An Evaluation of Regulatory Documents Towards Automated Compliance Checking in Green Building Design

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Abstract

Regulatory frameworks related to building design are typically complex, encompassing extensive sets of rules and regulations. In the case of green building projects, this includes both regulatory requirements and guidance documents. Previous studies have indicated that these documents often contain subjective criteria, which makes it challenging to implement automated compliance checking effectively. Most efforts to automate compliance checking are objective in nature. However, there is a lack of initiatives aimed at automating the compliance checking process specifically for green building designs, and there is insufficient documentation on the systematic evaluation of legal documents within the green building domain to ensure efficient automated compliance checking. Therefore, the aim of this research is to conduct a thorough evaluation of the legal documents pertaining to green buildings in order to propose requirements taxonomy for integrating automated compliance checking into the design process of green buildings. The study adopted a qualitative research approach. The LEED regulatory document was analysed to extract and categorise the design requirements. The semantic and syntactic information elements were employed to establish the requirements taxonomy. The study provides a taxonomy for the requirements and ambiguities contained in the regulatory document guiding green building designs.

INTRODUCTION

Evaluation of design solutions is necessary in light of the project's objectives and anticipated benefits. Before design is frozen or finalized, assessment entails finding and exposing discrepancies between requirements and design, including regulatory constraints (Eastman et al., 2009; Parsanezhad et al., 2016; Sommerville, 2007). These cycles of analysis and assessment enhance the quality of design in the context of building design by guaranteeing that the expectations of clients and stakeholders are met (Kamara et al., 2000) and that design solutions adhere to regulations and legal requirements (Dimyadi and Amor, 2013; Nawari, 2013). Thus, design assessment offers a chance to enhance value generation and facilitates the removal of flaws (Fiksel and Hayes-Roth, 1993; Formoso et al., 2011; Kagioglou et al., 2000).

The literature lists a number of possible advantages of using automation to support design compliance checking, which has been recommended as a crucial way to get through this process (Eastman et al., 2009). Automation makes it possible to integrate and coordinate various information types in building models (Kivinemi, 2005; Laakso and Kiviniemi, 2012; Chellappa and Park, 2010). It also makes design compliance verification faster, more dependable, and more efficient (Eastman et al., 2009).

Researchers and practitioners have developed a wide range of automated compliance checking systems. These include logic-based methods (Solihin and Eastman 2016; Tan et al. 2010; Zhang and El-Gohary 2016), language-driven methods (Kim et al. 2017; Preidel and Borrmann 2016; Sydora and Stroulia 2020), object-oriented methods (Doukari et al. 2022; Garrett and Hakim 1992), and semantic and ontology-based methods (Beach et al. 2015; Hjelseth and Nisbet 2011; Macit lal and Günaydın 2017; Wu et al. 2021; Zheng et al. 2022; Zhou et al. 2022). Numerous advantages of ACC have been demonstrated by the systems, including an increase in the effectiveness and precision of compliance checking (Beach et al. 2020; Shahi et al. 2019). Even with encouraging outcomes, the majority of ACC systems now in use are limited to verifying numerical criteria or other objective, quantitative requirements (Dimyadi et al. 2016; Soliman-Junior et al. 2020a). As noted by Nawari (2020), subjective and ambiguous requirements—defined as those involving words like "approximately" and "close to"—cannot be handled by any existing system. This problem has also been noted by other researchers. et al., Soliman-Junior (2020b, p. 4).

The decision-making stages, design approaches, procurement procedures, tasks, actors, roles, team cultures, and competencies necessary to complete building projects are all reinvented by Green Building (GB) projects (Qazi et al., 2021). The objectives of GB initiatives may be thwarted by these changes and needs, which expose adopters to procedurally challenging and complex organizational requirements related to adopting new technologies (Hwang et al., 2017; Qin et al., 2016). Due to the additional sustainability goals that must be met, GB projects are more difficult to design, build, and administer. Zhao and associates, (2016). This increases the urgency of making sure GB initiatives are compliant. The literature shows that GBPs perform significantly worse in terms of cost and schedule than traditional projects (Hwang et al., 2017; Hwang and Leong, 2013).

There is a lack of initiatives aimed at automating the compliance checking process specifically for green building designs, and there is insufficient documentation on the systematic evaluation of legal documents within the green building domain to ensure efficient automated compliance checking. Therefore, the aim of this research is to conduct a thorough evaluation of the legal documents pertaining to green buildings in order to propose a requirements taxonomy for integrating automated compliance checking into the design process of green buildings. The present study achieved its aim through the following objectives:

i. To determine Green Building Regulations susceptible to automated compliance checking.
ii. To develop requirements taxonomy for information extraction of Green Building Regulations.
iii. To develop ambiguities taxonomy for coreference resolution of Green Building Regulations.

LITERATURE REVIEW AND OTHER SPECIFIC WORK DIRECTLY RELATED TO THE RESEARCH

Regulatory Requirements and Automated Compliance Checking

Statutory documents, such as building codes, regulations, and design guidance, are typically written in natural language to be easily understood by humans (Eastman et al., 2009; Nawari, 2012). However, this human-centric approach often results in the inclusion of complex expressions and implicit knowledge, posing a challenge when attempting to translate these documents for automated processes (Fenves & Garrett, 1995). The inherent ambiguity of regulatory requirements, with their open-text elements that necessitate interpretation and can be understood in multiple ways, further complicates matters (Nawari, 2012). Recent research has highlighted the subjectivity involved in using regulatory documents for automated rule processing, emphasizing the need to formalize human knowledge to ensure accuracy and completeness (Fenves & Garrett, 1995). The main difficulty lies in converting information from regulatory documents, which encompass various forms such as text, schedules, drawings, sketches, and images, into logic expressions that computers can understand without losing the original meaning (Lee et al., 2016; Solihin & Eastman, 2016). Despite the challenges, ongoing efforts have been dedicated to structuring and translating information from statutory and guidance documents to facilitate automated compliance checking (Solihin et al., 2020).

Ambiguity in the Construction Domain

The topic of ambiguity in the construction domain has not received much attention, with only a few studies acknowledging its presence in this particular context. For instance, Soliman-Junior et al. (2020a) conducted a study on healthcare facility requirements and identified ambiguity in spatial connectivity rules, specifically in the concept of being "adjacent to." To address this ambiguity, they proposed the use of semantic enrichment techniques. In their more recent work, Soliman-Junior et al. (2021) further categorized ambiguous clauses into two types: natural subjectivity and artificial subjectivity. Natural subjectivity refers to clauses that involve abstract elements, such as "design flexibility," which inherently pose challenges in achieving unambiguous interpretations. On the other hand, artificial subjectivity can be avoided by carefully employing clear and precise terms.

In the classification of building requirements put forth by Zhang et al. (2022b), clauses related to quality and aesthetics are considered to be ambiguous. Several studies have attempted to tackle the challenge of compliance checking for ambiguous clauses. For example, Hjelseth (2013) introduced the Test Indicator Objectives (TIO) methodology, which transforms ambiguous phrases into quantitative metrics. Similarly, Li et al. (2020) developed an automated method that utilizes spatial artifacts, such as functional space, visibility space, and movement space, to handle spatial rules with ambiguity. They emphasized the significance of supporting the disambiguation process with relevant evidence. However, it is important to note that both of these methods still rely on converting ambiguous rules into quantitative metrics, which may not always capture the complete complexity of the underlying meanings.

Zhang et al. (2023) have devised a taxonomy of ambiguity to streamline the process of automated compliance checking in the healthcare industry. Nevertheless, it is crucial to acknowledge that a classification model tailored for a specific domain cannot be seamlessly transferred to another domain (Salama & El-Gohary, 2016). This is primarily due to the variations in requirements utilized during the development of these models across different domains. It is worth noting that ambiguities can lead to a significant portion, up to 53%, of building requirements not being scrutinized through automated compliance checking (Soliman-Junior et al., 2021; Zhang et al., 2023).

RESEARCH REVIEW AND METHODOLOGY

The research utilized a qualitative methodology in order to construct the requirements taxonomy. In contrast, a quantitative research approach was employed to fulfill the study's objectives. Through thorough review and analysis of documents, the study assessed green building standards to determine the necessary building compliance requirements for green building projects. These identified clauses served as the foundation for developing models for the requirements taxonomy. Detailed descriptions of the dataset and methodology utilized in this research can be found in the following sections. Similar methodologies were also utilized in studies conducted by Abdullahi et al. (2024a, 2024b).

RESEARCH METHOD

The LEED green building standards, specifically versions 4 and 5, were chosen for this study. According to Rybakova & Makisha (2021), LEED is considered suitable for automated compliance checking. These standards are widely recognized for their comprehensive coverage of various environmental aspects related to different types of buildings.

Furthermore, they can be adopted by multiple countries as they transcend national boundaries.

After identifying the relevant documents, the data preprocessing phase began by excluding unwanted contents. To ensure the consistency and quality of the classification process, two researchers developed a systematic protocol and classification guidelines, which included illustrative examples. All researchers involved in the identification, analysis, and classification of requirements underwent the same training to minimize the risk of misinterpretation. Additionally, ongoing interaction and discussions among the researchers were maintained to address any emerging issues.

To ensure prompt feedback and maintain consistent and appropriate classifications, the same researcher reviewed all classified requirements multiple times throughout the classification process, including at its conclusion. This iterative review process also facilitated the refinement of the taxonomy and the classification protocol. The requirements were then categorised using a taxonomy.

Proposed Semantic and Syntactic Information Elements for Deep Information Extraction for Supporting ACC

In this study, the representation of LEED documents requirements involves the use of two categories of information elements: semantic and syntactic information elements. The semantic information elements play a crucial role in defining the requirements outlined in the natural language sentences of the LEED documents. In this research, a specific subset of the semantic information elements proposed by Zhang and El-Gohary (2013) was utilized, which consists of six fundamental semantic information elements: subject, compliance checking attribute, deontic operator indicator, comparative relation, quantity value, and quantity unit. Furthermore, two novel semantic information elements introduced by Zhang and El-Gohary (2021), subject relation and reference, were also integrated into the investigation (refer to Table 1).

However, the present study did not utilize the secondary semantic information elements, such as subject restrictions and quantity restrictions, proposed by Zhang and El-Gohary (2013). The rationale behind this decision is that the current study goes a step further in refining the representation of regulatory information using the proposed information elements, compared to Zhang and El-Gohary's (2013) previous study. Hence, there is no need to include the secondary elements as suggested by Zhang and El-Gohary (2021). The methodology employed in this study aims to tackle certain ambiguities found in the green standards. This is because Berry et al. (2003) categorized ambiguity into lexical, semantic, syntactic, or pragmatic types. Therefore, by adopting the semantic and syntactic information approach proposed by Zhang and El-Gohary (2013) and Zhang and El-Gohary (2021), some of the ambiguities inherent in the green standards can be addressed.

Conversely, the syntactic information elements comprise three distinct categories of logic operator indicators, specifically conjunctions (e.g., "and"), disjunctions (e.g., "or"), and negations (e.g., "not"). Furthermore, syntactic units such as pronouns (e.g., "the"), adverbs (e.g., "so"), prepositions (e.g., "of"), and conjunctions that introduce a clause (e.g., "that") are also encompassed within the scope of the syntactic information elements. These syntactic information elements play a pivotal role in capturing the syntactic structures of requirements, particularly those that exhibit intricate nesting. Zhang and El-Gohary (2021) underscore the significance of this comprehensive comprehension of the complete meaning of requirements. Table 2 exemplify the LEED standards requirements, which have been annotated with the proposed syntactic and semantic information elements.

Table 1. Semantic information elements for representing requirements for automated compliance checking.

Semantic information element	Definition
Subject	An ontology concept representing a thing (e.g., building element) that is subject to a particular requirement
Compliance checking attribute	An ontology concept representing a specific characteristic of a “subject” that is checked for compliance
Deontic operator indicator	A term or phrase that indicates the deontic type of the requirement (i.e., obligation, permission, or prohibition)
Comparative relation	A term or phrase for comparing quantitative values, including “greater than or equal to”, “greater than”, “less than or equal to”, “less than”, "same as", "same with" and “equal to”
Quantity value	A numerical value that defines the quantity
Quantity unit	The unit of measure for a “quantity value”
Subject relation	A term or phrase that defines the type of relation between two subjects, a subject and an attribute, or a subject or an attribute and a quantity
Reference	A term or phrase that denotes the mention or reference to a chapter, section, document, table, or equation in a building-code sentence

Table 2. Example of LEED standards requirements annotated with the proposed syntactic and semantic information elements.

Requirement	Proposed syntactic and semantic information elements
Install new	Rel
or	LO
use	Rel
existing base building - level data energy	
metres	S
or	LO
submetres	S

that	SU
can	D
be aggregated to provide	Rel
base building - level data	S
representing	Rel
total building energy consumption	S

D=deontic operator indicator; LO=logic operator indicator; QU=quantity unit; QV=quantity value; Ref=reference; Rel=subject relation; S=subject; SU=syntactic unit

RESEARCH RESULTS AND DISCUSSION

Determination of Green Building Standards Susceptible to Automated Compliance Checking

This research examined a range of green standards in order to identify which standards are susceptible to automated compliance checking. The research assessed the feasibility of translating these standards into a format that can be read by machines, which is a crucial requirement for the development of an automated compliance checking system (Rybakova & Makisha, 2021). According to Rybakova and Makisha (2021), a total of 11 green standards developed worldwide were reviewed in this study. The findings revealed that three of these standards possess a significant potential for translation into a machine-readable format, while one standard demonstrated an average potential. On the other hand, the remaining seven standards were found to have a low potential for translation. This study analysed the Leadership in Energy and Environmental Design (LEED) – USA due to its international applicability, availability of requirements for objects of various purposes, as well as availability of large number of criteria covering various green building elements.

Regulatory Requirements Taxonomy Analysis

This section provides a concise overview of the main findings obtained from the application of the taxonomy, showcasing the outcomes derived from the analysis of various documents. The section delves into the essence of requirements and their categorisation based on the taxonomy.

Proposed Ambiguity Taxonomy

The primary aim of coreference resolution is to identify instances of referential ambiguity in the text, with a specific focus on recognizing all mentions that relate to the same entity. This encompasses both coreferents and referring expressions (Wang & El-Gohary, 2023). Initially, different categories of coreferents and referring expressions were determined by analysing particular sections of the selected LEED documents. Tables 3 and 4 present illustrations of these distinct types of coreferents and referring expressions, respectively.

Table 3. Examples of different types of coreferents.

Type of coreferent	Description	Example

Demonstrative pronoun	Comparison exists with something that occurred earlier	In the sentence "the photometric characteristics (1) of each luminaire when mounted in the same orientation and tilt (2) as specified in the project design," the anaphor (2) refers to (1)
Discontinuous set	Pronoun refers to more than one antecedent	In the sentence "planned stops (1) and stations (2) may count if they (3) are sited," pronoun (3) refers to (1), and (2) together as the same entity
Definite pronominal	Pronoun 'it' refers to antecedent	In the sentence "cleaning product (1) produced on site via a cleaning device that produce only ionized water, stabilized aqueous ozone, or electrolyzed water and if it (1) complies with one of the above standards" pronoun (2) refers back to (1)
Adjectival pronominal	Coreferent refers to adjective form of entity that occurred previously	In the sentence "Have a policy in place to track the removal of refrigerant (1) containing equipment, including proof of proper disposal of such equipment and the refrigerants. In the US, such (1) removals must meet EPA's Clean Air requirements as per Title VI," (1) is an adjectival form that has been referred to by (2)
Cataphora	Opposite of anaphora	In the sentence "lamps or fixtures (1) specifically designed to provide coloured lighting (2)" (1) refers to (2) that precedes it

Table 4. Examples of different types of referring expressions.

Type of referring expression	**Example of two expressions referring to same entity**
Possessive	"footprint of development" and "development footprint"
Article	"boundary of the development" and "boundary of a development"
Hyphen	"non-potable water" and "non-potable water"
Synonym	"development of environmentally sensitive lands" and "construction on environmentally sensitive lands"
Space	"healthcare" and "health care"
Abbreviation	"basis of design" and "BOD"

CONCLUSION

The lack of initiatives aimed at automating the compliance checking process specifically for green building designs, and lack of a sufficient documentation on the systematic evaluation of legal documents within the green building domain to ensure efficient automated compliance checking constituted a gap. Therefore, this study conducted a thorough evaluation of the legal documents pertaining to green buildings in order to propose a requirements taxonomy for integrating automated compliance checking into the design process of green buildings. The study analysed the LEED regulatory document and employed the semantic and syntactic information elements to develop requirements taxonomy, while employing the coreference resolution to address the ambiguities contained in the requirements. The study provides a taxonomy for the requirements and ambiguities contained in the regulatory document guiding green building designs. The study is not without its limitations. The ambiguities covered by the study are corefent and referring ambiguities. The study did not cover other types of ambiguities like intentional and unintentional ambiguities.

The study is poised to greatly assist project managers, architects, quantity surveyors, clients, and contractors by offering a taxonomy to facilitate automated compliance checking of buildings against green standards. This is expected to lead to a notable decrease in project time overruns and enhance the overall sustainability of green constructions. Moreover, it will contribute to environmental conservation by supporting design reviewers in verifying that green building plans align with international green building benchmarks.

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