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AUTOMATED CONSTRUCTION SPECIFICATIONS DIGITALIZATION FOR EFFICIENT COMPLIANCE CHECKING ON SITES

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Abstract

To ensure construction quality and the safety of workers, construction managers oversee projects in accordance with established construction specifications. Manual review of the specifications requires considerable time and effort due to the dispersion of diverse criteria across extensive documents. Although various studies have aimed to digitalize construction documents for computerized analysis, they have focused on the design phase. Furthermore, compliance checking has only covered the predetermined rules, not over the entire specifications. This research expands the scope to encompass both qualitative and quantitative criteria automatically, enabling construction managers to access comprehensive specification contents digitally, for instance, through mobile devices. The research introduces a methodology for the automatic digitalization of specification items into appropriate formats including original texts, checklists, and Python codes. The methodology involves categorizing each specification item into one of four predefined types (i.e., general references, subjective judgment criteria, adaptive guidelines, and Pass/Fail standards). Subsequently, the methodology employs generative pre-trained transformers (GPT) to write checklists for subjective criteria, and Python codes for adaptive guidelines and Pass/Fail standards. The methodology ensures that the full set of construction specifications can be automatically converted into formats that allow for easy and accurate compliance checking by construction managers. It is expected to facilitate the straightforward and precise comprehension of complex construction standards across different activities through digitized construction specifications.

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Keywords: automated compliance checking, construction specifications, digital representation, GPT, quality assurance.

1. Introduction

Construction specifications are the documents that state how facilities should be built. During the construction phase of a project, compliance to these specifications is inspected. This process is known as construction quality compliance checking. Ensuring compliance with specifications is essential, as failure to adhere to these standards not only jeopardizes the safety of facilities and workers but also cause legal disputes [1]. However, inspectors often rely on their own experience to make decisions due to reasons such as being unfamiliar with regulations or feeling overwhelmed by large volume of regulatory text [2]. Consequently, the current manual inspection process has been time-consuming, error-prone, and labor-intensive. Hence, there is a pressing need for automated compliance checking (ACC) to minimize inspection errors and enhance construction quality [3].

The initial step towards ACC involves converting the construction specifications, written in natural language, into a computer-processable format. Traditionally, domain experts have manually reviewed the text, identified rules, and subsequently transformed them into digital formats. However, this procedure has been lengthy and become a bottleneck for effective ACC [4]. To address these challenges, previous studies have employed natural language processing (NLP) techniques to automatically interpret regulatory documents in construction and convert them into digital representations. Nevertheless, little attention has been paid to construction quality checking, with the primary focus on design standards. Furthermore, while all criteria in the specifications require verification, previous research has predominantly concentrated on criteria that are semantically and structurally clear and suitable for automated transformation.

To overcome the limitations, this study aims to automatically transform all specification clauses into digital representations for construction quality review. To achieve this goal, three tasks were conducted. Firstly, construction specifications were analyzed to group them into four categories. Secondly, appropriate digital representations for each specification type were identified. Finally, a generative pre-trained transformer (GPT)-based model was developed to automate the classification of criteria and generation of appropriate digital expressions.

2. Related works

2.1. Digital representations for construction regulations

Researchers have utilized various representations to capture and depict crucial information in regulatory construction documents through logical and semantic analysis. Hjelseth and Nisbet [5] divided regulatory clauses into four components (i.e., requirement, applicability, selection, and exceptions (RASE)) and represented them using semantic annotation. 'Requirement' described criteria marked with 'shall' or 'must' indicating mandatory conditions, 'Applicability' identified the scope or conditions under which the criteria apply. 'Selection' specified alternative subjects or additional conditions to be considered. 'Exception' outlined conditions or clauses that exempt from the general applicability. This method aimed to streamline the interpretation and application of regulations. Balaban et al. [6] introduced the if-then structure to digitally express Turkish fire code standard. According to this framework, the outcome was marked as 'Pass' if all conditions were met. Conversely, if any of the criteria were not satisfied, the outcome was marked as 'Fail'. These approaches provided valuable tools for understanding the logic and semantics of construction regulations. However, they had limitations that the process of transforming construction regulations to digital representations relied on manual methods.

2.2. Semi-automated digital rule transformation method

Other studies have attempted to automate the rule transformation process using an NLP-based model, particularly leveraging an ontology-based approach for information extraction. Zhang and El-Gohary [7] automated document transformation by extracting words and phrases from sentences based on predefined regulatory rules and ontology. Zhou et al. [8] utilized a deep learning model to label semantic elements and context-free grammar to relocate parsed elements into rule representation for ACC. Additionally, Ren et al. [9] introduced a semantic and syntax-based NLP framework to automate the entity extraction and entity assembly process for a dam construction. These frameworks exhibited a high level of accuracy (e.g., over 85%) in information extraction and parsing, demonstrating potential for automating rule transformation. However, these methods have not been fully automated, as human intervention was needed to select suitable targets that can be easily converted into representations. In addition, these studies have primarily focused on converting design standards. Thus, they have overlooked the importance of identifying appropriate digital representation methods for effectively conveying information across various types of quality checking.

2.3. Generative pre-trained transformer (GPT)

GPT, developed by OpenAI, is a third-generation autoregressive language model that employs a deep learning architecture to generate text that closely resembles human language pattern and understanding. Trained on vast unlabelled datasets from diverse sources (e.g., Wikipedia) in multiple languages, it excels in tasks such as capturing contextual information and generating text. Prompt engineering is designing the 'prompt' input for GPT by suggesting a small number of examples related to the task. This technique assists the model to produce the desired output effectively [10].

It is observed that GPT is being utilized as a research tool in various fields. In the biomedical domain, Luo et al. [11] proposed BioGPT to generate and mine biomedical text, and Kosinski [12] used GPT-3 to impute unobservable mental states. In the business field, Paul et al. [13] showed the benefit of utilizing GPT within tourist companies and destination marketing organizations. In the construction domain, Prieto et al. [14] showed the advantages of using GPT to generate construction schedules. Although GPT is an effective tool, there is a lack of research exploring its application in transforming documents into digital representations, especially within the construction domain.

3. Methodology

This study automates the process of transforming Korean Construction Specification (KCS), managed by the Korean Construction Standards Center, into digital representation. Fig. 1 illustrates the research process consisting of three steps. In the first step, categories are defined to classify each clause of KCS based on quality compliance checking types. In the second step, digital representation for each regulation category is devised to effectively express construction information. In the final step, the creation of digital representations is automated through GPT prompting engineering.

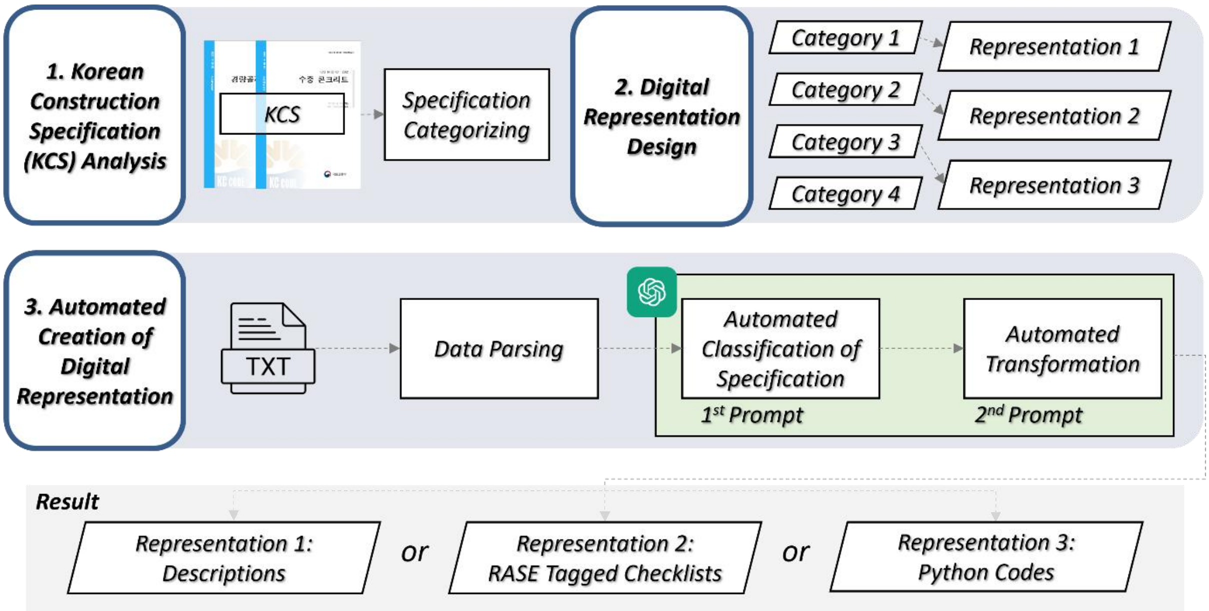

Fig. 1. research process for automated digitalization of construction specification

3.1. KCS analysis

KCS is a collection of documents, each describing a specific construction procedure and named with sequence of six numbers prefixed with 'KCS' (e.g., KCS 14 31 20). The first two digits indicate the type of facility to which KCS pertains. The 3rd and 4th digits represent the subcategory, reflecting the typical characteristics of the code. The final two digits specify the detailed criteria. For example, in the KCS code 14 31 20, '14' indicates it pertains to structural material construction, '31' refers to steel structure construction, and '20' specifies it as welding construction.

Each KCS document consists of three parts: 1. 'General', 2. 'Material', and 3. 'Construction'. In the 'General' section, definitions of terms and scope of application are explained. The 'Material' section describes the minimum standards and management methods for materials required during construction. The 'Construction' section explains the actual construction method through qualitative text or the quantitative criteria. As shown in Fig. 2, the content of KCS is hierarchically structured as '3. - 3.1 - 3.1.1 - (1) – circled digit number - Korean alphabet - …'. Hence, focusing solely on the lowest level clause cannot provide a complete understanding. To understand the lowest unit, one must read all higher-level texts. For example, understanding the lowest level clause in Fig. 2, 'there should be no cracks or other defects in the welded joints at a bending angle of 15°,' requires higher-level information such as 'inspecting bending', 'stud welding', and 'architectural structure'.

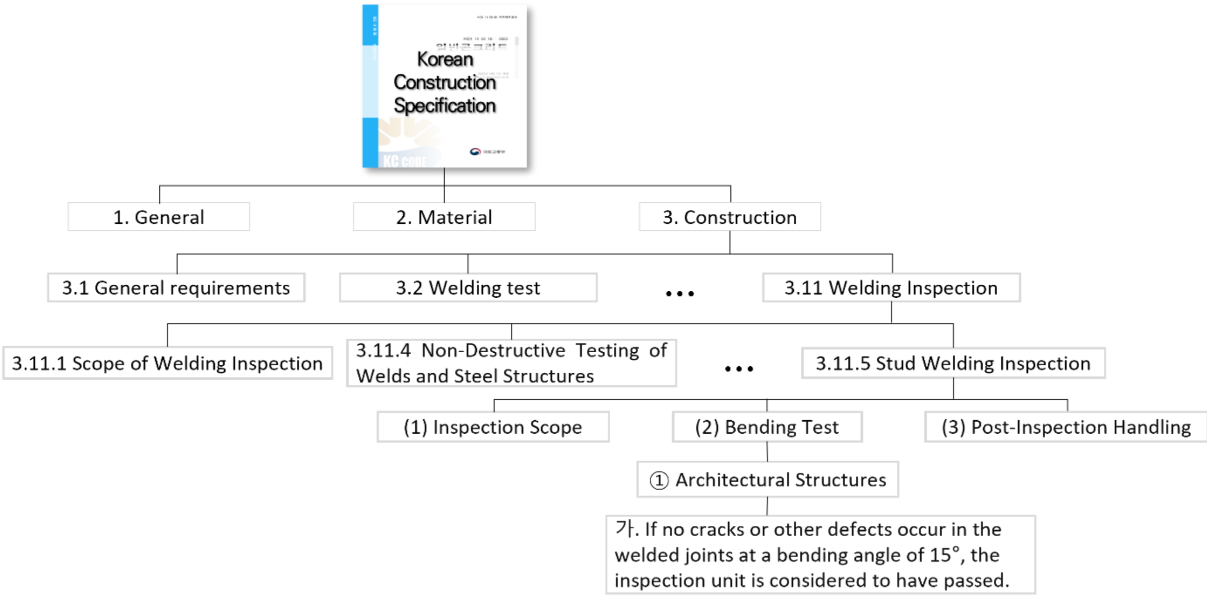

Fig. 2. hierarchy of KCS contents

By understanding the hierarchical structure of KCS contents, the categories of KCS contents were defined based on the compliance check types. Table 1 shows the description and example of each KCS category. The first category is general provisions or definitions, which serve as references without the need for direct compliance checks during construction. The second category involves subjective judgment criteria, where the site manager's subjective judgment is necessary for checking construction quality. The construction condition should undergo subjective judgment to verify compliance with the regulation. The third category 'adaptive guidelines' pertains to construction information, which can be determined based on acquired quantitative construction data. It also allows for identification of necessary construction measures using quantitative environmental data. Lastly, the fourth category is the Pass/Fail standard, which enables determining compliance with construction specifications based on quantitative criteria. It helps Pass or Fail assessment of whether the finishing height meets the standards.

Table 1. Description and example of each KCS category

KCS category	Description	Example
General references	Definitions or general provisions for reference during construction	These criteria apply to welding operations needed for fabricating and installing steel structures and steel bridges.
Subjective judgment criteria	Qualitative criteria that require site manager's subjective judgement	The connections of system headers should be securely fixed.
Adaptive guidelines	Criteria providing construction method or information based on quantitative data on sites	When the installation height of the steel pipe shore exceeds 4.0 m or the slab thickness exceeds 1 m, the prefabricated shoring system capable of safely supporting the load is used.
Pass/Fail standards	Quantitative criteria for which accessing adherence is possible	The finishing height of studs must be within ±2 mm of the design dimensions.

3.2. Digital representation design

The authors designed a representation of each category defined in the previous section to effectively store and present the specifications' contents. Fig. 3 shows the original and digitalized version of each specification category.

First, general references type is more efficient when provided in the textual description itself without any transformation, providing direct content for users.

Secondly, subjective judgment criteria should be presented in a checklist format to facilitate compliance checks. To create a practical checklist, it is necessary to separate verbose clause into concise phrases. Also, the purpose of each phrase should be identified. The RASE, semantic annotation for effectively conveying regulatory content described in Section 2.1, can be tagged to express the purpose of each phrase. Checklists are then intuitively provided so that construction supervisor can check components of clause: mandatory requirements (requirement), the condition under the clause applies (applicability), alternative subjects (selection), and exemption from the general applicability (exception). As shown in Fig. 3, some of the original clause can be too lengthy, making it challenging to check compliance easily. The following checklist, labeled with its semantic objective, is easier to comprehend than the original.

Regarding to the adaptive guidelines, construction method or information determined based on the specific construction conditions must be presented to the site manager. For the case in Fig. 3, if the slab thickness on-site is 1.5 meters, construction method that 'prefabricated shoring system is required.' should be provided. Lastly, the Pass/Fail standards should inform whether the construction condition adheres to the criteria. The evaluation should solely focus on determining whether obtained value for the finishing height of studs meets the criterion. Adaptive guidelines and Pass/Fail Standards both involve the output determined by if-then logic based on objective criteria. Python language enables the application of if-then logic in alignment with the logic described in the specifications. Therefore, using Python functions is an appropriate representation method for expressing them into rule.

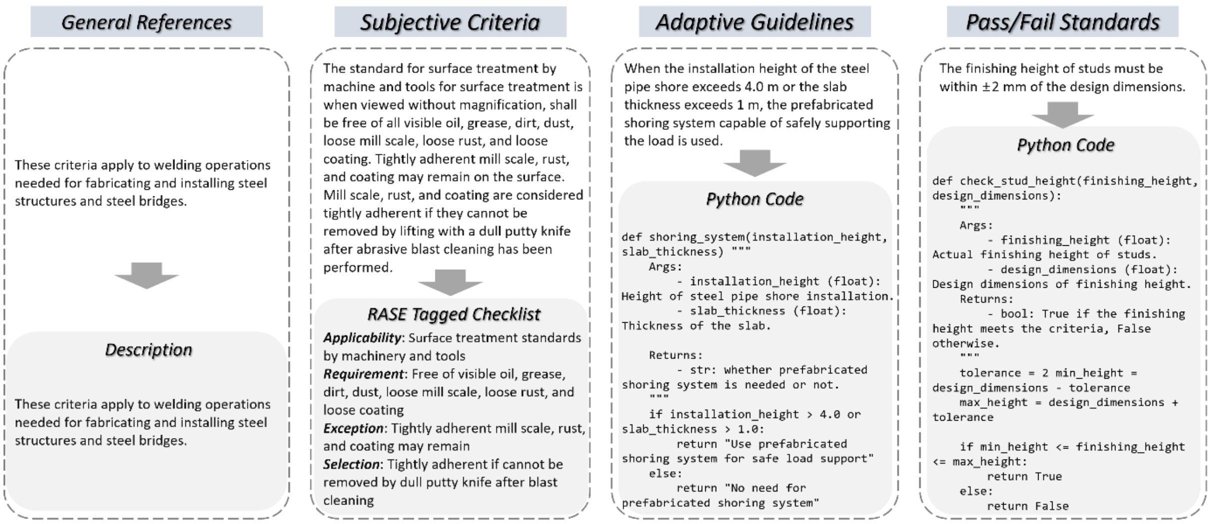

Fig. 3. examples of original text and digital representation for each specification category

3.3. Automated creation of digital representation

The GPT model is employed for automating creation of digital representation due to its capacity to handle complex language structures. The use of GPT, particularly through prompting engineering, enables generation of detailed digital representations for specifications, facilitating the efficient extraction of desired outputs.

In order to request GPT to generate digital representations for an entire document, it is necessary to break down the document into smaller units where digital representations can be created. The procedure of extracting the necessary parts by reading the data is referred to as data parsing. This process was automated to reduce effort required for manual text inputting. In data parsing step, each clause was broken down into the lowest-level units due to its independent meaning. In addition, as explained in Section 3.1, all higher-level information was included for a sufficient understanding of regulations. Fig. 4 illustrates the parsed results, with all the higher-level information incorporated within the lowest-level units of regulations.

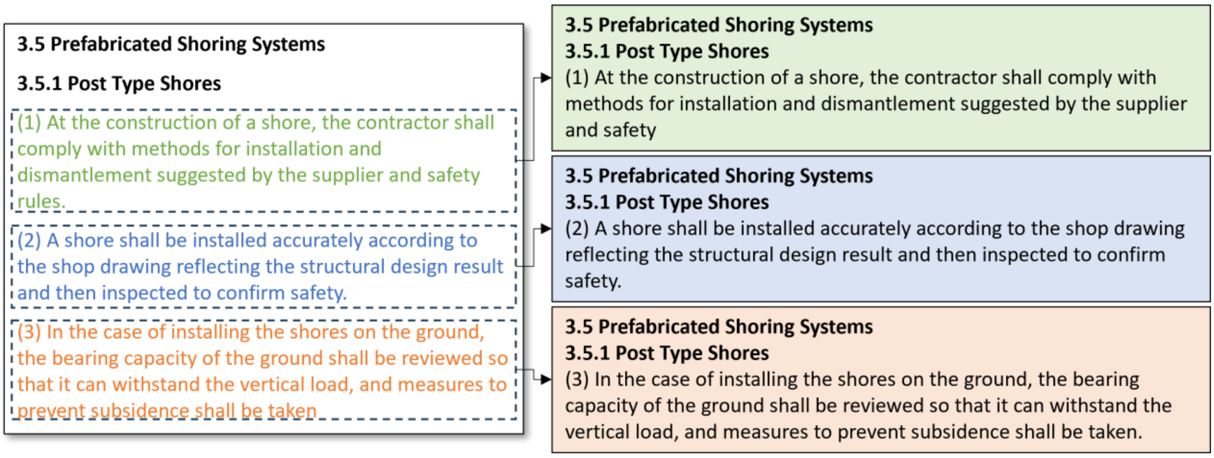

Fig. 4. examples of parsed specification

The extracted lowest-level items were then transformed into digital representations through two stages of GPT prompting. The first stage was the classification stage, where the GPT classifies the criteria items based on construction compliance checking type and determines which representation to use. In this stage, few-shot prompting was used to help the GPT classify the items more accurately by providing examples of each type. The second stage involved prompting to generate the digital representations corresponding to the classified categories. Similar to the first prompting, examples of digital representations were provided to improve the quality of the results. Fig. 5 is prompting example of a Python function to transform the 3rd or 4th category of the specification into digital representations. When the digitalization process is completed, each lowest-level text and its digital representation were stored in an Excel file.

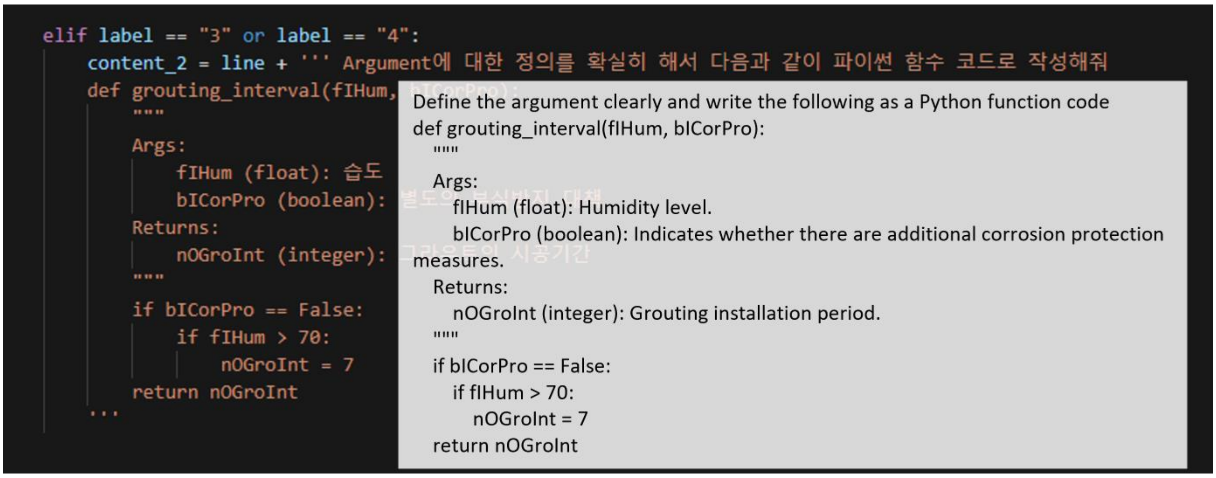

Fig. 5. prompting with an example of Python function

4. Verification of digitalization process

The section '3. Construction - 3.5 System Scaffold' of 'KCS 11 50 20 Pile Construction' was tested to evaluate the suitability of the output. Fig. 6 illustrates the results of digitalization process. The initial column contains the unaltered natural language specifications, encompassing all pertinent upper-level data. The subsequent column denotes the compliance checking type of each specification clause. The final column displays the digital representation that has been generated.

Upon checking the row 8, it was observed that the clause which entailed subjective judgment, ‘connections shall be securely fixed,’ was appropriately classified under category 2. Digital representation stated that the ‘requirements’ are (1) ‘Ledger members should be installed on both vertical and horizontal components,’ and (2) ‘Connections of the system scaffold must be securely fixed.’ ‘Application’ was ‘When installing the system scaffold,’ and there was no ‘selection’ or ‘exception’ checklist. It was successfully categorized and transformed into appropriate representations as intended.

Row 9 was categorized as a Pass/Fail standard for compliance checking. To verify the proper functioning of the Python function, it was tested with random input values to ensure that the output aligns with the specified criteria. When the scaffold installation height is 3000 mm and the single span length of the scaffold is 1500 mm, the output should be True (i.e., Pass), indicating that the criteria is satisfied. However, if the installation height is changed to 2000mm, the function result will be False (i.e., Fail), indicating that the criteria is not satisfied. This confirms that the function is well-written, as it aligns with the logic of the criteria, which states ‘the scaffold installation height should not exceed three times the single span length of the system scaffold.’

	A	B	C
1	Original Text	Category	Digital Representation
8	3.5 System Scaffold 3.5.1 Scaffold with Ledger Type (6) The system scaffold shall be installed by fixing the ledgers firmly to the vertical and horizontal members according to the assembly drawing prepared by the structural design to ensure structural stability against vertical and horizontal loads. 3.5 시스템 동바리 3.5.1 지주 형식 동바리 (6) 시스템 동바리는 연직 및 수평하중에 대해 구조적 안전성이 확보되도록 구조설계에 의해 작성된 조립도에 따라 수직재 및 수평재에 가새재를 설치하고 연결부는 견고하게 고정하여야 한다.	2	Apply: "When installing the system scaffold." Apply (적용범위): "시스템 동바리를 설치하는 경우" Requirement (필요조건): 시스템 동바리는 … The system scaffold shall be installed by fixing the ledgers 성된 조립도에 따 … firmly to the vertical and horizontal members 시스템 동바리의 … The connections of the system scaffold shall be securely fixed. Select (선택사항): 없음. None Exception (예외사항): 없음. None

9	3.5 System Scaffold
	3.5.1 Scaffold with Ledger Type
	(7) The height of the system scaffold installation shall not exceed three times the single span length, and if exceeded, measures to prevent collapse such as supporting on adjacent structures shall be taken. However, if structural stability against overturning and sliding is confirmed through the installation of horizontal bracing, etc., it may be installed exceeding three times the single span length.
	3.5 시스템 동바리
	3.5.1 지주 형식 동바리
	(7) 시스템 동바리를 설치하는 높이는 단변길이의 3배를 초과하지 말아야 하며, 초과 시에는 주변구조물에 지지하는 등 붕괴방지 조치를 하여야 한다. 다만, 수평버팀대 등의 설치를 통해 전도 및 좌굴에 대한 구조 안전성이 확인된 경우에는 3배를 초과하여 설치할 수 있다.
		4	def check_scaffold_installation(height, side_length, safety_measures=False, horizontal_bracing=False):
			"""
			Check if the scaffold installation meets the construction standard.
			
			Parameters:
			height (float): The height of the scaffold installation.
			side_length (float): The side length of the scaffold.
			safety_measures (bool): Whether safety measures are taken if the height exceeds 3 times the side length.
			horizontal_bracing (bool): Whether horizontal bracing is installed.
			
			Returns:
			bool: True if the scaffold installation meets the standard, False otherwise.
			"""
			if height > 3 * side_length:
			if safety_measures or horizontal_bracing:
			return True
			else:
			return False
			else:
			return True

Fig. 4. digitalized output of KCS 11 50 20_3.5

5. Conclusion

This study introduced a framework for converting construction specifications into digital representations, a significant step in ACC in construction sites. The framework involved three main steps: (1) analyzing KCS to categorize clauses based on compliance checking types, (2) selecting appropriate digital representations for each category, and (3) automating converting process. The verification of the automated digitalization on 'KCS 11 50 20 Pile Construction' clearly demonstrated the feasibility of the framework.

The research has made both academic and practical contributions. Academically, the research has established distinct categories to classify specification items for quality compliance checking in construction phases. Additionally, digital representations were introduced to address different types of compliance checking requirements. The practical contribution lies in streamlining the automation of generating digital representation. This automation eliminates the need for manual interpretation, allowing for quick and accurate transformation of entire specifications facilitating easy interpretation of regulations, swift verification of adherence, and informed decision-making during ACC. However, a notable limitation of the study is the absence of a comprehensive performance evaluation of the result against ground truth data. Additionally, the case study was conducted on KCS document comprised solely of textual information. Hence, documents containing tables and formulas have not yet been tested.

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