Developing rule-based model checking for verifying energy properties of windows: Promoting sustainable construction practices

Janees Riyaz[1] and Emara Merna[2]
[1,2]Institut für Bauinformatik, Technical University of Dresden, Nürnberger Str. 31a, 01062 Dresden, Germany
E-mail(s): janees_riyaz.janees_riyaz@mailbox.tu-dresden.de, merna.emara@tu-dresden.de

Abstract: Within the Architecture, Engineering and Construction (AEC) sector, collaboration among diverse stakeholders is essential for successful construction projects. The industry is witnessing a digital transformation, characterised by the emerging advancements in technology, ensuring co-operation across the project lifecycle. This study aims to reinforce models against deviations from construction standards, focusing on energy efficiency. To achieve this, model checking methodologies are considered, involving a comprehensive examination of prevailing industry standards and regulations for buildings which ultimately results in the formulation of custom rulesets for Solibri Model Checker. The research is verified through a case study which involves enhancement of the BIM model and checking against various rulesets for verifying energy properties of windows in Solibri. Through precise verification process, the efficacy of the developed model-checking framework is assessed.This undertaking streamlines project execution, mitigates risks, and enhances compliance with energy efficiency imperatives. This contributes to refining model technologies in the AEC domain and catalyses advancements towards more sustainable and efficient construction practices.
Keywords: Building Information Modelling (BIM), custom rulesets, energy efficiency, model checking, sustainable design.

Erschienen in Tagungsband 35. Forum Bauinformatik 2024, Hamburg, Deutschland, DOI: 10.15480/882.13552

1 Introduction

In the ever-evolving field of Architecture, Engineering and Construction (AEC), the use of sustainable practices play a crucial role in enhancing environmental responsibility and operational efficiency. Building Information Modelling (BIM) represents a methodical approach that covers the generation, storage, management, sharing, and distribution of building information in a manner ensuring compatibility and reusability. This approach requires the utilization of computer-generated models to effectively imitate the various stages of a project, including planning, design, construction, and operation [1]. The adoption of Building Information Modelling (BIM) has transformed the management of projects, offering all stakeholders an intricate digital representation of physical structures. It brings various benefits such as improved accuracy, saving of time, better design and analysis approaches, and the ability to foresee environmental and lifecycle outcomes [2]. However, with the sector's shift towards digital twins - virtual models of real-world assets, the growing necessity to put a stronger emphasis on energy efficiency within these replicas has become increasingly important. Energy efficiency is a crucial element in today's construction sector having a big influence on sustainability, cost-effectiveness and compliance with regulations. Buildings account for a significant share of global energy use and greenhouse gas emissions, making energy optimization crucial.This shift has made sure that comprehensive model checking procedures must be included in the Building Information Models to ensure compliance with energy efficiency regulations.The coming together of different stakeholders in the process and the complexity of the projects necessitates the need of a cohesive strategy.

This research encompasses a comprehensive approach towards enhancing energy efficiency in AEC projects through the development and deployment of model-checking methodologies.Windows significantly impact energy efficiency, as their inefficiency can lead to substantial heat loss and gain. Therefore, a targeted approach to assess and optimize their energy properties is crucial for enhancing building sustainability. Through examination of relevant standards for energy efficiency and developing rulesets for model checking to optimise energy usage for windows, it seeks to catalyse a paradigm shift towards greener and more resilient built environments by reducing energy costs and consequent reduction in the carbon footprint. The primary focus is on the "Förderschule Delitzsch" building as a case study where the effectiveness of the developed procedures is verified.

2 Methodology

This research presents an approach to enhance energy efficiency in AEC projects, with a specific focus on window optimization within Building Information Modelling (BIM) framework. The methodology encompasses several phases: Analysing standards, ruleset creation, BIM model enhancement and model checking as shown in Figure 1. The initial phase involves gathering data on energy efficiency standards and regulations pertinent to window performance. This includes reviewing existing literatures, codes, and guidelines. To ensure compliance with these standards, a comprehensive set of rules is formulated in the ruleset creation phase. These rules are based on the standards identified during the first phase and are designed to assess the energy performance of windows within the BIM model. Using the collected data, the BIM model is enhanced. The last phase involves model checking which involves running the model through the rulesets to identify any deviations from the established energy efficiency criteria. The model checking process highlights areas where windows do not meet the desired performance standards, providing specific feedback for optimization. Based on the results, iterative modifications can be made to the window properties to enhance energy efficiency. By adopting model checking techniques and rule sets derived from energy standards, the methodology provides a framework for identifying and rectifying inefficiencies in window design.

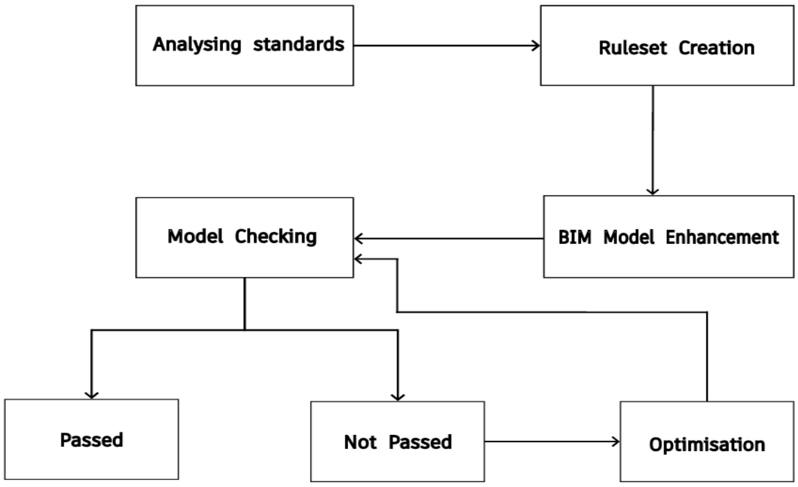


Figure 1: Methodology Overview

3 Implementation

3.1 Analysing Standards

The standard followed for verifying energy properties in windows is *Gesetz zur Einsparung von Energie und zur Nutzung erneuerbarer Energien zur Wärme- und Kälteerzeugung in Gebäuden* (Act on Energy Conservation and the Use of Renewable Energies for Heating and Cooling in Buildings) [3]. In addition to this, MVV TB - *Muster-Verwaltungsvorschrift Technische Baubestimmungen* 2023/1-part A6 (Publication of the Model Administrative Regulation Technical building regulations) [4] has been used which references various DIN codes including DIN 4108-2/2013-02 [5] and DIN 4108-7 [6] that have been used.

3.2 Ruleset Creation

The creation of rulesets for verification of energy properties for windows is carried out in the Ruleset Manager in Solibri. In the Libraries section, Solibri Common Rules contains multiple rule templates which can be customised as per the requirements of a specific task. For the scope of this research, Rule 203- 'Required Property Sets' was used to create all the rulesets required for verification of the case study building. According to Solibri Model Checker, this ruleset is used to verify whether a model contains required property sets and properties and that these properties contain a value or doesn't contain a value and then whether this value is acceptable or not. It consists of two component filters: Firstly, 'Checked Components'- where the rule checks whether the model contains a specific property or a value, secondly 'Property Sets'- where it checks whether the component that fulfils the first condition is fulfilling another property sets filter condition. If the properties are not fulfilling as per the criteria set in the rule, Solibri reports it as an issue [7]. The layout of the Rule 203 in the Ruleset Manager can be seen in figure 2.

The rules were created for checking the windows against all the parameters relevant for energy usage. The different codes and regulations were used to set up standard values for these properties. Gebäudeenergiegesetz provides the recommendation for the heat transfer coefficient (U value) to be

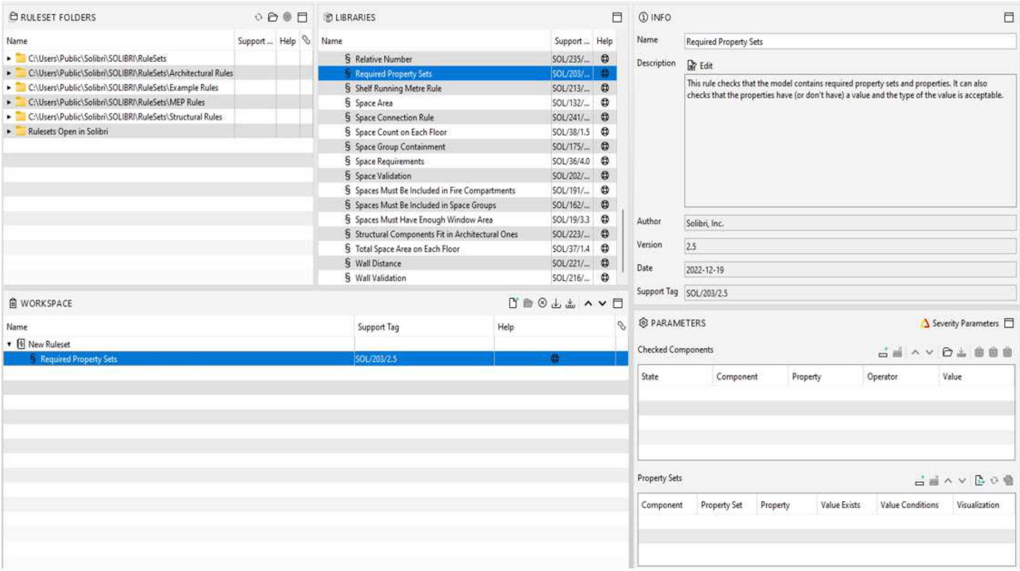


Figure 2: Solibri Common rule SOL/203/2.5

$1.3\,\mathrm{W/(m^2 \cdot K)}$. [3] The Heat transfer coefficient for window frames (U_f) should be less than or equal to $2.9\,\mathrm{W/(m^2 \cdot K)}$ and the Thermal resistance (R) should be greater than or equal to $1.2\,\mathrm{m^2\,K/W}$ as per DIN 4108-2/2013-02 [5]. Figure 3 shows the ruleset for the heat transfer coefficient. The rulesets for the Heat transfer coefficient for window frames U_f and Thermal resistance R were created in a similar fashion with their respective values in the Parameters Tab.

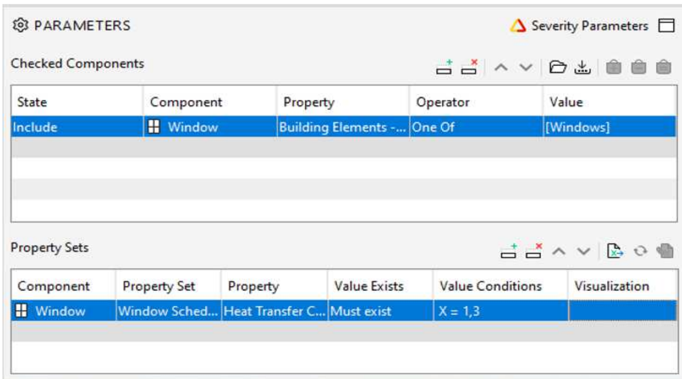


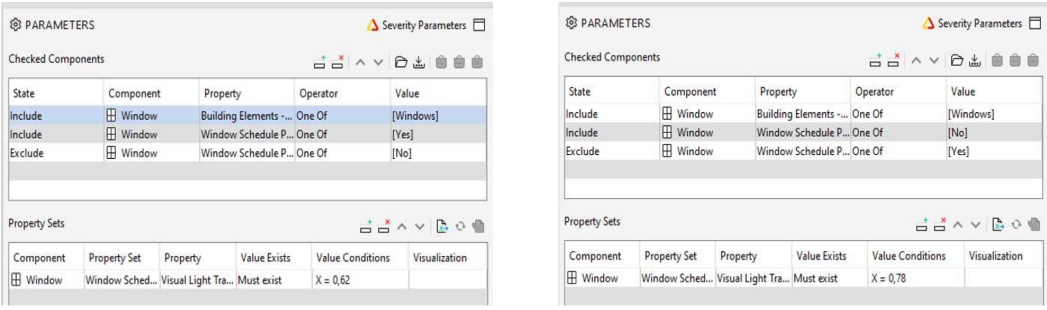
Figure 3: Ruleset for Heat Transfer Coefficient (Solibri 9.13.7)

For the creation of other rulesets viz, Visual Light Transmittance, Energy Transmittance and Daylight Supply Factor, shading was taken into consideration. Gebäudeenergiegesetz provides values for these properties depending upon whether there is sun protection or not as outlined in Table 1 [3].

Table 1: Values for properties

Property	With sun protection	Without sun protection
Visual Light Transmittance	0.62	0.78
Energy Transmittance	0.35	0.60
Daylight Supply Factor	0.15	0.70

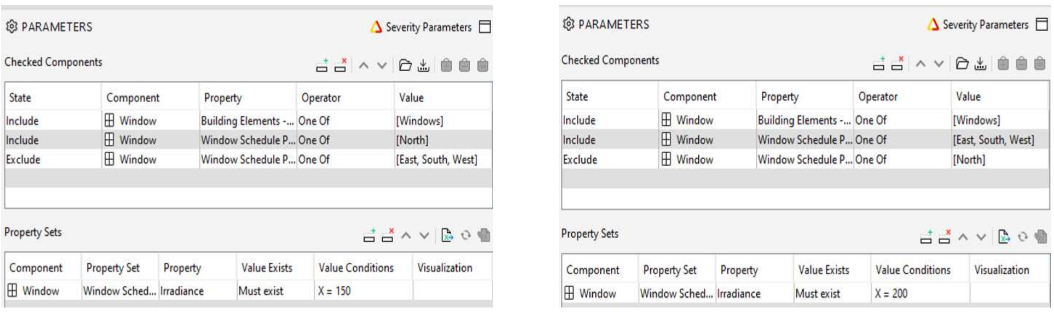
Figure 4 shows the creation of ruleset for checking Visual light transmittance. The rule for other two properties were created in a similar way as per discussed values in Table 1.



(a) With solar glazing (b) Without solar glazing

Figure 4: Ruleset for Visual Light Transmittance (Solibri 9.13.7)

The ruleset created for checking the Irradiance depends upon the direction windows are facing. Accordingly, DIN 4108-2/2013-02 provides irradiance guidelines for residential and non-residential buildings and the latter have been taken into consideration. The guideline states that the value should be $150W/\mathrm{m}^2$ for windows facing North, North-East, North-west directions and $200W/\mathrm{m}^2$ for windows facing South, East and West direction [5]. Figure 5 illustrates the incorporation of the 'Orientation' parameter within Revit and the specific rules created for windows based on their orientation for windows facing North, South, East and West.



(a) For windows facing North (b) For windows facing South, East and West

Figure 5: Ruleset for Irradiance Check (Solibri 9.13.7)

3.3 Case Study

The case study is a school building namely 'Förderschule Delitzsch' . It is built on Delitzscher Richard-Wagner-Straße. This is a new building which will accommodate two school buildings: Pestalozzi School and the Fröbel School and the capacity is for 300 students. The building is based on a modern energy concept. It is built by district of North Saxony, with an investment of 24.2 million euros [8]. The BIM model of this building shown in figure 6 is developed in Revit. The windows in this model serve as a use case for verifying energy properties. Monitoring and optimizing these properties can enhance sustainability by reducing energy costs and consequently lowering the carbon footprint.

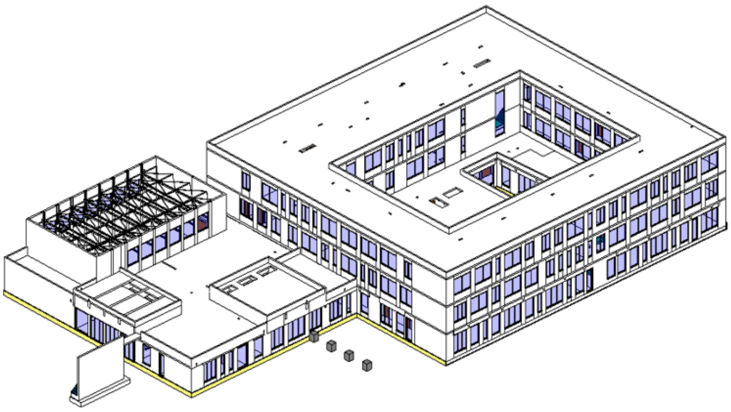


Figure 6: Case study building(Revit)

3.4 Enhancing the BIM Model

The Revit model for the case study building is enhanced to an appropriate level of detail, incorporating both the Level of Geometry (LOG) and the Level of Information (LOI). Once the enhancement is carried out, it is exported as an IFC file.

For having a suitable level of geometry, the modelling of windows and doors is carried out in Revit by utilizing the in-built Autodesk families. Additionally, a thorough examination of parameters associated with windows was carried out in Revit to address the information level. The type of glass selected for windows is ‘Double glazing - 1/4 in thick - clear/low-E (e = 0.05) glass’. This type was chosen due to its reputation as the best choice for school buildings in terms of sustainability taking carbon emissions and social impact into consideration. Even though a triple glazing window offers better noise reduction but that is not economical and results in higher emissions. [9]

There are two types of parameters for windows in Revit viz, default and custom. The default parameters associated with families are Visual light transmittance, Heat transfer coefficient (U) and Thermal resistance (R). The custom parameters created are Irradiance, Daylight Supply Factor, Energy Transmittance (Glazing), Shading and U-value window frame. These parameters have been created in accordance with relevant codes and regulations for windows, recognizing their crucial role in meeting standards. The values for these parameters were assigned based on previous research or practical insights in Germany with similar criteria. All the parameters were compiled in a schedule ‘Window Schedule Pset’ in Revit. The name for the schedule has "Pset" at the end rather than as a prefix, in accordance with IFC guidelines stating that the name for a user-defined property set should not include "Pset" as a prefix [10].

To enable seamless information exchange from Revit to Solibri, the model was exported as two IFC files: one for ’Structural’ and one for ’Architectural’ elements. A custom export setup was carefully configured to tailor the properties of the IFC files to specific project needs. During the export process, the project schedule was integrated as a property set, utilizing the ’Modify Setup’ tab in Revit. This ensured that the schedule data was embedded within the ’Property Sets’ of the IFC files, facilitating a more comprehensive data transfer to Solibri.

3.5 Model Checking Results

All the created rules were combined into a collective ruleset named ’Energy Properties of Windows Check,’ which was then used to perform the checks, yielding the results shown in Figure 7.

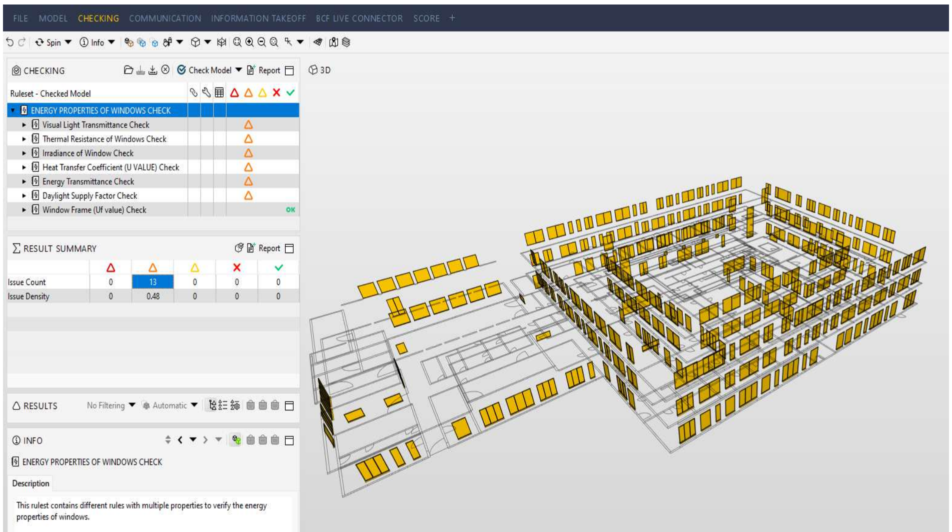


Figure 7: Ruleset checking results in Solibri

Only one ruleset namely U value for window frame passed the check as the values for all other properties were outside the acceptable range according to regulations. Hence the optimisation of window material needs to be performed for all the parameters to pass the checks and be energy efficient. The results were communicated using presentation in Solibri where all the issues are summed up and later communicated through the BIM Collaboration Format(BCF) Live Connector to the issue management platform ‘BIMcollab’.

4 Conclusion

This research has developed a method that can be used to check a building model against deflections from industry standards keeping energy efficiency on high priority. An extensive examination of prevailing industry standards and regulations was conducted using multiple databases including DIN codes and energy standards in Germany. Using this information, the requirements related to energy efficiency for windows are laid down in terms of rulesets through model checking. The efficacy of the developed model-checking framework was rigorously assessed through a case study centered on the BIM Model of the "Förderschule Delitzsch" building. The verification through accessing the energy properties of windows result in the development of a framework utilising BIM to support efficient and effective workflow. It paves a way to have better transparency in material choices for windows and better insulation properties leading to a comfortable and greener environment through less energy consumption. In future, these created rulesets can be extended to buildings with diverse utilities and various components including doors, walls, and floors, sourced from existing codes to enhance energy efficiency. Incorporating standards such as 'PassiveHaus Institut' can further strengthen the framework, ensuring even more rigorous energy efficiency checks. By embracing these strategies and harnessing the abundance of real-time data available, one can revolutionize the effectiveness and precision of energy efficiency checks in buildings, paving the way for a more sustainable environment.

Acknowledgements

The publication is part of the research project entitled “iECO – Intelligence Empowerment of Construction Industry” which has received funding from Bundesministerium für Wirtschaft und Klimaschutz (BMWK) based on a resolution of the German Bundestag. The authors gratefully acknowledge the support and funding from the BMWK. The content of this publication reflects the author view only and the BMWK is not responsible for any use that may be made of the information it contains.

References

[1] Loan Petri, Ali Hussain S Alhamami, Yacine Rezgui, and Sylvain Kubicki, “Bim for energy efficiency requirements capture”, Mar. 2018.

[2] S. Beazley, E. Heffernan, and T. J. McCarthy, “Enhancing energy efficiency in residential buildings through the use of bim: The case for embedding parameters during design”, *Energy Procedia*, vol. 121, pp. 57–64, 2017. DOI: 10.1016/j.egypro.2017.07.479.

[3] “Geg: Gebäudeenergiegesetz vom 8. august 2020 (bgbl. i s. 1728), das zuletzt durch artikel 1 des gesetzes vom 16. oktober 2023”, Aug. 2020.

[4] “Mvv tb 2023/1, ausgabe 2: Veröffentlichung der muster-verwaltungsvorschrift technische baubestimmungen 2023/1”, Apr. 2023. [Online]. Available: https://www.dibt.de/de/aktuelles/meldungen/nachricht-detail/meldung/mvv-tb-20231-veroeffentlicht.

[5] Baunormenlexikon, *Din 4108-2 | 2013-02: Thermal insulation and energy saving in buildings - part 2: Minimum requirements for thermal insulation*. [Online]. Available: https://www.baunormenlexikon.de/norm/din-4108-2/a06abee6-e691-4f50-959d-f42cce00bc7c.

[6] DIN 4108-7, *Thermal insulation and energy economy in buildings: Part 7: Air tightness of buildings*, Jan. 2011. [Online]. Available: https://nautos.de/O9G/search/item-detail/DE30042761.

[7] Solibri, *230 property rule template with component filters*. [Online]. Available: https://help.solibri.com/hc/en-us/articles/1500004738562-230-Property-Rule-Template-with-Component-Filters.

[8] *Stadt delitzsch*, Jan. 2022. [Online]. Available: https://www.delitzsch.de/portal/meldungen/landkreis-investiert-24-2-millionen-euro-in-neuen-foerderschulcampus-900001552-27640.html.

[9] A. T. Balasbaneh, D. Yeoh, and A. R. Zainal Abidin, “Life cycle sustainability assessment of window renovations in schools against noise pollution in tropical climates”, *Journal of Building Engineering*, vol. 32, p. 101 784, 2020. DOI: 10.1016/j.jobe.2020.101784.

[10] IFC4_ADD2_TC1 - 4.0.2.1, *Version 4.0 - addendum 2 - technical corrigendum 1*. [Online]. Available: https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/.