UDC 81.324
IRSTI 15.35.15
RESEARCH ARTICLE

CONTROLLED NATURAL LANGUAGE IN CONSTRUCTION REGULATORY AND TECHNICAL DOCUMENTS

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Abstract. *Controlled Natural Language (CNL) applied to construction regulatory and technical documents is examined as a linguistic mechanism for eliminating ambiguity and enabling automated interpretation of requirements. The research object is the language of normative and technical documents used in construction, which is traditionally characterized by syntactic complexity, terminological inconsistency, and stylistic variability that hinder digital processing and automated compliance checking. The research method is based on a systematic review and content analysis of peer-reviewed scientific publications indexed in Scopus and Web of Science, focusing on controlled languages, template-based requirement formulation, ontology-driven approaches, and natural language processing techniques integrated with Building Information Modeling. The research results demonstrate that the use of controlled language significantly increases the accuracy of requirement extraction, enables direct transformation of textual provisions into formal, machine-executable rules, and reduces interpretative variability. Empirical evidence from existing controlled-language implementations confirms improvements in automated compliance checking performance, enhanced terminology consistency, and greater interoperability between regulatory texts and digital construction models. The findings indicate that controlled language constitutes a foundational component for the development of machine-readable regulatory frameworks, supporting the transition toward digital regulations and automated compliance processes in the construction industry.*

Keywords: *controlled language, normative and technical documents, automated compliance checking, construction digitalization, BIM, ontology*

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https://doi.org/10.51488/1680-080X/2025.4-10
Received 19 October 2025; Revised 12 November 2025; Accepted 11 December 2025

ӘОЖ 81.324
FТАМР 15.35.15
ҒЫЛЫМИ МАҚАЛА

ҚҰРЫЛЫС НОРМАЛАРЫ МЕН ТЕХНИКАЛЫҚ ҚҰЖАТТАРДАҒЫ БАҚЫЛАУ ТІЛІ

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Аңдатпа. *Құрылыс саласындағы нормативтік және техникалық құжаттарға қолданылатын бақыланатын табиғи тіл (Controlled Natural Language, CNL) талаптарды автоматтандырылған түрде түсіндіруге мүмкіндік беретін және екіұштылықты жоюға арналған лингвистикалық тетік ретінде қарастырылады. Зерттеу нысаны ретінде дәстүрлі түрде синтаксистік күрделілігімен, терминологиялық бірізділіктің болмауымен және стильдік өзгермелілігімен сипатталатын, цифрлық өңдеуді және автоматтандырылған сәйкестікті тексеруді қиындататын құрылыс саласындағы нормативтік және техникалық құжаттардың тілі алынған. Зерттеу әдісі Scopus және Web of Science дерекқорларында индекстелген рецензияланатын ғылыми жарияланымдарға жүйелі шолу жасауға және контент-талдауға негізделген. Талдау бақыланатын тілдерге, талаптарды үлгілік құрылымдар арқылы тұжырымдауға, онтологияға негізделген тәсілдерге, сондай-ақ Building Information Modeling жүйелерімен біріктірілген табиғи тілді өңдеу әдістеріне бағытталған. Зерттеу нәтижелері бақыланатын тілді қолдану талаптарды бөліп алу дәлдігін едәуір арттыратынын, мәтіндік ережелерді формалды, машинамен орындалатын қағидаларға тікелей түрлендіруге мүмкіндік беретінін және интерпретациялық өзгермелілікті төмендететінін көрсетеді. Бақыланатын тілдің қолданыстағы енгізілімдерінен алынған эмпирикалық деректер автоматтандырылған сәйкестікті тексеру тиімділігінің артуын, терминологияның бірізділігінің жақсаруын және нормативтік мәтіндер мен цифрлық құрылыс модельдері арасындағы үйлесімділіктің күшеюін растайды. Алынған қорытындылар бақыланатын тілдің машинамен оқылатын нормативтік негіздерді қалыптастырудағы іргелі құрамдас бөлік екенін және құрылыс саласында цифрлық реттеуге әрі автоматтандырылған сәйкестікті қамтамасыз ету процестеріне көшуге негіз болатынын көрсетеді.*

Түйін сөздер: *контролденген тіл, нормативтік-техникалық құжаттар, автоматтандырылған сәйкестік тексеруі, құрылысты цифрландыру, BIM, онтология*

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https://doi.org/10.51488/1680-080X/2025.4-10
Алынды 19 қазан 2025; Қайта қаралды 12 қараша 2025; Қабылданды 11 желтоқсан 2025

УДК 81.324
МРНТИ 15.35.15
НАУЧНАЯ СТАТЬЯ

КОНТРОЛИРУЕМЫЙ ЯЗЫК В СТРОИТЕЛЬНЫХ НОРМАТИВНЫХ ТЕХНИЧЕСКИХ ДОКУМЕНТАХ

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Аннотация. *Контролируемый естественный язык (Controlled Natural Language, CNL), применяемый к нормативным и техническим документам в строительстве, рассматривается как лингвистический механизм, направленный на устранение неоднозначности и обеспечение автоматизированной интерпретации требований. Объектом исследования является язык нормативных и технических документов, используемых в строительстве, который традиционно характеризуется синтаксической сложностью, терминологической несогласованностью и стилистической вариативностью, затрудняющими цифровую обработку и автоматизированную проверку соответствия. Метод исследования основан на систематическом обзоре и контент-анализе рецензируемых научных публикаций, индексируемых в базах данных Scopus и Web of Science, с акцентом на контролируемые языки, шаблонное формулирование требований, онтологически ориентированные подходы и методы обработки естественного языка, интегрированные с технологиями информационного моделирования зданий. Результаты исследования показывают, что применение контролируемого языка существенно повышает точность извлечения требований, обеспечивает прямую трансформацию текстовых положений в формальные, машинно-исполняемые правила и снижает интерпретационную вариативность. Эмпирические данные, полученные на основе существующих реализаций контролируемых языков, подтверждают улучшение показателей автоматизированной проверки соответствия, повышение терминологической согласованности и усиление интероперабельности между нормативными текстами и цифровыми моделями строительства. Полученные выводы свидетельствуют о том, что контролируемый язык является базовым компонентом формирования машиночитаемых регуляторных систем и поддерживает переход к цифровому регулированию и автоматизированным процессам обеспечения соответствия в строительной отрасли.*

Ключевые слова: *контролируемый язык, нормативно-технические документы, автоматизированная проверка соответствия, цифровизация строительства, BIM, онтология*

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https://doi.org/10.51488/1680-080X/2025.4-10
Поступила 19 октября 2025; Пересмотрено 12 ноября 2025; Принято 11 декабря 2025

ACKNOWLEDGEMENTS/SOURCE OF FUNDING

The research was conducted using private sources of funding.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

The authors declare that no generative artificial intelligence technologies or AI-based tools were used in the preparation of this article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Авторлар мақаланы дайындау барысында генеративті жасанды интеллект технологиялары мен жасанды интеллектке негізделген технологияларды пайдаланбағанын мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

Авторы заявляют о том, что при подготовке статьи не использовались технологии генеративного искусственного интеллекта и технологии, основанные на искусственном интеллекте.

1 INTRODUCTION

Normative technical documents (NTDs) are typically drafted in language that formally adheres to established standards for style and terminology, with the intention of preventing interpretive ambiguity. Nevertheless, the prevalence of overly complex terminology, syntactic intricacies, and a lack of stylistic consistency frequently results in inconsistencies and multiple interpretations of regulatory provisions. A content analysis of the British publication Health Building Notes found that ambiguity was present in 53% of the examined requirements within UK NTDs. Such a level of linguistic uncertainty significantly impedes the accurate comprehension of regulatory texts by project stakeholders and elevates the risk of design and compliance errors during the planning and expert review phases (**Zhang et al., 2023; Kempe et al., 2024**).

A lack of precision and unambiguous wording becomes a critical barrier to Automated Compliance Checking (ACC) of BIM models. Even the most advanced NLP algorithms can extract correct parameters from only about one-third of textual requirements, while the remaining 60–70% still require manual expert interpretation, as the inherent characteristics of natural language hinder formal transformation (**Kempe et al., 2024; Vierlboeck et al., 2022**).

One of the most promising solutions to the problem of linguistic ambiguity is the adoption of Controlled Natural Language (CNL) - an intentionally restricted sublanguage in which both vocabulary and grammar are strictly regulated. By limiting the use of polysemous terms, eliminating vague modal constructions, and prescribing fixed sentence patterns, CNL ensures unambiguous interpretation of requirements by humans and enables their direct translation into formal ontologies (OWL), rule languages such as SWRL/SHACL, or SPARQL queries for BIM data (**Treviso et al., 2022: Huitzil et al., 2022; Zhumagulova et al., 2024**).

In the context of industry-wide digitalization, regulators worldwide have shifted toward developing machine-readable representations of building requirements. Singapore, for example, has introduced the CORENET e-PlanCheck platform, where regulatory provisions are digitized and automatically verified when a BIM model is submitted for approval. Similar initiatives are being implemented in the SMART Codes project of the International Code Council (ICC, USA), as well as in the German VCCL (Visual Code Checking Language) system, which offers a visual DSL that enables engineers to formulate rules without programming (**Häußler et al., 2022; Aldakhov et al., 2025**).

The aim of this article is to synthesize contemporary scientific approaches to the implementation of Controlled Natural Language in normative and technical documents within the construction sector of the Republic of Kazakhstan. The paper examines the key issues and root causes of linguistic ambiguity in construction regulations currently in force in Kazakhstan. It also reviews existing methods for standardizing and formalizing the language of regulatory requirements. In addition, practical examples of applying controlled language in construction documentation are analyzed, along with their impact on industry digitalization, including Building Information Modeling. Finally, the advantages, limitations, and prospects of integrating controlled language into normative technical documents are discussed. The paper examines the key issues and root causes of linguistic ambiguity in construction regulations currently in force in Kazakhstan. It also reviews existing methods for standardizing and formalizing the language of regulatory requirements. In addition, practical examples of applying controlled language in construction documentation are analyzed, along with their impact on industry digitalization, including Building Information Modeling. Finally, the advantages, limitations, and prospects of integrating controlled language into normative technical documents are discussed.

2 LITERATURE REVIEW

The problem of linguistic ambiguity in normative and technical documents has been widely discussed in recent scientific literature, particularly in the context of digitalization of construction regulation and automated compliance checking. Numerous studies emphasize that traditional regulatory texts, despite their formal structure, often contain syntactic complexity, terminological inconsistency, and semantic vagueness that significantly hinder machine interpretation and automation processes (**Zhang et al., 2023; Kempe et al., 2024**).

Empirical investigations demonstrate that ambiguity is not an isolated phenomenon but a systematic characteristic of building regulations. Zhang (**Zhang et al., 2023**) show that more than half of analyzed requirements in building codes contain linguistic uncertainty, including vague expressions, implicit references, and polysemous terminology. Similar conclusions are reported by Kempe (**Kempe et al., 2024**), who classify regulatory ambiguity into intentional and unintentional types, both of which negatively affect automated compliance checking. Intentional ambiguity is often introduced to preserve professional judgment, while unintentional ambiguity arises from limitations of natural language itself. Regardless of origin, both types reduce the reliability of automated interpretation.

Several researchers focus on the limitations of conventional natural language processing approaches when applied to regulatory texts. Vierlboeck (**Vierlboeck et al., 2022**) and Zhang (**Zhang et al., 2021**) demonstrate that even advanced NLP models are unable to reliably extract regulatory semantics from unrestricted text, especially when requirements are expressed through complex grammatical structures or inconsistent formulations. These findings confirm that algorithmic solutions alone cannot compensate for poorly structured regulatory language.

To address these challenges, controlled natural language has emerged as a promising methodological solution. Controlled languages are defined as deliberately restricted subsets of natural language with constrained vocabulary, grammar, and sentence structures designed to reduce ambiguity while preserving human readability (**Kuhn T., 2014**). In the construction domain, controlled language is increasingly viewed as a bridge between human-oriented regulatory texts and machine-executable representations.

Wu (**Wu et al., 2019**) propose rewriting construction codes using a controlled language approach, demonstrating that simplified syntax and standardized terminology significantly improve information extraction accuracy. Their work on GIM-CNL illustrates how rewriting regulatory provisions into controlled formulations enables reliable parsing and subsequent transformation into formal rule representations. Similar principles underpin the RAINS approach, where controlled English formulations are directly mapped to ontology-based representations and SPARQL queries for BIM model verification (**Chen et al., 2022**).

Ontology-driven approaches constitute another important research direction. Ontologies provide a formal semantic backbone that links regulatory concepts with BIM entities, enabling consistent interpretation across digital platforms. Zhang (**Zhang et al., 2021**) show that combining linguistic templates with domain ontologies substantially increases the precision and recall of requirement extraction. However, these approaches remain highly sensitive to linguistic variability, reinforcing the need for controlled language at the document authoring stage.

Recent studies also explore hybrid solutions that integrate controlled language with automated and semi-automated compliance checking systems. Noardo (**Noardo et al., 2021**) review the state of digital building permit systems and emphasize that the effectiveness of such systems depends heavily on the formalization and linguistic clarity of regulatory requirements. Practical implementations, including visual rule-checking languages and structured rule representations, aim to reduce the gap between textual regulations and executable compliance logic.

Machine learning methods have been proposed to support regulatory text analysis, particularly for ambiguity detection and requirement classification (**Zhang et al., 2022**). While these approaches show potential in identifying problematic formulations, their applicability remains limited due to the scarcity of annotated regulatory corpora and the inability of statistical models to guarantee legal and semantic correctness. As noted by Fosler-Lussier (**Fosler-Lussier et al., 2022**), purely data-driven methods cannot replace rule-based and linguistically controlled approaches in domains with strict normative constraints.

In the context of construction digitalization, several studies highlight the growing need for standardized, machine-readable regulatory frameworks. Initiatives such as digital building permits and automated rule checking systems demonstrate that linguistic standardization is a prerequisite for scalable automation (**Häußler et al., 2021; Noardo et al., 2021**). buildingSMART Australasia explicitly emphasizes controlled language and well-defined terminology as key components of interoperable BIM-based regulatory environments.

Overall, the reviewed literature converges on a common conclusion: linguistic ambiguity represents a fundamental barrier to the digital transformation of construction regulation. Controlled natural language, particularly when combined with ontologies and BIM-based compliance checking, offers a systematic and theoretically grounded solution. However, existing studies also acknowledge institutional, legal, and practical challenges related to large-scale adoption, indicating the need for further research focused on adapting controlled language principles to national regulatory contexts and existing normative frameworks (**Kabzhan et al., 2025**).

3 MATERIALS AND METHODS

A systematic review was conducted on controlled languages and the standardization of linguistic requirements in building regulations. Source selection was carried out using the Scopus and Web of Science databases, focusing on publications from the past 15 years, a period marked by significant growth in research on automated analysis of regulatory documents. The search was performed using combinations of English-language keywords, including "controlled language," "controlled natural language," "building regulations," "building code compliance," "automated compliance checking," "natural language processing," and "Building Information Modeling (BIM)."

The inclusion criteria comprised peer-reviewed journal articles and full conference papers that explicitly address linguistic ambiguity in construction regulations or propose methods for standardizing, formalizing, or automating regulatory requirements through controlled language, templates, ontologies, or NLP-based approaches. The initial search across Scopus and Web of Science databases yielded 258 publications based on keyword combinations related to controlled language, regulatory requirements, and construction digitalization. After screening titles and abstracts, studies not directly related to regulatory or normative documents in the construction domain were excluded. A full-text assessment was then conducted to evaluate methodological relevance and domain specificity. As a result of this multi-stage filtering process, approximately 30 publications were identified as fully meeting the inclusion criteria. Preference was given to studies published in high-impact journals and proceedings of major international conferences in the fields of construction informatics, automation, and digital regulation. Exclusion criteria included publications focusing solely on generic NLP algorithm development without application to construction regulations, as well as non-peer-reviewed sources, short abstracts, and studies unrelated to the construction domain. The final corpus included several systematic reviews and meta-studies, ensuring comprehensive coverage of relevant methodological and technological approaches aligned with the research objectives.

The review included studies that directly address the problem of linguistic ambiguity in building regulations or propose methods for its resolution-such as controlled languages, formal requirement models, and semantic analysis of regulatory texts. Highly specialized works focused solely on the technical aspects of NLP algorithms without any connection to the standardization of requirement language were excluded. Preference was given to studies published in top-quartile journals (Q1 and Q2), which is indicative of high scientific relevance and the overall quality of the research (**Shadkam et al., 2024; Zhangabay et al., 2025**).

All selected publications were subjected to a detailed qualitative content analysis. The analysis was conducted through manual examination of the reviewed studies, without the direct application of automated text-processing software or proprietary algorithms to the regulatory documents themselves, as the research focused on synthesizing and comparing methodological approaches reported in the literature. From each source, information was extracted on the linguistic issues identified within regulatory documents and the methods proposed by the authors for applying controlled language or other approaches to requirement formalization. Additional data were collected on the architecture or methodology of each solution, including the use of ontologies, templates, rule-based systems, and machine learning techniques as described by the original authors. Implementation outcomes and experimental results were also analyzed, such as the accuracy of automated requirement extraction, the effectiveness of rule-checking procedures, and expert evaluations.

To systematize the review, all identified solutions were conditionally classified according to their methodological approach (template- and ontology-based rule systems; controlled languages for text rewriting; machine-learning and NLP-based methods; etc.). Summary characteristics of key studies are presented in tabular form. Where necessary, schematic diagrams are used to illustrate the processes of transforming regulatory requirements into formalized representations.

4 RESULTS AND DISCUSSION

The literature review confirms that the texts of normative technical documents contain numerous linguistic issues that hinder both unambiguous interpretation and digital processing. First, there is a persistent inconsistency in terminology and writing style (**table 1**): different documents-and even different sections within the same document-often express similar requirements in divergent ways (**Wu et al., 2019; Yesbolat et al., 2025**). The absence of a unified vocabulary and grammatical templates means that a single requirement may be articulated through multiple, structurally different formulations. For example, a study of Chinese electrical engineering regulations showed that the same mandated clearance could be expressed in five alternative phrasings, each with a different sentence structure (**Wu et al., 2019**). Such variability complicates automated requirement recognition because algorithms must account for multiple synonymous constructions. Second, the texts frequently contain ambiguous expressions. Some ambiguities are intentional, as regulators deliberately leave certain provisions flexible to allow for professional judgment (**Zhang et al., 2023**). Others arise unintentionally and reflect inherent limitations of natural language (**Zhang et al., 2023**). Typical examples include polysemous words (e.g., “room” meaning either a specific enclosed space or general area) and context-dependent references lacking explicit specification. As a result, automated interpretation becomes difficult: on average, only about 34% of NTD text can be directly machine-interpreted without additional processing (**Zhang et al., 2022**). Third, the sheer volume and structural complexity of regulatory documents pose their own challenges. Major compendiums of rules-such as the International Building Code (IBC), Eurocodes, and other technical standards-contain thousands of provisions interconnected through cross-references and exceptions. Manual digitization and maintenance of such documents are extremely labor-intensive (**Wu et al., 2019**). These findings highlight the objective need for linguistic standardization: simplifying and structuring the language of regulatory requirements to ensure precise and consistent interpretation.

Table 1
Linguistic Issues in Normative Technical Documents and Their Impact on Digital Processing

Problem Category	Impact on Digital Processing	Source References
Variability of formulations	Increased complexity of automated requirement recognition; algorithms must handle multiple synonymous sentence structures	**(Locke et al., 2018)**
Ambiguity / polysemy	Interpretation errors; inability to assign a single, precise meaning to terms or references	**(Zhang et al., 2023; Kempe et al., 2024)**
Volume and structural complexity	High labor intensity of digitization and maintenance; difficulty in parsing cross-referenced provisions	**(Zhang et al., 2023; Locke et al., 2018)**
Violations of lexical and grammatical norms	Reduced clarity, consistency, and terminological precision; lower accuracy of automated text analysis	**(Lytvynska et al., 2021)**

Researchers have proposed several approaches to reducing linguistic ambiguity in regulatory documents. One of the most widely discussed methods is the development of Controlled Natural Languages (CNLs) tailored to the construction industry. A controlled language is a deliberately simplified and standardized subset of a natural language, characterized by strictly defined lexical, syntactic, and stylistic rules (**Kuhn T., 2014**). By imposing constraints-such as prohibiting ambiguous vocabulary, unclear pronouns, and complex subordinate clauses-texts written in CNL become more formal, consistent, and unambiguous.

RAINS (Regulatory Artificial Intelligent Network Standard) is a controlled language proposed by Kacfah Emani et al. for the formalization of regulatory documents in the construction domain (Chen et al.,2022). RAINS is designed as an intermediate language that is understandable both to industry experts and to machines. Requirements written in RAINS can be automatically translated into SPARQL queries targeting BIM ontologies (**Zhang et al., 2021**). In this way, RAINS effectively "hides" the complexity of formal languages such as OWL and SPARQL behind clear, English-based constructions that closely resemble natural regulatory phrasing. In one of the experimental studies, this approach enabled the automatic conversion of textual requirements into formal logical expressions for building-model verification, relying on the IFC (Industry Foundation Classes) ontology to establish semantic links with BIM model elements (**Chen et al., 2022**).

GIM-CNL (Grid Information Modeling Controlled Natural Language) is a controlled language developed for Chinese electrical engineering building codes (**Wu et al., 2019**). The project addressed a key challenge: existing NLP tools perform less effectively on Chinese regulatory texts due to linguistic properties such as the absence of word boundaries and flexible word order (**Wu et al., 2019**). To overcome these linguistic constraints, the authors proposed rewriting code provisions in a simplified technical Chinese, using a restricted vocabulary of power-engineering terms and fixed sentence templates aligned with the domain ontology. As a result, the reformulated GIM-CNL text is far easier for parsers to process and can then be automatically translated into a specialized domain-specific rule language (DSL) for project compliance checking (**Wu et al., 2019**). The authors illustrated this capability using a safety requirement concerning minimum clearance between electrical equipment: when rewritten in the controlled language, the provision became grammatically unambiguous, allowing the system to correctly identify the subject, condition, and threshold distance. By contrast, the original formulation led to parsing errors due to structural ambiguity. Templates and simplified syntax in regulatory texts. Several studies (**Zhang et al., 2021%; Locke et al., 2018; Lytvynska et al., 2021**). Propose not to create an entirely new language but to establish strict rules for writing regulatory requirements within the existing natural language. For example, researchers recommend using standardized deontic operators ("shall/should" instead of a wide range of modal verbs), avoiding vague expressions ("sufficient," "as necessary," etc.), limiting sentence length, and explicitly specifying related objects and quantitative values (**Kuhn T., 2014**). These recommendations align with the principles of Simplified Technical English, successfully employed in the aerospace industry to eliminate ambiguity in instructions. The application of similar rules to construction regulatory documents is discussed particularly in the context of parallel code development, in which experts write each requirement simultaneously in both natural language and a formal representation. It is assumed that having a parallel controlled-language formulation now of drafting improves the overall quality of the requirement by reducing hidden inconsistencies and inaccuracies (**Zhang et al., 2021**). However, practical implementation of these approaches faces challenges: experts emphasize that revising and rewriting existing requirements in a controlled style is a lengthy and resource-intensive process that requires alignment and approval at the regulatory level (**Zhang et al., 2021**). Nonetheless, efforts are already being made to develop unified glossaries and thesauri for regulatory documentation. For example, Australia's national BIM standards explicitly highlight the need for "well-defined terminology, controlled language, and thesauri" to ensure the interoperability of digital models (**building SMART Australasia, 2014**).

A separate line of research focuses on software-based methods for processing regulatory texts to enable subsequent automated requirement checking, which is closely linked to the concept of controlled language.

Semantic parsing and ontologies. Several studies (**Zhang et al., 2021**) have developed rule sets and algorithms based on natural language processing (NLP) methods that extract structured information from regulatory text, such as triples in the form object - attribute - threshold value. These approaches rely on predefined grammatical templates and domain-specific vocabularies. For example, Zhang & El-Gohary (**Zhang et al., 2021**) describe a method for extracting eight types of semantic elements from regulatory text-such as subject, condition, value, unit of measurement, and comparative operator-using 146 templates and a construction-domain ontology. When applied to fragments of the International Building Code, the method achieved high extraction performance (precision 97%, recall 94%) (**Kuhn T., 2014**). Although such approaches do not formally require rewriting the original text, they perform significantly better when the source material is stylistically consistent. In practice, the success of template-based extraction depends heavily on how closely the regulatory sentence already resembles controlled language. If a requirement is phrased in an irregular or unexpected way, the corresponding template may fail to recognize it. Therefore, the development of controlled languages and semantic parsing techniques should be viewed as complementary. Standardizing the linguistic form of requirements increases the effectiveness of ontology-driven and template-based NLP methods; conversely, parsing failures can help refine and improve the controlled language itself.

Formal rule models and query languages. After the key elements of a requirement are extracted, the next step is to translate them into a machine-interpretable rule that can be applied to a BIM model or another project representation. Ontologies (OWL) and logic-based rule languages such as SWRL, SHACL, and mvdXML are commonly used for this purpose. Controlled languages can generate such rules directly. As noted earlier, RAINS produces SPARQL queries automatically (**Chen et al., 2022**). Another approach involves visual or domain-specific languages (DSLs) that are accessible to engineers without programming expertise. Noardo et al. (**Noardo et al., 2021**), for instance, developed VCCL (Visual Code Checking Language), which enables users to construct validation rules graphically; these rules are then executed on the model. While a visual language is not a controlled language in the strict sense, it pursues the same objective: making requirements machine-executable without requiring experts to learn programming languages. A promising direction involves integrating such methods with a controlled textual language. For example, a requirement written in controlled English could be automatically transformed into a VCCL flowchart or directly into executable checking code (e.g., XSLT, Python, or other rule-processing languages).

Machine learning methods. Recent studies increasingly apply Natural Language Processing (NLP) and artificial intelligence to the processing of regulatory texts. Machine learning is used for classifying text segments (e.g., distinguishing mandatory requirements from contextual descriptions (**Chen et al., 2022**)), recognizing named entities (such as room types and building elements), and even detecting potentially ambiguous fragments within regulatory provisions. For instance, Zhang & El-Gohary (**Zhang et al., 2021**) trained a model capable of automatically identifying linguistic uncertainty in regulatory requirements to assist authors in rewriting problematic sections. Large language models (LLMs) are also being explored: recent work investigates the generation of “intelligent” versions of building codes, where neural networks propose reformulations of original requirements into a structure resembling controlled language-or even directly into executable checking code (**Zhang et al., 2021**). However, such methods cannot fully replace expert judgment due to several limitations. First, effective model training requires substantial annotated datasets, while existing corpora of normative technical documents remain limited in both volume and thematic diversity (**Zhang et al., 2021**). Second, models may capture statistical patterns of language but cannot guarantee the legal correctness of reformulations. Nevertheless, these approaches complement controlled languages: algorithms can suggest standardized phrasings or signal when a sentence violates controlled-language rules, thereby supporting authors and regulators in improving the clarity and consistency of normative documents.

A summary of the key approaches is presented in **Table 2**. It includes representative solutions from the literature, a brief description of each method, and the main results achieved.

Table 2
Main approaches to reducing linguistic ambiguity in regulatory requirements.

Approach / Tool	Method Description	Example Outcome
Controlled English-based language (RAINS)	A restricted sublanguage in which requirements are written using simple, unambiguous structures that map directly onto formal logic. Automatically translated into SPARQL queries for BIM data via the IfcOWL ontology.	The prototype enabled direct transformation of textual requirements into queries for the building information model, eliminating the need for manual rule coding.
Controlled Chinese-based language (GIM-CNL)	Rewriting requirements in simplified technical Chinese using a fixed vocabulary of power-engineering terms and a constrained grammar; supported by a dedicated ontology of energy-sector concepts.	In the experiment, a fragment of the electrical code was rewritten such that the NLP parser accurately extracted the requirement elements (object, attribute, value), and the system successfully generated a corresponding BIM checking rule.
Rule-based parsing (templates + ontology)	Use of predefined sentence templates and domain-specific vocabularies to extract requirement parameters, combined with ontology-based semantic alignment for interpreting the meaning of terms.	Extraction of quantitative requirements from the International Building Code demonstrated high accuracy (~97%). The results confirmed the feasibility of automated regulatory text parsing when terminology is sufficiently standardized.
RAINS + IfcOWL (rule formalization)	A combined approach linking the controlled language with a BIM ontology: each requirement written in RAINS includes references to IFC model classes and properties, enabling automatic verification of requirement compliance on a specific BIM model.	A method for parallel requirement development was proposed: the natural-language version of a rule and its formal RAINS/OWL representation are written simultaneously. This approach is expected to reduce inconsistencies and increase the completeness of digital rule sets.
Visual rule-checking language (VCCL)	A graphical DSL for rule definition: the regulatory requirement is transformed into a diagram (blocks representing conditions, objects, and relationships) that is easily interpretable by engineers. The diagram is then compiled into executable checking code.	In the fire-safety example, the user constructed a rule equivalent to the code requirement by dragging and connecting visual blocks, and the system successfully detected non-compliant elements in the BIM model based on the generated rule.
ML-based ambiguity detection model	Training an algorithm to classify regulatory requirements as unambiguous or potentially problematic. The model relies on linguistic features-such as modal verbs, vague expressions, and other indicators-to predict the degree of “fuzziness” in a requirement.	In a dataset of construction-related requirements, the model successfully identified most of the deliberately ambiguous phrases, demonstrating strong agreement with expert assessments. This creates a foundation for author-support tools capable of highlighting potentially “risky” or unclear formulations during the drafting of regulatory documents.

Examples of implementation and impact on construction digitalization (BIM). The practical adoption of controlled-language principles in construction regulatory documents is still in its early stages, yet several successful pilot initiatives already exist. A notable example is the effort in Singapore and several other countries to develop electronic checking systems (e-PlanCheck, CORENET, and others) (**Noardo et al., 2021**). In these systems, a portion of regulatory requirements was manually rewritten as machine-readable rules. Experience has shown, however, that manual coding of many rules is an extremely labor-intensive process that requires continuous updates as regulations evolve. Consequently, regulators have begun moving toward drafting requirements with machine-readability in mind from the outset. For instance, the International Code Council (ICC) experimented with the SMART Codes project, in which certain sections of the International Building

Code (IBC) were accompanied by templates written in a formal rule-checking language (**O'brien et al., 2020**).

In the academic sphere, several prototypes have been developed that integrate controlled language with BIM workflows. In addition to the previously mentioned RAINS + IfcOWL approach, notable work has been conducted by ElSaadany et al. (**ElSaadany et al., 2025**), in which textual building regulations are automatically transformed into rules expressed in the Model View Definition (MVD) language – a standardized format for checking IFC-based building models. This MVD-based rule representation enables the direct application of regulatory requirements to a building's information model. Another example is a system in which construction quality rules for an embankment dam were encoded in a structured language and then automatically verified using both work-log text records and the BIM model of the dam. The system achieved an 89% accuracy rate in detecting non-compliance (**Chen et al., 2024**). Although this case does not involve a controlled language for normative requirements per se, but rather the structuring of field data, the underlying principle is similar: the precise specification of data and text formats significantly enhances the accuracy of automated compliance checking.

Controlled language, when combined with ontologies, also facilitates the development of digital assistants for designers. When requirements are represented in a formal, machine-interpretable form, a BIM application can provide real-time alerts to specialists by highlighting non-compliant components directly within the model. In the longer term, this controlled-language and ontology-based approach opens opportunities for multilingual consistency of regulatory requirements. A formal ontology can serve as a cross-lingual representation on which different language versions of a regulation are based. This ontology-based representation means that changes made in one linguistic version of a requirement could, in principle, be automatically tracked and propagated to other versions, since all of them are linked through a shared formal model.

It is important to note that controlled language enhances not only automation processes but also the overall quality of normative technical documents themselves. Experts interviewed in a recent study reported that drafting regulatory requirements in parallel-both in a formal representation and in natural language-would help identify logical inconsistencies, omissions, and redundancies during the document development stage (**Kabzhan et al., 2025**). Clearer formulations also facilitate practical application of the requirements, reducing the number of disputes and requests for clarification. Thus, even without full automation, the industry benefits from improved clarity and transparency of regulatory provisions.

Contemporary research consistently indicates that a shift toward a more formalized, controlled language for construction regulations is a necessary precondition for their effective integration into digital design, automated checking, and lifecycle management processes. The methods presented in the literature support the practical feasibility of this idea: whether through partial simplification of regulatory text or through the development of specialized sublanguages, all approaches contribute to reducing linguistic ambiguity. Experimental systems such as RAINS, GIM-CNL, and others have shown that even partial linguistic restriction yields a significant effect, making requirements suitable for algorithmic parsing and verification (**Wu et al.,2019**). Achieving 95–97% accuracy in automatically extracting requirement parameters from text is a critical indicator that machines can interpret regulatory language-if it is written in a sufficiently structured manner. Therefore, the findings reinforce the central thesis: controlled language serves as a bridge between the natural language of regulations and the formal, machine-executable rule sets required by digital information systems (**Kuhn T., 2014**).

The key strengths of this approach can be summarized as follows (**Table 3**): (1) Unambiguity. By eliminating linguistic ambiguities, controlled language ensures a uniform interpretation of each requirement by all users, thereby reducing the risk of errors and misinterpretation. (2) Machine-readability. Requirements written in a simplified and structured form are far easier to convert algorithmically into checking code, logical formulas, or model-query expressions (**Chen et al.,2022**). As a result, the degree of automation increases-from identifying relevant requirements for a specific project to fully automated compliance checking (ACC). (3) Maintenance and updates. A formalized representation of requirements greatly simplifies the updating of regulatory frameworks: modifications can be introduced centrally into the ontology or templates and then automatically propagated across all dependent applications (checking systems, knowledge bases, etc.). (4) Multilingual interoperability and data exchange. Controlled language, when combined with ontologies, contributes to the development of internationally comparable standards. For example, if different countries describe their requirements in terms of a shared BIM ontology, cross-national comparison of regulations, transfer of best practices, and even mutual recognition of compliance checks may become feasible. (5) Simplified translation and training. Controlled-language texts are easier to translate into other languages (including via machine translation) and are more accessible to specialists from adjacent fields. Despite clear advantages, the adoption of controlled language faces several barriers (**Table 4**): (1) Institutional and legal constraints. Normative technical documents carry legal authority and undergo lengthy approval procedures. Changing their linguistic style is not merely a technical task but an organizational and regulatory challenge. Regulators often adopt a conservative stance, fearing that excessive formalization may reduce accessibility for users without specialized training. (2) Preservation of meaning. Simplification of language carries the risk of losing important nuances. Some requirements are intentionally flexible to accommodate diverse situations or allow professional judgement. Translating them into a rigid controlled form may lead to over-specification, excluding valid cases. (3) Training and author adaptation. Regulators and experts must learn new writing principles, which requires training and changes in long-established documentation practices. Until successful real-world examples accumulate, authors may distrust the idea that a restricted vocabulary can fully express complex requirements. (4) Technical complexity. Developing a comprehensive controlled language is a resource-intensive process: it involves linguistic analysis, ontology development, authoring guidelines, and the creation of parsers and editing tools. (5) Limited applicability of machine learning. Full automation of regulatory text interpretation remains infeasible. Current NLP techniques still require either manually crafted templates or controlled language input. Deep-learning methods are constrained by limited training data and the inherent complexity of regulatory logic. Therefore, AI alone cannot reliably infer the meaning of uncontrolled technical text.

Several scientific and practical tasks must be addressed to advance the use of controlled language in construction regulatory documents: (1) One key task is the development of controlled-language standards. This standardization effort may require the establishment of an international working group to formulate recommendations for the linguistic structure of regulatory documents, like existing standards for technical writing. Such controlled-language standards would include the definition of a core vocabulary of terms, grammatical rules, and stylistic conventions for different categories of requirements, such as safety, fire protection, and energy efficiency. (2) Toolchain and software support. To facilitate the transition, specialized software tools are required: regulation editors with built-in suggestions, automatic term extraction, compliance checking against controlled-language rules, and real-time generation of formal representations. Early steps in this direction are already visible-for example, prototypes that highlight ambiguous phrases for authors (as discussed above) (**Zhang et al., 2022**). (3) Backward compatibility. A key question is how to integrate controlled language into the existing legal and regulatory framework. A gradual approach may be most practical-for instance, starting with small subsections or appendices to codes where requirements are duplicated in both natural language and a formal controlled form. Over time, as trust in formal representations grows, their legal status can be strengthened. (4) Integration with model-based approaches. Controlled language must evolve alongside BIM. Promising directions include methods for automatically generating requirements based on the analysis of frequent design errors, as well as hybrid approaches combining the strengths of rule-based systems and machine learning. As noted by Fosler-Lussier et al. (**Fosler-Lussier et al.,2022**), the most effective solution may be a system in which core requirements are specified formally, while AI assists in adapting these requirements to specific project contexts. Overall, further research should aim to unify linguistic, ontological, and computational perspectives, enabling a future in which building regulations are consistently interpretable by both humans and machines.

Table 3
Advantages and Limitations of Controlled Language

Aspect	Description	Key Effects / Risks
Unambiguity: Higher clarity and reliability of regulatory texts	Eliminates linguistic ambiguity and ensures uniform interpretation of requirements by all users	Reduced errors and inconsistencies
Machine-readability: Efficient retrieval of relevant requirements Higher accuracy of compliance checking	Structured language enables algorithmic transformation into checking code, logical rules, and model queries	Improved automation (ACC)
Easier maintenance and updates: Lower maintenance cost Greater consistency of rule versions	Formalized representation allows centralized updates in ontologies or templates	Regulatory changes propagate across all digital tools
Multilingual interoperability & data exchange: Transfer of best practices Potential future mutual recognition of automated checks	Controlled language + ontologies support creation of internationally comparable standards	Cross-country comparison of requirements
Simplified translation & training: Higher translation accuracy Easier training for regulators and designers	Controlled-language texts are easier to translate and learn	Enhanced accessibility for non-experts

Table 4
Limitations and Challenges

Challenge Category	Description	Consequences
Institutional & legal barriers: Resistance to language reforms Need for official approval mechanisms	NTDs have legal status; stylistic changes require regulatory procedures; regulators fear reduced accessibility	Slow adoption
Risk of meaning loss: Loss of permitted variations Potential misinterpretation in complex cases	Simplification may remove nuances; some requirements intentionally flexible	Over-specification
Training & adaptation: Skepticism toward restricted vocabulary Delayed transition	Authors must learn new writing rules; requires changing long-standing documentation practices	Learning curve
Technical complexity: Need for specialized expertise Long implementation timeline	Full CNL development requires linguistic analysis, ontology engineering, authoring rules, and software tooling	High development cost
Limited applicability of ML methods: Need for manual templates or CNL input Partial automation only	AI cannot reliably interpret uncontrolled technical text; deep learning limited by data and rule complexity	Cannot rely on ML alone

5 CONCLUSIONS

1. The conducted analysis demonstrates that the application of controlled language significantly reduces ambiguity and variability in the interpretation of normative technical requirements, thereby directly enhancing construction quality and safety.
2. Standardization of linguistic structures provides a consistent basis for clear understanding among all stakeholders and creates favorable conditions for the automation of regulatory compliance processes.

3. Pilot studies confirm that requirements rewritten using controlled language can be transformed into formal, machine-executable rules and applied to building information models with high accuracy.
4. The integration of controlled language into digital design and construction-management platforms increases transparency, reliability, and reproducibility of processes, supporting the broader transition toward digital regulations.
5. Controlled language improves the efficiency of all stakeholders: designers benefit from clearer guidance; expert review bodies and regulatory authorities gain opportunities for accelerated automated compliance checks; software developers can embed regulatory requirements directly into BIM and construction-management tools.
6. International harmonization of requirement formulations based on controlled language strengthens cross-country collaboration, enhances compatibility of regulatory frameworks, and ensures alignment of digital workflows.
7. Controlled language serves as a foundational linguistic mechanism for the development of digital regulations, enabling normative requirements to exist simultaneously in human-readable and machine-readable forms and to function as the basis for automated compliance checking.

In the long term, controlled language will facilitate the transformation of traditional textual regulatory documents into digital knowledge bases, where each rule operates both as a normative statement and as an algorithm, enabling greater efficiency, safety, and innovation in the construction industry.

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