Research Statement

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I am a Purdue University Ph.D. candidate interested in developing and testing new computing technologies to assist construction automation. The construction sector is frequently seen as reluctant to embrace new technology, resulting in productivity stagnation. In my dissertation, I applied the most recent advances in Artificial Intelligence (AI) and Natural Language Processing (NLP) (such as the Attention Mechanism, Language Model, and Recurrent Neural Network (RNN)). When the size of the dataset prevented me from attaining high performance, I used a rule-based technique instead.

My dissertation research is focused on automating the extraction of regulatory information from building codes to facilitate Automated Compliance Checking (ACC). Many research, government programs, and commercial ventures have attempted to push code compliance checking to full automation during the course of ACC's more than half-century history. Many of them, however, have discontinued operations because the expense of manually converting building codes into a computer-processable, formal, and structured format is prohibitively expensive. In my dissertation, I presented: (1) error-driven transformational rules to improve the performance of Part-of-Speech (POS) taggers on building codes, (2) a POS tagger tailored for building codes that combines error-driven transformational rules with a pre-trained neural network model, and (3) a ruleset expansion method to increase the range of checkable building codes of ACC systems by adding new pattern matching-based transformational rules to an existing ruleset, (4) a semi-automated method to extract regulatory information from tables in building codes, and (5) a rule-based method that extracts and interactively visualizes the hierarchical and cross-reference structure of building. The results of the above-mentioned research have been outlined through seven peer-reviewed journal articles (two of which have been published, one of which has been accepted, and four of which are still being reviewed) and three conference papers (one of which was accepted and two of which are still being reviewed).

I have determined that the accuracy of POS taggers could be improved by 8.65% after applying error-driven transformational rules. The building-code-specific POS tagger achieved an accuracy of 95.11%. Before iterative refinement, the tabular information extraction system processed 91.67% of the tables in the testing dataset correctly. After iterative refinement, the tabular information extraction system processed all the tables in the testing dataset correctly. With a low marginal cost, the ruleset expansion method can increase the range of ACC systems' checkable building code requirements. In the testing dataset, the building code hierarchical and cross-reference structure extraction methods had precision, recall, and F1-score of 100%, 88.9%, and 94.12%, respectively, and enabled interactive visualization of extracted networks.

Project 1: Automated Transformation of Building Code to Logic Clause

Innovation: I combined a rule-based approach with deep learning to develop the first POS taggers specifically for building codes. My method expands the range of checkable building code requirements of ACC systems with minimum marginal effort.

Impact: This research finding increases the correctness of the transformation of building codes. ACC systems will be able to check a broader range of building code requirements.

Currently, I am working on converting natural language building code into a computer-processable, formal, and structured format (i.e., logic clause). The transformation is a multi-step pipeline that uses both syntactic (POS tagging) and semantic (ontology) information from building codes. In my first conference paper, I evaluated at how well seven cutting-edge POS taggers performed on building codes, despite the fact that they were designed for generic English corpus rather than building codes. According to the findings, ACC must enhance the POS taggers' accuracy on building codes to support the automated conversion of building code into a computer-processable, formal, and structured format.

I built error-driven transformational rules and coupled them with deep learning to improve the accuracy of POS tagging in my first two journal papers (and the first two chapters of my dissertation). I discovered that the rule-based technique may result in excellent performance, when appropriately used. In the age of deep learning, it is not uncommon for computer scientists to battle for a fraction of a percentage gain in performance using a highly complex neural network. Their approaches, however, may need a huge training dataset and have low accuracy outside of the domain of the training data. To convert the tagging outputs of machine POS taggers to human-labeled gold standards, error-driven transformational rules are created, from simple ones to sophisticated ones (Figure 1). For my first journal publication, I assembled results of seven cutting-edge POS taggers. None of them were trained on building codes or domain texts in the construction industry. My research provides a new way to obtain accurate POS tagged building codes when no POS tagger that is designed for building code is available.

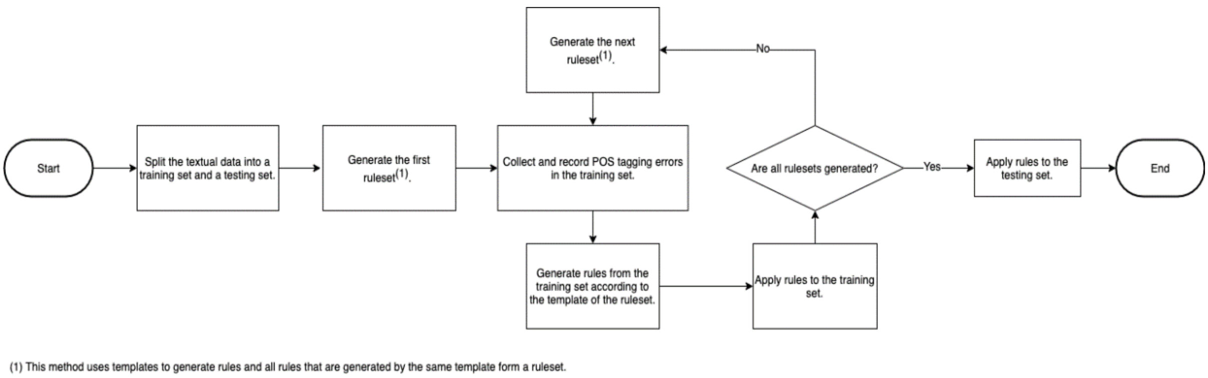

Figure 1 Error-driven Transformational Rule

In my second journal article, I developed a POS tagger that is customized for building codes by combining pre-trained deep learning language models with error-driven transformational rules (Figure 2). The pre-trained model is trained on a large body text to learn knowledge about language (i.e., English) itself. By providing knowledge about English, the pre-trained model was introduced to ease the problem of lack of training data (POS tagged building codes). In training, the trainable layer can make the neural network model to gain additional knowledge about POS tagging of building codes. Overfitting can be reduced by using a dropout layer. To provide intermediate tagging results, a TimeDistribute layer is employed. The accuracy of POS tagging is further improved by using error-driven transformational rules.

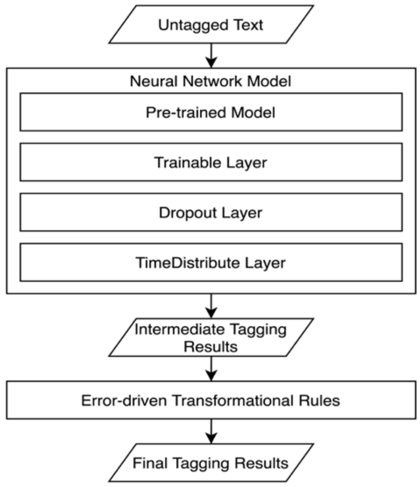

Figure 2 The Architecture of the POS

I focused on increasing the breadth of ACC systems' checkable building code requirements in my third journal article. Due to the significant expense of manually converting building codes, several prior ACC systems by academia, government, and industry have discontinued development. For example, DesignCheck (Dimyadi and Amor 2013), which was developed by a group of university researchers, the Construction and Real Estate Network (CORENET) project (Sing et al. 2001), which was backed by the Singapore government, and the SmartCode project, which was launched by the Duany Plater-Zyberk & Company (DPZ) (Duany et al. 2009) all ceased to development for this as well as other reasons. With minimum manual work, I created a ruleset expansion method for ACC systems to increase the range of checkable building code requirements (Figure 3). The extended ruleset's backward compatibility is preserved by neither deleting nor changing any rules of the original ruleset.

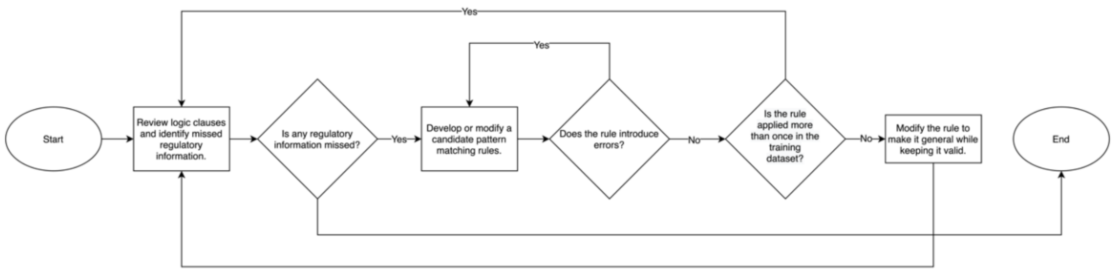

Figure 3 Ruleset Expansion Method

Future work: Now I am working on a journal article about utilizing deep learning-based NLP approaches to determine the subject of compliance of logic clauses. A dataset on subject of compliance with each requirement of the International Building Code 2015's Chapters 5 and 10 is currently being developed. I am also working on a paper regarding the direct conversion of natural language building code requirements to logic clauses. In this paper, I could reuse the dataset that I created from my third journal publication. The National Science Foundation (NSF) has a long history of funding research in this field. I participated in NSF projects, such as PFI-RP: Automating Building Code Compliance Checking and Modular Construction Through

Interoperable Building Information Modeling Technology program (NSF [Award #1827733](#)). I also collected and summarized data about civil infrastructure assessment from State Department of Transportations (DOTs) and construction domain ontology for Convergence Accelerator Phase I (RAISE): Civil Infrastructure Systems Open Knowledge Network (CIS-OKN) project ([NSF Award #1937115](#)). Local DOTs may also be interested in funding my study because it could be used to support roads and other infrastructure development. I also want to teach undergraduate and graduate-level courses based on my research. For example, I could share my neural network model training code with students. Students might potentially train multiple neural network models without any coding experiences by changing hyper-parameters of neural network models in computer code. Students will have the opportunity to learn about the impact of cutting-edge AI advances on the Architect, Engineering and Construction (AEC) sector.

Project 2: Building Code Hierarchical and Cross-Reference Structure Extraction and Visualization

Innovative: This is the first research that considers regulatory information in building codes as interconnected objects rather than separate items

Impact: The BCNEV method allow cross-references between building code requirements to be considered by ACC systems and supports navigation and understanding of building code.

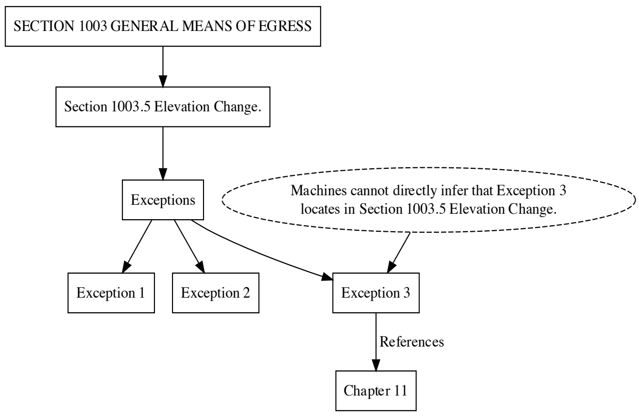

Figure 44 Importance of Context-awareness to Machine Processing

Existing ACC systems mostly treat building code requirements as isolated items. However, the abundance of cross-references in building codes, on the other hand, clearly implies that building code requirements are linked together. To systematically extract the hierarchical and cross-reference structures in building codes, I created a rule-based technique called the Building Code Network Extraction and Visualization (BCNEV) method. "Context awareness" is the major problem addressed by the extraction (Figure 4). The human reader, for example, could then easily identify that Exception 3 falls within Section 1003.5. Machines, on the other hand, lack context awareness in the absence of additional information. I created a rule-based

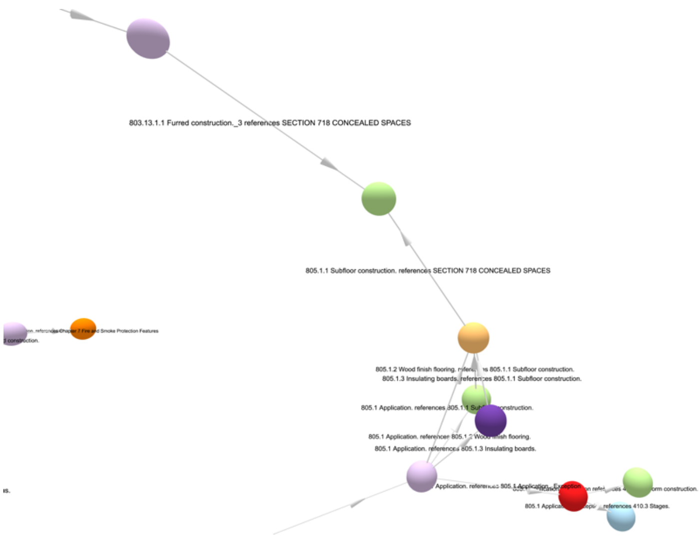

Figure 5 Visualization Example

technique for giving robots context awareness similar to that of humans. An example visualization using the BCNEV method is displayed in Figure 5.

Future work: The BCNEV approach demands the development of specific rules for various building codes. To reduce the need for specific rules, I aim to build a deep learning extraction approach. I can utilize existing data from the BCNEV method's development. The NSF and DARPA are likely to fund this kind of fundamental research. When applied to teaching, I can show students visualization results in class about building regulations. I also can encourage students to generate their own visualization.

Project 3: Network-level energy and traffic optimization for sustainable rural-urban network

Innovative: The research will be one of the first projects that concurrently optimizes traffic and energy consumption in a region that contains both rural and urban areas.

Impact: The research has the potential to reduce energy consumption, traffic congestion as well as slow down global warming,

I plan to perform an analysis of network-level energy and traffic optimization, with an emphasis on energy, material, and traffic movement between urban and rural areas. I learned network analysis and computer graph theory for Project 2, so this inspired my interest in related research. This study can make use of publicly available traffic data. I also intend to use sophisticated sensors, such as a drone and a laser scanner, to acquire fresh data. This study might be incorporated into a graduate or undergraduate course. Students could get a simplified version of an urban-rural network or a portion of one and optimize it for the least amount of energy usage, traffic volume, or congestion. A recent Request for Proposal about Sustainable Reginal Network from NSF indicates that NSF is willing to fund this type of research.

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