format (e.g., JSON). The ontology-driven filtering mechanism ensures that only relevant compliance-related content is extracted and mapped to predefined categories, such as Welding Procedure Specification (WPS), material requirements, or inspection criteria. The fine-tuned LLM then structures and classifies the extracted content, storing it in a database for later retrieval during compliance verification.

Once regulatory documents are structured, the workflow enables real-time compliance verification by cross-referencing welding process data with applicable regulations. Welding activities on-site generate process data, including welding current, voltage, shielding gas supply, heat input, and material usage, which can be monitored using sensor-based tracking or manual data entry. If inconsistencies arise, the workflow retrieves relevant regulatory clauses using RAG and ontology-based rule matching. The LLM analyzes discrepancies, identifies whether they constitute regulatory violations, and determines necessary compliance actions. If non-compliance is detected, the system flags the issue, assesses its impact, and generates automated recommendations for corrective actions.

Table 1 presents a sample case to showcase the workflow's end-to-end compliance-checking capability. Given a user query about whether an weld undercut depth in a specific load-bearing beam exceeds tolerance, the workflow retrieves a relevant requirement clause and performs reasoning. The generated response includes the clause ID stored in the database and text, and provides a step-by-step explanation comparing the actual undercut to the specified limits. The workflow concludes that the case does not comply with the requirement, showcasing its ability to trace, interpret, and justify compliance decisions.

Table 1: An example case of compliance checking.

User query	Generated response
The weld undercut in this load bearing beam (GUID:0uJ$wcm0vAOA0F51klkCSH) is 0.1 in. Does it stay within tolerance?	**Requirement sentence ID:** 9, **Text:** In primary members, undercut shall be no more than 0.01 in deep when the weld is transverse to tensile stress under any design loading condition. Undercut shall be no more than 1 /32 in [1 mm] deep for all other cases. **Building Element(s):** 0uJ$wcm0vAOA0F51klkCSH. The user query states that the undercut in the load-bearing beam is 0.1 inches. The selected requirement specifies that the undercut shall be no more than 0.01 inches deep for certain conditions and no more than 1/32 inches (which is approximately 0.03125 inches) for all other cases. Since 0.1 inches exceeds both tolerance limits, it does not comply with the requirement.

Following compliance checking, the workflow automatically generates structured regulatory reports, summarizing identified welding deviations, regulatory references, and recommended corrective actions. The LLM synthesizes the compliance findings into a standardized report format, which can include: (1) a summary of detected welding issues, such as inconsistent welding parameters or non-compliance with WPS, (2) regulatory citations that correspond to the identified issues, (3) suggested corrective actions, such as removing defective material, re-welding, or reevaluating WPS, (4) approval suggestions for inspectors and quality control teams.

The final compliance report can be exported in JSON, XML, or PDF formats for submission to regulatory authorities or internal audits. Additionally, the system can issue real-time alerts to site engineers, enabling them to implement corrective measures immediately and maintain compliance.

The LLM-driven workflow incorporates several advanced capabilities to enhance the regulatory reporting process. Document classification and parsing represent the initial stage, where the LLM is fine-tuned with predefined rules to differentiate between various types of regulatory documents. By analyzing unstructured text, the model extracts relevant compliance-related information and links it to corresponding industry regulations, ensuring a structured and organized representation of regulatory

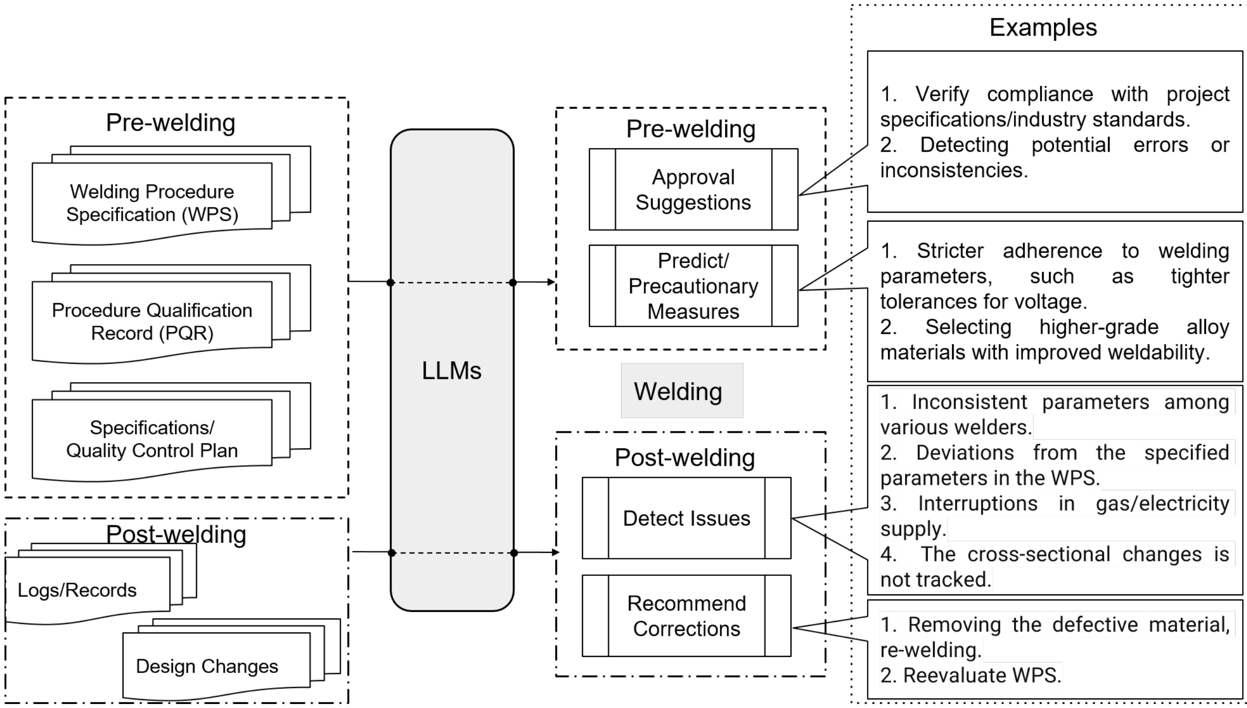

Figure 2. A potential use case with proposed LLM-driven regulatory reporting workflow

requirements. This capability enables the system to effectively manage complex regulatory frameworks, facilitating more efficient document retrieval and interpretation. Besides, the other critical aspect of the workflow is its ability to automate report generation and compliance checking. Traditional regulatory reporting methods require extensive manual effort in drafting and formatting compliance reports, leading to inefficiencies and inconsistencies in documentation. By using the generative capabilities of LLMs, the proposed workflow streamlines the creation of structured compliance reports, approval suggestions, and corrective action recommendations. This automation significantly reduces the time required for report preparation and minimizes errors that may arise due to manual data entry.

CONCLUSIONS

This study introduces an LLM-driven workflow designed to enhance the efficiency and accuracy of regulatory reporting in nuclear construction. Traditional compliance tracking methods rely heavily on manual document review, making regulatory reporting time-consuming, error-prone, and inefficient. The proposed framework uses LLM capabilities to automate document classification, compliance verification, and regulatory report generation, addressing the challenges associated with unstructured regulatory data and complex compliance requirements. By introducing an LLM-driven approach to regulatory compliance, this study contributes to the advancement of automated compliance verification and reporting solutions.

As a conceptual framework, this study lays the foundation for future implementation and validation of LLM-driven regulatory reporting. While the workflow is designed to streamline regulatory processes and reduce manual effort, further research is needed to evaluate its real-world applicability, optimize fine-tuning techniques, and ensure regulatory alignment with evolving compliance requirements. Future work will focus on integrating this workflow into existing compliance management systems and conducting case studies or pilot applications in nuclear construction projects to assess its effectiveness in practical settings.

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