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# Assessing the Effectiveness of BIM in Achieving Compliance with NECB Energy Efficiency Pathways

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**ABSTRACT:** Building Information Modeling (BIM) has become a foundational technology in the construction sector, revolutionizing collaboration and lifecycle information management and leading to building design and management efficiency. When applying BIM to energy efficiency, meeting the requirements of the National Energy Code of Canada for Buildings (NECB) poses unique challenges due to its distinct compliance pathways: prescriptive, trade-off, and performance based. Each pathway demands different design precision and analysis levels, often resulting in complexities and inefficiencies. This study investigates BIM's potential to streamline NECB compliance, focusing on improving efficiency, precision, and effectiveness in achieving energy performance standards. The research aims to evaluate how BIM can support automation, facilitate decision-making, and streamline the integration of energy compliance requirements. The research methodology includes an extensive literature review, and a comparative analysis of BIM workflows and tools tailored to the NECB pathways. Key performance indicators such as energy optimization, compliance timelines, and error minimization are assessed to understand BIM's value in this context. The findings suggest that BIM can potentially improve compliance verification, especially within the prescriptive and trade-off pathways, by minimizing manual work and enabling efficient energy simulations. However, performance-based compliance continues to depend on complex computational modeling, restricting full automation. Key challenges, including data interoperability issues, difficulties in rule interpretation, and obstacles to industry adoption, emphasizing the need for enhanced regulatory frameworks and stronger BIM-NECB integration. This study highlights BIM's capacity to streamline NECB compliance and support sustainable building practices, reinforcing the role of digital technologies in achieving national energy efficiency objectives.

## 1. INTRODUCTION

The increasing need for sustainable construction practices and energy conservation has led to the establishment of regulatory frameworks such as the National Energy Code of Canada for Buildings (NECB) (National Research Council Canada, 2023). The NECB provides detailed guidelines to enhance energy efficiency, minimize greenhouse gas emissions, and improve cost-effectiveness in building operations (Natural Resources Canada, 2022). Due to the complexity and significant energy demands of modern buildings, leveraging digital technologies is crucial to meet NECB requirements and more importantly its objectives and stated outcomes.

To meet NECB requirements, building professionals can follow one of three compliance pathways: prescriptive, trade-off, or performance-based (National Research Council Canada, 2023). Each method requires comprehensive energy evaluations, which, when performed manually, tend to be both timeintensive and susceptible to errors, especially in large-scale projects. As Building Information Modeling (BIM) approaches maturity and becomes an industry standard, its integration into compliance workflows offers a structured and automated mechanism that can improve the efficiency and accuracy of regulatory assessments, reducing the reliance on error-prone manual processes (Chen, Lin, Jiang, & An, 2024). BIM consolidates building geometry, spatial relationships, and system data, enabling engineers to simulate and enhance energy performance (Eastman et al., 2009). By integrating these tools, NECB compliance processes can be streamlined, improving accuracy and efficiency while reducing reliance on manual assessments. Despite this potential, the implementation of BIM for NECB compliance remains limited, and its effectiveness across different compliance pathways is not well-documented. This research investigates how this technology can automate compliance verification and enhance energy performance assessments. Given the intricate nature of NECB compliance, this study aims to explore the broader implications of BIM integration in simplifying compliance procedures and advancing energy efficiency efforts. The findings suggest that prescriptive NECB rules can be effectively automated using BIM because they include clear numerical criteria. Trade-off rules also show some potential for automation when supported by BIM-based simulations. However, performance-based rules are more difficult to automate since they depend on complex energy modeling, and certain NECB requirements are not yet fully compatible with the current IFC schema. The paper is structured in three sections, with a literature review on BIM and energy code compliance and analysis, a description of the methodology used and a presentation of the findings and their implications for future research and practice.

## 2. LITERATURE REVIEW

### 2.1 Compliance Pathways for the National Energy Code of Canada for Buildings

The NECB identifies three compliance pathways, meaning that there are three ways in which a project can comply with the NECB: the prescriptive pathway, the trade-off, and the performance-based pathway. The prescriptive pathway mandates strict compliance with NECB standards for various building elements, including insulation, lighting power density, and HVAC system efficiency. In other words, the code prescribes the values that certain building elements must achieve to be compliant. The trade-off pathway introduces flexibility by permitting suboptimal performance in certain areas to be balanced by enhancements in others. Finally, the performance-based pathway shifts the focus from individual components to the building's overall energy efficiency. Table 1 provides a comparative overview of compliance assessment methods across the three NECB pathways, highlighting key features, advantages, and challenges specific to each approach.

Table: Compliance assessment methods across NECB Pathways

| pathway | Compliance assessment methods | Advantages | Compliance Focus |
|---|---|---|---|
| Prescriptive | Embedding NECB's predefined standards for automated validation within a data base or information model. | Reduces manual effort and errors.<br>Immediate Feedback. | Meeting specific NECB component standards. |
| Trade-Off | Simulating different scenarios and assessing design trade-offs for overall energy compliance. | Flexibility: Allows to explore various design options.<br>Enhanced Analysis: Allows to assess energy impacts of changes. | Allows variations if overall energy performance meets NECB. |
| Performance-Based | Creating a dynamic information model to simulate total energy consumption, | Comprehensive: Offers a holistic energy view.<br>Innovation: Supports novel design strategies. | Evaluates total energy consumption, not just components. |

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| | refining designs to meet NECB targets. | |

## 2.2 BIM in Energy Code Compliance Assessment

The use of Building Information Modeling (BIM) to evaluate and automate compliance with NECB is still an emerging research area, with few studies specifically focusing on automation in this context. However, the role of BIM in energy code compliance has been investigated in international contexts.BIM functions as a digital model that enables designers to simulate and optimize energy performance by experimenting with various building envelope and system configurations, reducing costs and improving sustainability (Yildirim & Polat, 2023). Studies highlight that BIM's automated compliance verification streamlines regulatory adherence by enhancing accuracy, reducing manual errors, and providing real-time design feedback (Amor & Dimyadi, 2021) (Preidel & Borrmann, 2018). Traditional compliance assessments, which are often manual and error-prone, can be improved through BIM's automated rule-checking capabilities, ensuring adherence to NECB energy performance standards (Tan et al., 2010).

For each method described in Table 1, BIM can support the evaluation or automation of the NECB pathway. For the prescriptive pathway, BIM enables the embedding of regulatory criteria directly within digital design environments, thereby enabling automated verification of design parameters (NECB, 2020). BIM facilitates the trade-off pathway by offering energy simulations that allow designers to explore and compare design alternatives, ensuring adherence to NECB requirements through optimized trade-off decisions (Kücükavci et al., 2024; Amor & Dimyadi, 2021). Finally, BIM can be effective in the performance-based pathway, as it enables comprehensive whole-building simulations that assess heating, cooling, lighting, and ventilation loads (Tan et al., 2010).

A specific focus is put on open BIM, as developed by buildingSMART International, due to its focus on seamless data exchange through interoperability and its growing range of services that can support multiple software solutions and platforms. Open BIM for energy analysis and compliance checking has been the focus of past research by several institutions and organizations. It is essential for supporting consistent information exchange between modeling platforms, which helps reduce inconsistencies and improves the precision of energy performance evaluations. Its open structure allows stakeholders to collaborate more efficiently and enables rule-based automation. Notably, AECOM and ArchSD in Hong Kong applied open BIM in automated plan review workflows to improve energy code compliance efficiency (AECOM, 2024). Similarly, Preidel and Borrmann (2018) developed a system for encoding German building codes into machine-interpretable formats using open BIM, while Temel & Başağa (2020) evaluated how IFC can support automated rule-checking in Turkey. These initiatives showcase the potential of open BIM in enabling compliance automation across jurisdictions and advancing digital practices for sustainable building design.

## 2.3 Challenges in BIM Adoption for NECB Compliance

While past research and increasing use in practice have shown great potential in improving the effectiveness and hence the value of using BIM to enable automated compliance assessment, it remains that significant challenges remain in seamlessly deploying solutions to achieve these objectives. Indeed, despite its advantages, BIM adoption in NECB compliance faces several obstacles, particularly in automating rule interpretation, ensuring data accuracy, and integrating compliance verification processes, as these processes rely heavily on accurate data and advanced modeling capabilities, underscoring the importance of high-quality BIM inputs. These obstacles are discussed below.

**Limitations of Automated Compliance Checking (ACC):** The biggest challenge in deploying ACC is converting NECB regulations into machine-readable rules and formats. Past research, such as that performed by AECOM and ArchSD's in Hong Kong, has demonstrated that ACC in an openBIM environment enhances efficiency and accuracy in building plan reviews, reducing reliance on manual verification. However, NECB's interpretive nature and complex rule structures remain a barrier to full automation (AECOM, 2024). Additionally, regulatory requirements often vary based on project conditions and jurisdictional guidelines, making it difficult for automated verification systems to consistently capture compliance complexities (Zhong et al., 2020).

**Data Accuracy and Compatibility Issues:** BIM requires accurate and up-to-date data for reliable energy modeling and automated compliance checking. Inconsistencies in datasets, be they materials, products, equipment such as HVAC efficiency ratings, insulation values, and lighting performance can lead to inaccurate compliance evaluations (Tan et al., 2010).

**Compliance Challenges Across NECB Pathways:** Within the prescriptive pathway, BIM proves effective in automating the validation of predefined regulatory standards; however, it does not facilitate optimization for holistic energy performance. In the trade-off pathway, BIM supports compliance through its dynamic energy comparison tools, although the accuracy of outcomes depends heavily on the availability of detailed and precise input data. For performance-based compliance, BIM's advanced simulation capabilities offer significant advantages, yet the intricate nature of modeling and the high computational requirements present obstacles to achieving full automation.

Although several studies have investigated the use of BIM in NECB compliance, there is still a lack of systematic evaluation of how automation can be applied across all three NECB compliance pathways. Moreover, limited research has explored rule classification and interpretability as tools for assessing the feasibility of automation through BIM. This study seeks to fill these gaps by emphasizing interpretability scoring and distinguishing between the different compliance pathways.

## 3. METHODOLOGY

This study explores how BIM, specifically open BIM, can contribute to NECB compliance assessment by evaluating its effectiveness across all three compliance pathways.: prescriptive, trade-off, and performance-based. To do so, a four-phased methodology is developed and implemented:

1. Extracting and Categorizing NECB Rules
2. Assessing Machine Readability with an Interpretability Scoring System
3. Mapping NECB Rules to IFC Standards
4. Comparative Evaluation of BIM's Effectiveness Across NECB Pathways

The overall effectiveness of BIM for a particular pathway is seen as an aggregate of systematically evaluating which NECB rules can be automated, how they relate to IFC-based BIM workflows, and where manual intervention remains necessary. These steps ensure a structured approach to determining this overall effectiveness.

### 3.1 Extracting and Categorizing Rules from NECB Clauses

The first step involved extracting and formalizing rules from the NECB clauses. Since the NECB defines three compliance pathways—prescriptive, trade-off, and performance-based—rules were initially classified according to these pathways. To further analyze their computability for ACC, the study introduced a secondary classification system inspired by Zheng et al. (2024). Each rule was categorized into one or more of the following seven classes, based on its structure and complexity. The categories are summarized in Table 2.

Table 2: Types of rule extraction and their representation within BIM (Zheng et al., 2024)

| Category | Description | Computability |
|---|---|---|
| Direct | Explicit values can be extracted and verified automatically (e.g., insulation R-values, lighting power density limits). The necessary information can therefore be explicitly made available in the BIM model. | Easy |
| Indirect | Values require calculations but can still be interpreted by software (e.g., U-factor derivations for thermal performance). The required | Easy |

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| | information can be embedded within the BIM model and needs derivations and calculations to be extracted. | |
| Method | Rules specify a procedure rather than a fixed numerical value. Computation requires an extended data structure and specialized domain knowledge. | Medium |
| Reference | Rules requiring external standards or datasets for verification. Computation involves external information such as images, formulas, tables, or appendices from building codes. | Medium |
| General | Broad recommendations that lack strict compliance criteria. The rules provide broad guidance for the design process and therefore are difficult to compute. | Hard |
| Term | Definitions or terminology-related rules. These clauses define specific terms used in the regulations. While necessary for interpretation and therefore ACC they are not directly computable. | Hard |
| Other | Rules that do not fit into the previous categories but still impact compliance. | Hard |

Following this categorization, each NECB rule was assigned one or more of these seven categories, ensuring a structured classification system that would later inform machine-readability scoring. This scoring system allowed the quantification of which NECB rules could be automated and which require manual review, offering insights into the opportunities and limitations of BIM for ACC.

### 3.2 Machine Readability Scoring System

Once the NECB clauses were categorized, a machine readability score was attributed. Indeed, to evaluate the extent to which NECB rules could be automated, an interpretability scoring system was developed. Scores, ranging from 0 to 1, were attributed based on their categorization. In this sense, each rule category listed in Table 2 was assigned a weight corresponding to its anticipated level of interpretability. Categories such as 'Direct' and 'Indirect' were given higher weights due to their clear, computable structure, while 'General', 'Term', and 'Other' categories received lower weights because of their vague or non-quantifiable content. This scoring system ultimately provided a structured foundation for identifying which NECB rules could be feasibly automated.

The scores were determined by the author, based on their expertise in interpreting NECB rules and understanding the practical application of BIM technologies. Although the classification categories were adapted from Zheng et al. (2024), the scoring relied on informed judgment to estimate the feasibility of automation. A spot check was performed by an external member of the research team to assess validity.

Clauses with values above 0.8 generally indicated that a rule was machine-readable and suitable for full automation with minimal human input. Scores between 0.6 and 0.8 reflected rules that were partially machine-readable, requiring some level of interpretation or data transformation. Rules scoring below 0.6 were deemed not machine-readable due to their complexity or ambiguity, thus necessitating manual review.

### 3.3 Mapping NECB Rules to the IFC Schema

Part of the objective of this research was also to investigate the efficiency and availability of open BIM solutions to support ACC of the NECB. To evaluate the potential for automating NECB compliance through BIM, the machine-readable rules were aligned with the Industry Foundation Classes (IFC) schema. The IFC mapping process involved:

1. Reviewing all IFC entities: Since the current version of IFC (IFC 4.3.2, ISO 16739-1:2024) includes over 1,300 entities and their types as well as around 2,500 properties organized in 750 sets. From this, a targeted subset was selected based on relevance to NECB compliance—specifically properties related to envelope performance, space definitions, and HVAC systems. This selection aimed to identify IFC elements that support automated rule verification.

2. Filtering key IFC entities: Identifying relevant IFC components linked to NECB compliance, such as IfcWall, IfcSpace, IfcHVACSystem, and IfcEnergyConversionDevice.
3. Aligning NECB Rules with IFC properties: Cross-referencing NECB-defined standards with IFC-supported parameters for automated compliance verification.
4. Identifying Gaps in IFC Representation: Highlighting NECB rules that lack direct IFC entities or properties , requiring extensions through services such as the buildingSMART Data Dictionary.

This mapping process helped determine how well the current version of the IFC-schema can support NECB rule automation, where modifications are needed, and which rules lack a direct BIM representation. To this effect, although IFC is a well-established standard for organizing BIM data, not every NECB rule directly corresponds to IFC parameters.In particular, the mapping of Property Sets to NECB rule requirements is still in progress; while preliminary analysis has been conducted, comprehensive

### 3.4 Comparative Evaluation of BIM's Effectiveness Across NECB Pathways

To evaluate the effectiveness of BIM-based NECB compliance verification, the three NECB compliance pathways were analyzed based on three Key Performance Indicators (KPIs):

1. Automation Feasibility: The proportion of rules in each compliance pathway that can be processed without manual intervention.
2. Accuracy: The degree to which BIM-based compliance checking correctly interprets NECB rules, based on interpretability scores.
3. Compliance Efficiency: The time savings achieved through BIM automation relative to conventional compliance processes.

This comparative evaluation reveals clear distinctions in automation feasibility across the three different pathways. Prescriptive rules, with their structured format and explicit numerical thresholds, are the most amenable to automation. Trade-off rules offer moderate automation potential but require an interpretive balancing of energy performance across systems, introducing added complexity. Performance-based rules present the greatest challenges, as they rely heavily on comprehensive energy modeling and dynamic simulations, which demand extensive manual input and expert judgment.

## 4. FINDINGS AND KEY OBSERVATIONS

The results from the analysis show that prescriptive rules, which define specific numerical criteria such as insulation R-values and lighting power limits, are the most suitable for automation, with interpretability scores exceeding 0.8. Trade-off rules, which allow design flexibility based on energy performance calculations, require greater interpretation and fall within the 0.6 to 0.8 range, indicating partial automation feasibility with some manual intervention. In contrast, performance-based rules rely on complex energy simulations, scenario modeling, and iterative adjustments, making them the least machine-readable. With scores below 0.6, these rules pose significant challenges for full automation. BIM could therefore prove effective in prescriptive and trade-off pathways, allowing automated rule-checking and design optimizations. However, the performance-based pathway requires advanced energy modeling tools, high computational resources, and expert oversight, limiting full automation. The IFC standard, while useful for structuring BIM data, shows gaps in representing certain NECB compliance criteria, particularly those requiring dynamic energy performance assessments.

### 4.1 Challenges in Implementing BIM for NECB Compliance

Although BIM-based compliance automation has seen significant progress, challenges related to data accuracy and interoperability continue to pose major barriers, necessitating improved regulatory frameworks and stronger industry collaboration (Peng & Liu, 2023). One of the primary challenges is rule interpretation, as NECB regulations are written in natural language, which complicates their translation into machine-readable formats. This issue is particularly evident in the performance-based pathway, where compliance relies on dynamic energy simulations rather than predefined numerical limits(Amor & Dimyadi, 2021).

Data accuracy and interoperability also pose significant barriers. Variability in material properties, HVAC efficiency ratings, and lighting performance can introduce inconsistencies in BIM-generated compliance assessments.

Additionally, IFC's current framework does not fully support NECB parameters, requiring modifications or custom workflows to bridge gaps in energy performance modeling.
Beyond technical constraints, industry adoption remains slow due to high implementation costs, a shortage of professionals proficient in BIM-based energy modeling, and resistance to transitioning from traditional compliance methods. Many firms continue to rely on manual assessments, limiting the scalability and efficiency of automated compliance verification.

To address this reluctance and promote wider BIM adoption for NECB compliance, this study outlines several targeted strategies. These involve providing specialized training to enhance workforce proficiency in BIM-driven energy modeling, introducing financial incentives to offset initial implementation costs, and establishing regulatory policies that support digital innovation. Additionally, creating standardized BIM templates and sharing successful case studies can help build stakeholder trust and expedite adoption across the industry.

### 4.2 Future Research and Recommendations

To advance BIM's role in NECB compliance, further research and development are needed in the following areas. First, enhancing automation and improving machine readability are essential for streamlining NECB compliance verification is foundational for the next steps. AI-powered Natural Language Processing (NLP) tools could translate NECB regulations into machine-readable formats, reducing reliance on manual rule-checking and improving automated compliance verification (Zhang, Ma, & Broyd, 2022). Additionally, the increasing adoption of BIM in the AEC sector is driving technological advancements that enable automated code compliance checking, utilizing IFC to streamline verification processes and improve regulatory compliance (Temel & Başağa, 2020).

Moreover, pre-configured BIM templates embedded with NECB rule sets can further simplify compliance verification by integrating regulatory requirements directly into the modeling process. Standardizing IFC frameworks is another key factor in improving BIM-based compliance automation. Expanding IFC schemas to incorporate NECB parameters can address existing gaps, ensuring a more accurate representation of building components and energy performance requirements. Moreover, strengthening BIM and Building Energy Modeling (BEM) interoperability can facilitate more precise performance-based compliance verification, reducing inconsistencies in energy assessments.

Beyond technical enhancements, broader industry adoption requires strategic initiatives. Conducting cost-benefit assessments, offering specialized training programs, and implementing regulatory incentives can encourage firms to transition from manual compliance methods to digital solutions.

## 5. CONCLUSION

This research explored the capacity of BIM with a focus on open BIM to facilitate automated compliance with the NECB. Using a four-phase methodology that included extracting and classifying rules, scoring their interpretability, mapping to the IFC schema, and evaluating performance across different compliance pathways, the study assessed the practicality and effectiveness of automation through BIM.

Findings reveal that prescriptive NECB rules are best suited for automation due to their clear structure and defined thresholds. Trade-off rules offer moderate potential, especially when paired with BIM-enabled energy simulations. However, performance-based rules remain the most challenging to automate, as they rely heavily on dynamic simulations and expert interpretation. Additionally, the current IFC schema lacks full coverage of NECB requirements, particularly for performance-related parameters.

Overall, the study underscores both the opportunities and current constraints of using BIM for NECB compliance. While BIM can significantly streamline verification under prescriptive and trade-off approaches, achieving full automation—especially in performance-based assessments—will require further advancements in technology, greater data consistency, and broader industry adoption. Persistent issues include data interoperability, ambiguity in rule interpretation, and limitations in software tools.

Future work should prioritize real-world case studies to validate these findings, improve the machine readability of NECB rules—potentially with AI and NLP—and enhance IFC schema support for complex energy metrics. Bridging these gaps will be crucial for positioning BIM as a scalable, automated solution to support Canada's energy efficiency targets.

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