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İmar Mevzuatına Uygunluk Denetimi için Yapı Bilgi Modellemesi Tabanlı Otomatik Kural Kontrolü Uygulaması: Türkiye Örneği

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Öz

Türkiye'de inşaat projelerinin tasarım ve onay aşamalarında, yapı bilgi modellemesi (YBM) ile oluşturulan proje verilerinin imar mevzuatına uygunluğunu hızlı, şeffaf ve verimli biçimde denetlemeye olanak tanıyan bir otomatik kural kontrolü uygulaması geliştirilmesi bu çalışmanın temel amacını oluşturmaktadır. Bu kapsamda, mevzuat metinlerinde yer alan kurallar önermeler mantığı esas alınarak yazılım diline uyarlanabilir bir yapıya dönüştürülmüş, karar yapıları oluşturulmuş ve YBM ortamına aktarılacak ayırt edici parametreler tanımlanmıştır. Model verileri, paylaşıma açık olan Endüstri Temel Sınıfları (Industry Foundation Classes, IFC) formatında dışa aktarılmış ve Python diliyle geliştirilen yazılım aracılığıyla dört farklı örnek proje üzerinde test edilerek otomatik denetim raporları elde edilmiştir. Elde edilen bulgular, mevzuat kurallarının mantıksal yapılara dönüştürülerek Endüstri Temel Sınıfları veri yapılarıyla karşılaştırılabileceğini ve böylece yapı projelerinin mevzuata uygunluğunun dijital ortamda denetlenebileceğini göstermektedir. Bu yaklaşım, kamu otoritelerinin tasarım ve onay süreçlerinde daha etkin ve şeffaf bir kontrol mekanizması geliştirmelerine katkı sağlayabilir. Çalışmanın özgün yönü, klasik mantık sisteminde yer alan ve karmaşık mantıksal operatörler içermeyen önermeler mantığının, yönetmeliklerdeki girift kurallara uygulanabilmiş olmasıdır. Ayrıca elde edilen doğru önermeler kümesi, yalnızca kural ihlalini göstermekle kalmayıp, ilgili kuralın kapsamlı bir analizini mümkün kılan tamamlayıcı bilgilerle birlikte sunulmaktadır.

Anahtar kelimeler: Otomatik kural kontrolü, Yapı bilgi modellemesi, Mantık tabanlı kural yorumlama, Model tabanlı kural denetimi, İmar mevzuatına uygunluk

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A Building Information Modeling Based Automated Rule-Checking Application for Zoning Regulation Compliance: The Case of Turkiye

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Abstract

The aim of this study is to develop an automated rule-checking application that enables the rapid, transparent, and efficient verification of building design data, created through Building Information Modeling (BIM), in compliance with zoning regulations during the design and approval phases of construction projects in Turkiye. In this context, rules expressed in regulatory texts were transformed into a format adaptable to software using propositional logic, and decision structures were created. Distinctive parameters based on the rules to be checked were assigned to the BIM environment. Model data were exported in the shareable Industry Foundation Classes (IFC) format, and a Python-based software was developed to test the automated rule-checking method on four different sample projects, generating result reports. The findings show that regulatory provisions can be converted into logical structures and compared with Industry Foundation Classes data, making it possible to digitally assess a project's compliance with regulations. This approach could contribute to enabling public authorities to implement a more effective and transparent control mechanism in the design and approval processes. The originality of the study lies in the successful application of classical propositional logic—despite its lack of complex logical operators—to complex regulatory rules. Moreover, the set of validated propositions not only defines the outcome of the rule check but also provides comprehensive contextual information related to the rule, allowing for a more in-depth evaluation of the results.

Keywords: Automated rule checking, Building information modeling, Logic-based rule interpretation, Model-based code checking, Zoning regulation compliance

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1. Introduction

Digitalization has led to profound transformations in the production and service sectors since the Industrial Revolution. However, the construction sector has adapted to this transformation process more slowly compared to other industries. Studies show that the construction industry is still one of the sectors with the lowest level of digitalization [1]. This situation prevents the industry from fully achieving its potential productivity gains and sustainability goals.

Traditional construction projects are inherently complex systems due to their multi-stakeholder structures, variable conditions, and high coordination requirements. This complexity poses significant challenges to the integration of digital technologies and constitutes a major barrier to digital transformation [2]. Additionally, the prevailing traditional approach to construction and habits in the sector create a cultural barrier to technological adaptation when combined with resistance to innovation. Furthermore, firms in the sector often operate under intense competitive pressure, leading them to focus on short-term cost advantages. This results in delays in investments in digital infrastructure that offer long-term benefits. As a result, the integration of industrial innovations into the construction sector remains limited. Despite all these challenges, the construction sector needs new technologies supported by digital transformation for more efficient, safer, and sustainable projects to replace traditional methods.

One of the most prominent technologies in this transformation is Building Information Modeling (BIM). BIM offers an information-driven approach in the design, planning, construction, and maintenance phases, increasing integration among all stakeholders and ensuring transparency in project management [3]. BIM is considered one of the core elements of digital transformation in the construction industry. Researchers and BIM software developers define BIM not only as a design tool but also as a holistic information management process that encompasses information generation, management, and usage across all stages of the project lifecycle [4]. In this context, the impact of BIM is not limited to its technical dimension; it is also directly related to business processes, communication between stakeholders, and legal regulations.

Since the early 2000s, many countries, including the United States, European countries, Australia, and East Asia, have begun to promote the use of BIM at a strategic level [5]. Key factors accelerating the adoption of BIM in these countries include increasing project efficiency, reducing costs, lowering error rates, and enhancing stakeholder interaction [6]. Public institutions have taken various strategic steps to promote the widespread use of this technology. For example, in the United States, the General Services Administration (GSA) has encouraged the use of BIM in public projects, while the United Kingdom made BIM usage mandatory for all central government projects by 2016, paving the way for transformation in the sector. Similarly, countries like Singapore, Norway, and Finland have institutionalized BIM integration by creating guidelines, application manuals, and mandatory standards [5].

Although the implementation of Building Information Modeling (BIM) in Turkiye remains limited, it has started to be adopted in large-scale projects carried out through public–private partnerships, such as city hospitals, airports, and certain infrastructure developments [7]. However, these examples are exceptional, and BIM has yet to be widely adopted across the construction sector. The main barriers to the widespread use of BIM in Turkiye include the complexity of the industry, high investment costs, lack of knowledge and technical skills, as well as the absence of a well-established legal and institutional framework [8-10]. In particular, the lack of explicit provisions for BIM integration in current zoning and building inspection regulations, the absence of defined standards, and the lack of a legal basis for the structured digital exchange of project data have significantly hindered progress. Consequently, the full potential of BIM-enabled information management, automated rule checking, and data exchange has not yet been realized.

The primary objective of this research is to examine an application for integrating BIM practices with the existing legal framework in Turkiye. Specifically, it aims to test a system that enables the comparative analysis of data extracted from BIM models against legal regulations in areas such as building inspection, zoning compliance, and energy performance codes. The study employs classical logic-based propositional reasoning to enable the computational processing of construction regulations. Complex rules from regulatory texts are translated into simplified and inferable propositions, which are then structured into decision frameworks and decision tables within the software. Although a software application has been developed within the scope of this research, the primary objective of the study is not the software itself, but rather the examination of how BIM data can be integrated with existing legal regulations. In this context, the scope of the research is primarily limited to building inspection processes and compliance checks with zoning regulations.

2. Literature Review

In the construction industry, knowledge sharing and management are critically important in projects where various disciplines (architecture, civil engineering, electrical, mechanical, etc.) collaborate during the project management, planning, and design phases. In this context, common data environments (CDE) and model-based working methods, which are considered key components of digital transformation, have gained significant momentum in recent years [12].

In recent years, although there has been a noticeable increase in the digitalization of the construction industry, it remains one of the least digitized sectors [1, 13]. Compared to other industries, the construction sector has been slow to adopt and integrate digital technologies. Despite the potential benefits, the industry continues to face challenges in fully embracing digital transformation and incorporating digital tools into its operational processes. One of the major barriers in this regard is the inherent complexity of construction projects [2, 14]. Another significant factor is the sector's strong adherence to traditional construction practices, which contributes to resistance to change. Moreover, the lack of digital skills and knowledge among industry professionals further exacerbates the difficulties faced during the digitalization process [15].

Despite these challenges, there is a growing need in the construction sector to replace traditional methods with new technologies supported by digital transformation to ensure more efficient, safer, and more sustainable project delivery. These technologies have led stakeholders—particularly contractors, engineers, and designers—to increasingly adopt various digital tools to optimize construction processes and reduce costs. Among these tools, Building Information Modeling (BIM) stands out as the most widely adopted foundational technology [2].

Digitalization is regarded not only as a technological innovation but also as a strategic necessity for sustainability, efficiency, and competitive advantage. Rapid urbanization, climate change, and increasing global competitive pressures are among the main factors that make it inevitable for construction companies to use digital tools [13, 14]. Nonetheless, in the past decade, national Building Information Modeling (BIM) mandates and digital transformation policies introduced in many countries have facilitated the adoption of software-supported design approaches in the sector. The digitalization process not only simplifies information management but also contributes to preventing project errors by enabling real-time data sharing among stakeholders. For example, early detection of a design error in the design phase can prevent costly revisions on the construction site.

In this context, the analysis of the necessity of digital transformation and the current state of the industry stands out as a strategic factor that will directly affect the future competitiveness of the construction sector. Globally, efforts to digitalize the construction industry are accelerating through university-industry collaborations and public support, further supporting the structural transformation of the sector.

2.1. Application areas and concepts of building information modeling (BIM)

Building Information Modeling (BIM) is at the center of the digital transformation of the construction industry and is regarded as a catalyst by governments and public suppliers to achieve productivity, cost, and quality policy goals in the sector [3]. Although BIM is defined in various ways, it is widely accepted as a form of collaboration that makes information about buildings and facilities digitally accessible and analyzable [16-18]. This approach surpasses the traditional two-dimensional design understanding by integrating multiple disciplines and not only going beyond three-dimensional models but also systematizing data sharing in the design, construction, and operation processes.

The scope of BIM has expanded over time, and this expansion has led to the emergence of the concept of BIM dimensions. Today, the term “nBIM” indicates that there is no limit to these dimensions, with 3D, 4D, 5D, 6D, and 7D being the most commonly used BIM dimensions [19].

3D BIM offers an enhanced visualization capability, but it is not limited to the three-dimensional digital representation of the structure. This application can include information for analysis tailored to the goals of stakeholders such as designers, contractors, employers, and project managers, and through dynamic use, it enables early detection of potential problems.

4D BIM integrates the construction schedule by adding the time dimension to the 3D model. This integration visualizes the flow of the work schedule, enabling more effective planning and time management.

5D BIM integrates cost data into the project, allowing cost estimation in the design process and evaluating the cost impacts of design decisions. During the construction process, it helps in conducting cost analysis.
6D BIM is focused on sustainability and contributes to improving the energy efficiency of buildings through energy calculations. Interventions such as optimizing the layout plans can reduce energy loss and waste.

7D BIM enables information management throughout the lifecycle of buildings. By integrating information such as technical specifications, maintenance schedules, inspection records, and warranty details, it creates an efficient operational process for project managers and owners.

The BIM dimensions are not limited to these. 8D addresses occupational health and safety issues, helping to reduce risks in projects, while 9D incorporates lean manufacturing principles and aims to improve the efficiency of production processes [20].

BIM is also an essential tool that supports management approaches such as Integrated Project Delivery (IPD). IPD is a management system aimed at increasing productivity and improving project delivery speed in construction projects. Emerging in the United States in the 1990s, this system requires widespread and comprehensive communication between teams, taking into account the complexity of projects, and the effective use of digital tools such as BIM in project decision-making processes [21, 22].

The Common Data Environment (CDE) is a critical component in the success of BIM applications. CDE allows all project-related data to be collected, managed, and shared on a centralized platform. This digital system enables project stakeholders (architects, engineers, contractors, consultants, etc.) to access the most up-to-date data they have created, making information exchange between the project team transparent, consistent, and effective [23].

The BIM implementation plan provides a strategic roadmap for how a project will use BIM technologies. This plan defines details such as which data will be collected in which processes and how this data will be managed and shared. As a result, it ensures that project processes are managed more transparently and efficiently. Furthermore, the implementation plan creates an effective collaboration environment among project stakeholders by minimizing potential inconsistencies and uncertainties [24]. Preparing the BIM implementation plan correctly is a crucial step that facilitates the achievement of project objectives.

The ISO 19650 standard defines the principles and requirements for information management and provides fundamental guidelines for implementing BIM applications. This standard provides detailed guidelines on issues such as information sharing, digital data management, production methods, and delivery processes. Additionally, it clarifies the roles and responsibilities of project stakeholders along with BIM Execution Plan (BEP) templates [25].

Eastman et al. (2011) emphasize that BIM reduces error rates in projects, lowers costs, and increases efficiency by preventing material waste [26]. Bryde et al. (2013) highlight the importance of BIM as a strong communication tool among project stakeholders [2]. Similarly, Becerik-Gerber and Rice (2010) state that BIM has systematized information management in the construction industry, optimized project processes, and allowed all stakeholders to meet on a common platform [4].

In conclusion, the use of BIM technology enables construction projects to be executed more effectively, efficiently, and sustainably. BIM allows significant gains in project processes and will continue to be an essential tool for the digitalization of the construction industry in the future.

2.2. IFC standard

Industry Foundation Classes (IFC) is an open and international data standard that enables data exchange and interoperability between building information models (BIM). IFC provides an object-based data model that allows for the detailed definition of building elements, systems, and processes. Through this standard, data transfer and model integration between different BIM software can be performed seamlessly [27, 28]. IFC was approved by ISO in 2012 and standardized in 2013, becoming an open and international standard that can be used across hardware devices, software platforms, and interfaces for various use cases [29].

The IFC data model offers the possibility of sharing data used at every stage of the project process by encompassing the geometric and functional properties of building elements, their connections, material information, and other technical details [27]. The IFC model consists of four main layers. These layers ensure that information is organized hierarchically and shared in an orderly manner [30].

- Main Layer: The main layer contains asset definitions, including customizations for specific disciplines, products, processes, or resources.
- Interoperability Layer: This layer facilitates the sharing of structure, construction, and management information between the project team. It is particularly useful when different disciplines need to collaborate and make decisions together.
- Core Layer: The core layer contains the most general asset definitions for building components. Here, the properties of building elements, additional comments, and other detailed information can be found.
- Resource Layer: The resource layer includes all individual schemas containing resource definitions. These definitions generally do not include unique identifiers and should not be used without a definition provided at a higher layer. This layer stores the basic properties and simple information of building components, such as geometry, material, quantity, measurements, timing, and cost.
-

There are various challenges that arise during the model and data transfer, especially when using different software. To effectively address these challenges, a collaborative approach is adopted, and IFC is often preferred as a solution. IFC facilitates model conversion between different software, offering solutions to such issues.

2.3. Automatic rule checking

Various automatic rule-checking methods have been developed to automatically verify legal requirements during the design and approval processes of construction projects. However, in some applications, written rules are directly interpreted and converted into computer code by the programmer without using a systematic method. This requires both expertise in interpreting regulations and proficiency in software development. Furthermore, the first studies on automatic rule processing date back to the 1960s. One of the pioneering studies in this field is the decision table approach developed by Fenves in 1966. However, due to its inadequacy in defining the relationships between rules and the overall organization, a four-layer theoretical structure was proposed in 1973 by AISC (American Institute of Steel Construction). This structure defines elements such as terms forming the rule, provisions, relationships between provisions, and rule organization in hierarchical layers [31].

Another important approach in this field is the rule-based method. In this method, rules are represented as condition-action pairs expressed in the "If-Then" format. In other words, the action to be performed when a specific condition is met is clearly defined [32]. Although this structure allows rules to be modeled systematically, it can be limited in expressing more complex situations.

The logic-based approach is similar to the rule-based method in that it uses the "If-Then" structure; however, it employs a more formal language expressed with logical predicates and propositions. This method allows for the complete and consistent definition of rules. Additionally, it enables inferences to be made in cases of missing information. However, the use of this method requires knowledge of logic, and it would involve user-defined predicates and logic operators [33].

In the object-based approach, rules are directly linked to the objects in the building model and organized through class-subclass relationships. For example, in a building model, objects such as "floor," "room," and "column" are defined by their properties (height, material type, etc.), and rule checks are performed based on these objects [34]. However, it may not always be easy to directly incorporate regulatory rules into an object-based model. In this regard, Yabuki and Law (1993) argue that engineering standards should be supported by logic rules alongside object models [35].

Recently, Natural Language Processing (NLP) techniques have emerged as an important tool for digitizing and interpreting regulatory texts. Regulatory texts are often long, complex, and written in natural language, making it difficult for machines to directly understand these documents [36]. Chalkidis et al. (2019) demonstrated with their system for the automatic analysis of legal documents that judicial decisions can be interpreted using machine learning and NLP methods [37]. Fuchs and Amor (2021) discuss the analysis of building regulations with NLP algorithms and their transformation into logic-based structures [38]. However, these studies highlight that complex sentence structures, exceptions, and ambiguous definitions limit the performance of NLP systems. Construction regulations are characterized by a formal, technical, and often complex linguistic structure. Since most regulatory texts are not explicitly written in a rule-based format, extracting logical rules from these documents is a highly intricate process. Representing rules using Natural Language Processing (NLP) techniques such as generating "if-then" structures requires advanced semantic analysis and contextual tracking. Moreover, NLP tools available for the Turkish language are not as developed as those for English. For these reasons, NLP was not utilized in the software developed within the scope of this study.

The primary motivation behind these historical developments has been to reduce human error that may occur during manual checking processes and to accelerate project approval procedures. At the same time, how to effectively integrate factors such as the continuous updating of regulations and regional variations into digital environments has emerged as a significant area of research. In particular, differences in language and terminology across countries are frequently cited as one of the main barriers to the widespread adoption of automated code compliance checking.

3. Method

The framework proposed by Eastman et al. (2009) for systematically implementing rule-based control applications in Building Information Modeling (BIM) has formed the basis for many subsequent studies and is frequently referenced in the development of rule-checking applications [39]. As shown in Figure 1, this framework defines the overall process as the flow and interaction of four distinct steps.

In this study, the application examined will be structured according to the steps of rule interpretation, preparation of the building information model, execution of rule checking, and reporting of the results, as shown in Figure 2.

The first and most fundamental stage of BIM-based rule checking applications is the conversion of regulatory rules into machine-readable language. This process aims to digitize the contents of rules expressed in natural language as accurately as possible, meaning converting them into binary or logical codes. However, the diversity of syntactical structures and the content-related ambiguities in rule expressions make it quite difficult to standardize this process [40].

The regulatory compliance checking software to be developed in this study will be usable both by engineers and architects during the design process and by authorized institutions during official approval procedures. Therefore, the software will be developed as an independent structure that does not rely on design tools but instead can receive and evaluate design data from external sources. In this context, the IFC (Industry Foundation Classes) open data standard, which is supported by many BIM software tools and offers an impartial data model, will be used for the sharing and processing of design data.

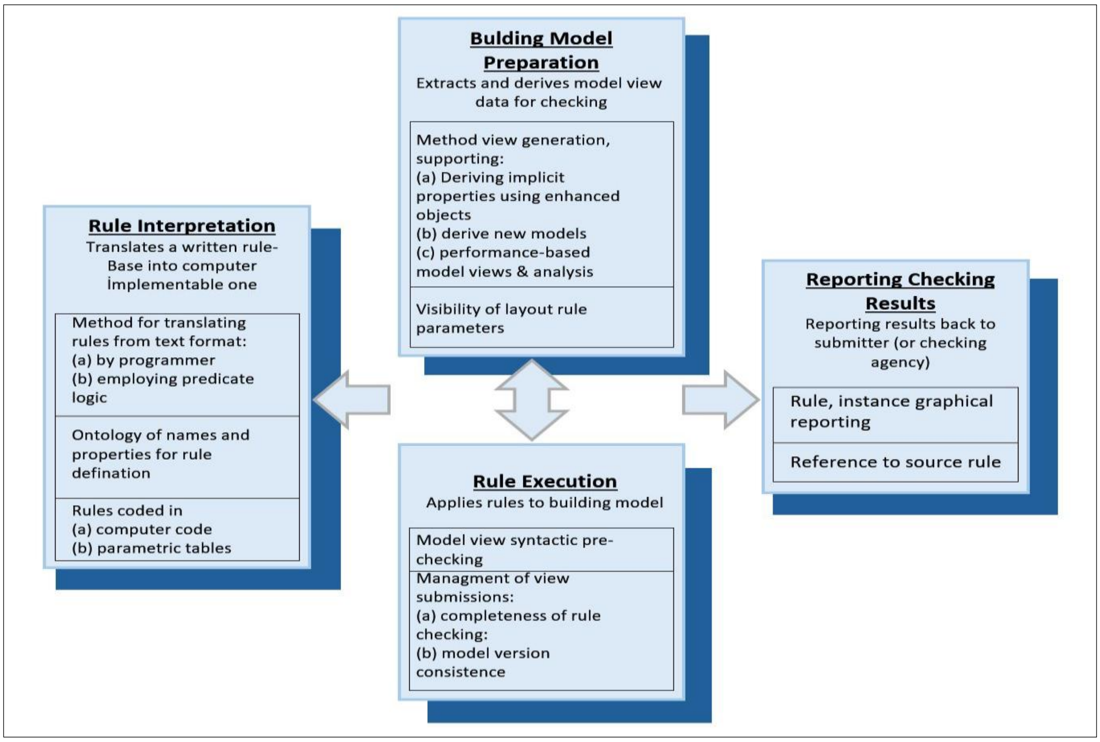


Figure 1: Framework for BIM-based rule checking [39]

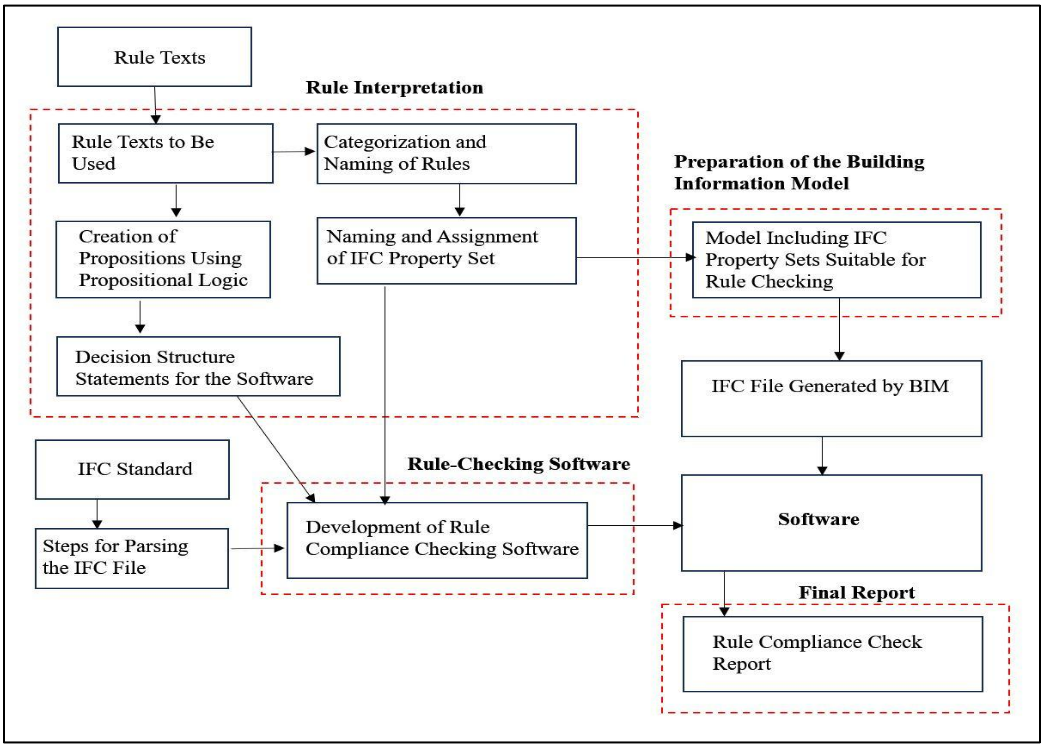


Figure 2: Connection diagram of the rule checking software

3.1. Rule interpretation

One of the primary legal instruments regulating construction processes in Turkiye is the Regulation on Planned Areas Construction, which defines the construction requirements for planned development zones. In addition to this national regulation, there are also locally issued zoning regulations specific to metropolitan municipalities such as Istanbul, Ankara, and Izmir. However, these local regulations are generally aligned in terms of core content and guiding principles. In this study, the Regulation on Planned Areas Construction (2017) is selected as the primary normative source for testing the developed automated rule-checking application [41].

To enable the application to assess architectural project compliance, two specific provisions, Articles 9 and 28, located under the section titled "Provisions Related to Construction" in Chapter 4 of the regulation have been selected as focal points.

- Article 9 outlines the relationship between road width and the permissible number of building floors.
- Article 28 establishes the maximum floor heights for various building usage types, including residential, commercial, and mixed-use developments.

Both articles contain multi-variable rule structures that are directly related to project data and serve as representative examples of automated rule-checking systems. For instance, when evaluating a project, the system must determine whether the number of floors and the building height are explicitly defined in the zoning plan. If not, the number of floors is inferred based on road width, and building height is subsequently calculated, considering the number of floors. Floor height, in turn, is determined based on both floor location and functional building usage. This process requires simultaneous consideration of multiple interdependent variables.

Such multi-variable logic exemplifies the complex rule inference structures often encountered in automated compliance systems.

In this study, a logic-based approach is adopted for the digital modeling and interpretation of regulatory provisions. Specifically, propositional logic (zero-order logic) is utilized, which enables formal reasoning based on the truth values of propositions. This logic framework is widely used in information systems for rule inference, knowledge representation, and automatic interpretation, and is also frequently applied in BIM-based compliance checking processes [42].

Within this framework, propositions are categorized into two types based on the source of their truth values:
- Direct Propositions, which are dependent on observable project variables.
- Inference Propositions, which are based on logical premise-consequence relationships.

Figure 3 schematically illustrates the structural relationship and logical sources of these propositions.

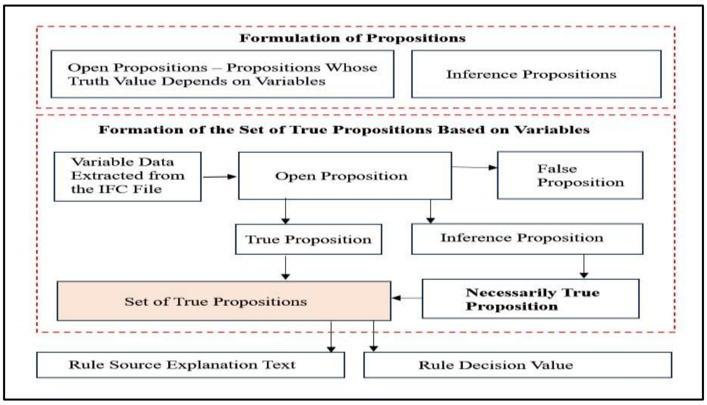
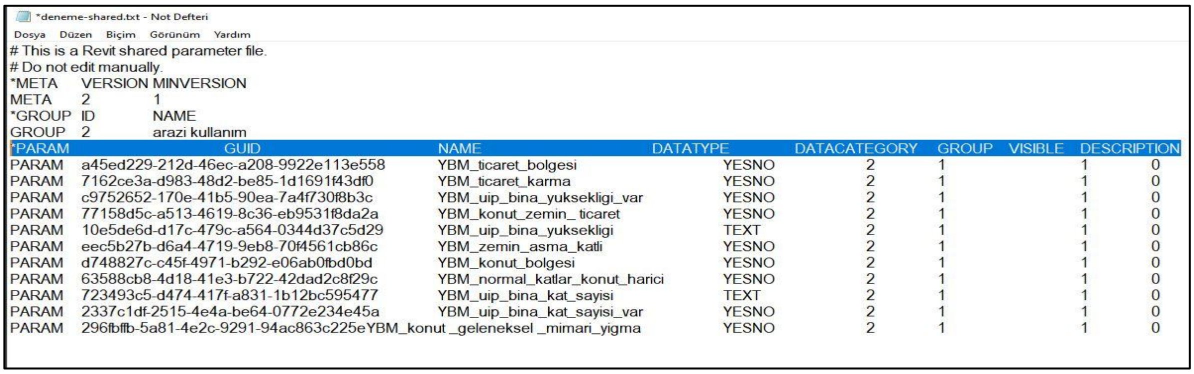


Figure 3: The truth source and formation of propositions

3.2. Preparation of the building information model

To enable the automatic digital control of regulatory rules, propositions validating the values to be compared have been predefined. In evaluating these propositions, the Building Information Modeling (BIM) model will be used as a second data source. For the joint processing of both data sources (i.e., the regulatory rules and the BIM model parameters), it is essential to distinctly define the parameters of the BIM objects. Therefore, concepts representing the regulatory rules will be assigned as parameter names to the relevant objects within the BIM model (Figure 4).

Since the model developed in this study is intended not only to be specific to a certain regulation but also adaptable to regulations across different disciplines, this naming system has been categorized and structured. The IFC (Industry Foundation Classes) format will be used for independent data sharing of the BIM model across software platforms. By using the IFCPROPERTYSET class, which represents object properties within the IFC structure, the defined naming conventions will be directly integrated into the model. After these definitions, the model file produced with the BIM software "Autodesk Revit" will be exported in IFC format, allowing the establishment of a digital environment that facilitates the automatic control of the rules [43, 44].


*deneme-shared.txt - Not Defteri
Dosya Düzen Biçim Görünüm Yardım
This is a Revit shared parameter file.
Do not edit manually.
*META VERSION MINVERSION
META 2 1
*GROUP ID NAME
GROUP 2 arazi kullanım

*PARAM	GUID	NAME	DATATYPE	DATACATEGORY	GROUP	VISIBLE	DESCRIPTION
PARAM	a45ed229-212d-46ec-a208-9922e113e558	YBM_ticaret_bolgesi	YESNO	2	1	1	0
PARAM	7162ce3a-d983-48d2-be85-1d1691f43df0	YBM_ticaret_karma	YESNO	2	1	1	0
PARAM	c9752652-170e-41b5-90ea-7a4f730f8b3c	YBM_uip_bina_yuksekligi_var	YESNO	2	1	1	0
PARAM	77158d5c-a513-4619-8c36-eb9531f8da2a	YBM_konut_zemin_ ticaret	YESNO	2	1	1	0
PARAM	10e5de6d-d17c-479c-a564-0344d37c5d29	YBM_uip_bina_yuksekligi	TEXT	2	1	1	0
PARAM	eec5b27b-d6a4-4719-9eb8-70f4561cb86c	YBM_zemin_asma_katli	YESNO	2	1	1	0
PARAM	d748827c-c45f-4971-b292-e06ab0fbd0bd	YBM_konut_bolgesi	YESNO	2	1	1	0
PARAM	63588cb8-4d18-41e3-b722-42dad2c8f29c	YBM_normal_katlar_konut_harici	YESNO	2	1	1	0
PARAM	723493c5-d474-417f-a831-1b12bc595477	YBM_uip_bina_kat_sayisi	TEXT	2	1	1	0
PARAM	2337c1df-2515-4e4a-be64-0772e234e45a	YBM_uip_bina_kat_sayisi_var	YESNO	2	1	1	0
PARAM	296fbffb-5a81-4e2c-9291-94ac863c225eYBM_konut _geleneksel _mimari_yigma		YESNO	2	1	1	0

Figure 4. Shareable parameter file

3.3. Rule control software

The rule control software has been developed using Python 3.9 version on the Windows operating system. The user interface of the software has been prepared in Turkish. This software processes the data of files created in the "Autodesk Revit" model and produced in the appropriate format (IFC) by parsing them. The features and workflow of the software can be summarized as follows:

Loading and Parsing the IFC File: The software analyzes the uploaded IFC file and performs a parsing operation for design project information, applicable rules, and project values.

Creating the Data Set: After parsing, the obtained data is converted into a data set. This set includes the design project information, comparison values for applicable rules, and project values. If there is not enough data to make a comparison, the process is stopped and the user is informed about the missing data.

Comparison and Inspection: If the necessary data is available, the project's compliance with regulations is determined using the comparison values and project values. At this stage, a comparison is made for each rule related to the project.

Generating the Results Report: In the final stage, a results report containing the user's information and the design project's data is prepared. The report includes the propositions in the correct propositions set, comparison values, and compliance statuses. This report is presented to the user in HTML format.

User Interface: The software's user interface is designed using Python's "tkinter" library. The software's workflow is shown in Figure 5 as a flow diagram.

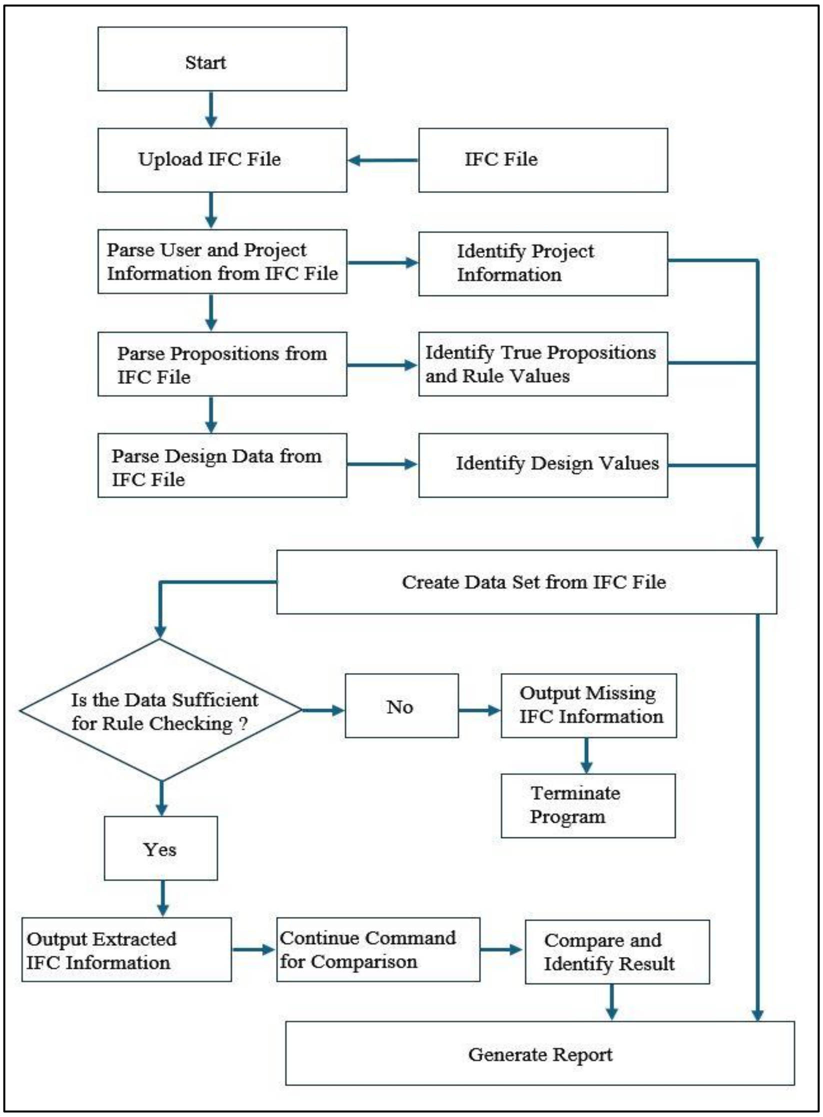


Figure 5. Rule-Checking Software Flowchart

3.4. Results report

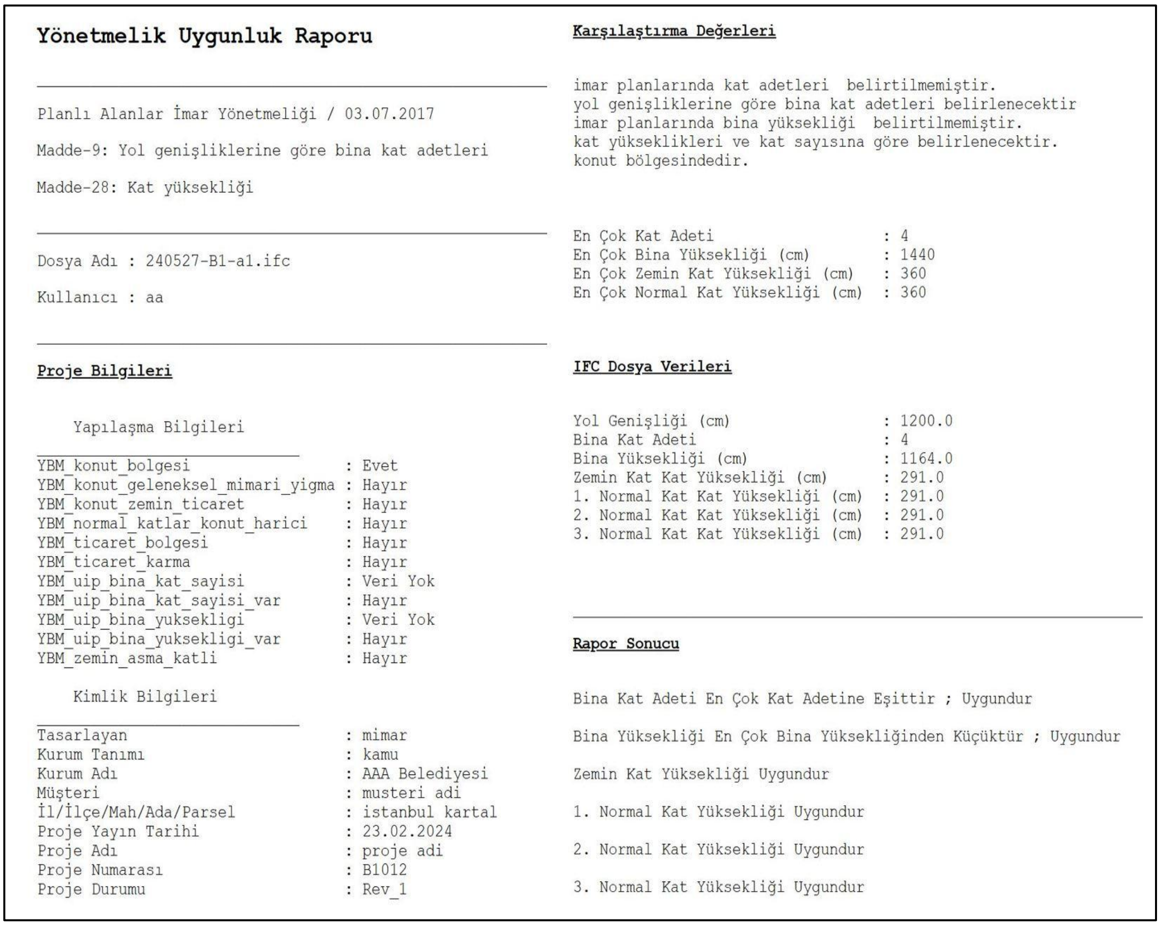
The software generates a detailed document titled " Regulation Compliance Report", which systematically presents each stage of the rule-checking process to the user. This report is produced in HTML format, making it easily accessible across various operating systems and web browsers.

The report provides a comprehensive overview of all data related to the project that has undergone compliance validation. The content is organized into the following eight sections:

- Regulation Reference: The title and date of the applicable regulation, along with the specific articles and headings used in the compliance validation.
- Source File and User Information: The name of the IFC file from which the data was extracted and the username of the individual running the analysis.
- Construction Information refers to the construction-related project data that is retrieved from the IFC file.
- Project Identification: General project information identified from the IFC model.
- Correct Propositions: A list of validated logical propositions used for deriving comparison values.

- Comparison Values refer to the reference values derived from the correct propositions for compliance evaluation.
- Extracted Project Data refers to all relevant project data obtained from the IFC file.

This structured report format enables users to access detailed information regarding all data inputs and validation processes. As shown in Figure 6, the user interface for report presentation is currently available in Turkish. Furthermore, the software enhances the transparency and traceability of regulatory validation, thereby supporting stakeholders in making accurate and timely decisions.



Yönetmelik Uygunluk Raporu

Planlı Alanlar İmar Yönetmeliği / 03.07.2017

Madde-9: Yol genişliklerine göre bina kat adetleri

Madde-28: Kat yüksekliği

Dosya Adı : 240527-B1-a1.ifc

Kullanıcı : aa

Proje Bilgileri

Yapılaşma Bilgileri

YBM_konut_bolgesi	: Evet
YBM_konut_geleneksel_mimari_yigma	: Hayır
YBM_konut_zemin_ticaret	: Hayır
YBM_normal_katlar_konut_harici	: Hayır
YBM_ticaret_bolgesi	: Hayır
YBM_ticaret_karma	: Hayır
YBM_uip_bina_kat_sayisi	: Veri Yok
YBM_uip_bina_kat_sayisi_var	: Hayır
YBM_uip_bina_yuksekligi	: Veri Yok
YBM_uip_bina_yuksekligi_var	: Hayır
YBM_zemin_asma_katli	: Hayır

Kimlik Bilgileri

Tasarlayan	: mimar
Kurum Tanımı	: kamu
Kurum Adı	: AAA Belediyesi
Müşteri	: musteri adi
İl/İlçe/Mah/Ada/Parsel	: istanbul kartal
Proje Yayın Tarihi	: 23.02.2024
Proje Adı	: proje adi
Proje Numarası	: B1012
Proje Durumu	: Rev_1

Karşılaştırma Değerleri

imar planlarında kat adetleri belirtilmemiştir.
yol genişliklerine göre bina kat adetleri belirlenecektir
imar planlarında bina yüksekliği belirtilmemiştir.
kat yükseklikleri ve kat sayısına göre belirlenecektir.
konut bölgesindedir.

En Çok Kat Adeti	: 4
En Çok Bina Yüksekliği (cm)	: 1440
En Çok Zemin Kat Yüksekliği (cm)	: 360
En Çok Normal Kat Yüksekliği (cm)	: 360

IFC Dosya Verileri

Yol Genişliği (cm)	: 1200.0
Bina Kat Adeti	: 4
Bina Yüksekliği (cm)	: 1164.0
Zemin Kat Kat Yüksekliği (cm)	: 291.0
1. Normal Kat Kat Yüksekliği (cm)	: 291.0
2. Normal Kat Kat Yüksekliği (cm)	: 291.0
3. Normal Kat Kat Yüksekliği (cm)	: 291.0

Rapor Sonucu

Bina Kat Adeti En Çok Kat Adetine Eşittir ; Uygundur

Bina Yüksekliği En Çok Bina Yüksekliğinden Küçüktür ; Uygundur

Zemin Kat Yüksekliği Uygundur

1. Normal Kat Yüksekliği Uygundur

2. Normal Kat Yüksekliği Uygundur

3. Normal Kat Yüksekliği Uygundur

Figure 6. Regulation compliance report (interface in Turkish)

4. Findings

Four different models were used to test the software, and the different results obtained from the IFC files of these four models clearly demonstrate the functionality of the software. As the first step, the software checked whether the necessary data for comparison was available. Additionally, it detected whether there were any contradictions within the data. In models with sufficient data and no contradictions, the software determined the comparison values for the model and the rule. As a result, the software generated a report containing the outcomes of the operations performed. The software's user interface consists of two main sections, both designed to facilitate intuitive and efficient user interaction.

When the software is launched, the user is presented with the initial interface, which includes five functional components. As illustrated in Figure 7, the interface is currently available in Turkish:

- Drag-and-Drop Area for the IFC File: Users can drag and drop a suitable IFC file into this area. The file name and path are automatically detected. The system verifies the file format, and if a format other than IFC is selected, a warning message is displayed.

- Username Entry: Users can enter their username for identification purposes. If this field is left blank, a warning message is triggered.
- Naming for IFC Objects: This section allows users to modify the default names assigned to objects within the IFC file.
- Start Data Validation: Users initiate the parsing process by clicking the "Validate IFC File Data" command button.
- Rules to Be Checked: At the bottom of the interface, the rule set to be applied during the validation process is displayed.
- Rules to Be Checked: At the bottom of the user interface, the rules that will be checked are displayed.

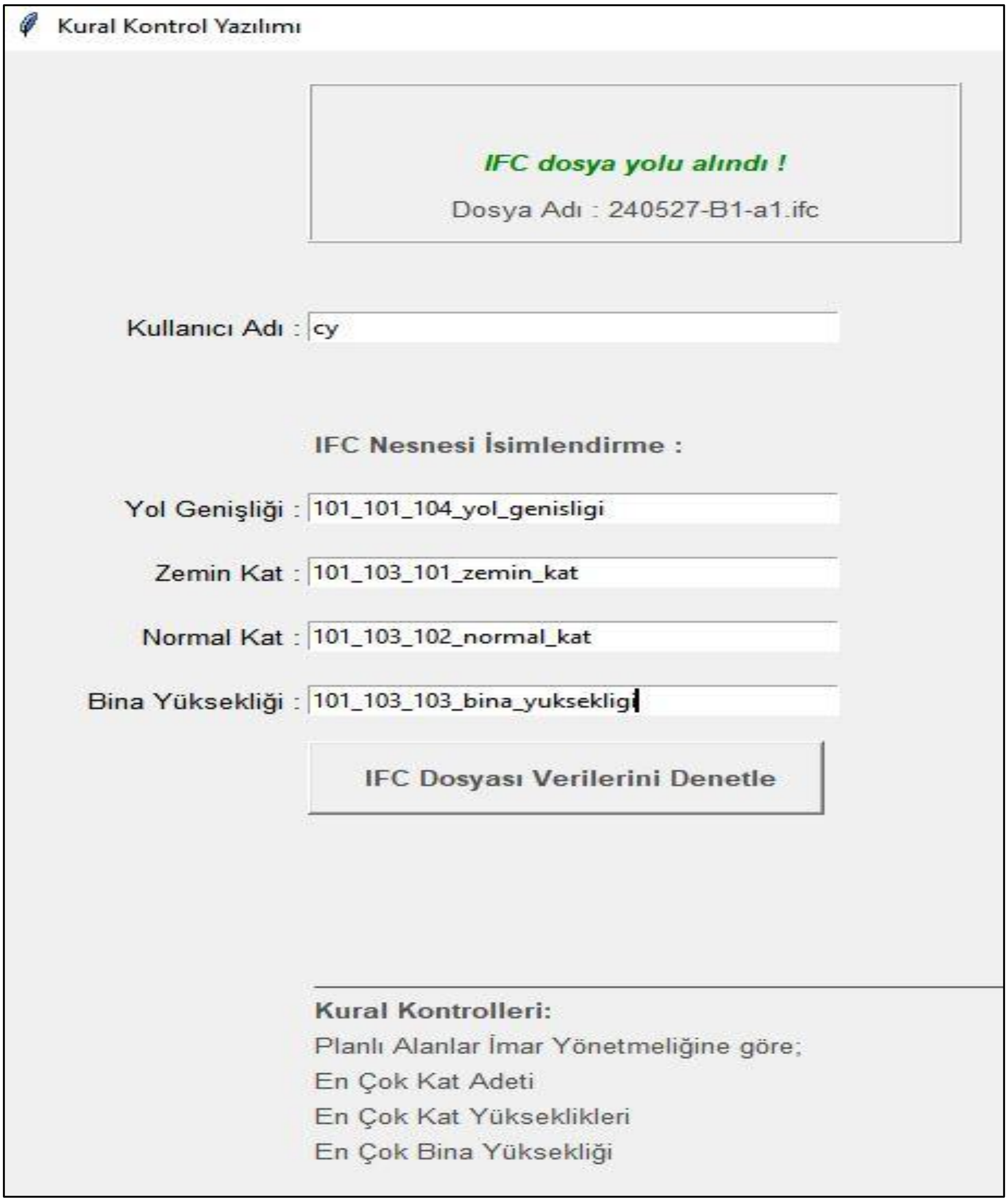


Figure 7. Software startup interface (interface in Turkish)

If the IFC file format is invalid or the username is not provided, the system alerts the user via a warning message (see Figure 8). Once the parsing process is initiated, the second user interface is automatically launched (see Figure 8). It comprises the following five components:

- Name of the Parsed IFC File and User Information: Displays the name of the selected IFC file along with the entered username.
- Project Information and Values: Presents extracted project data and construction parameters retrieved from the IFC file.
- Comparison Values: Displays the values used for rule-based comparisons against the model.
- Missing Information Status: If any required data is missing, a message listing the incomplete items is shown, along with a command button to restart the process.
- Create Rule Control Report: If no missing information is detected, the user is enabled to generate the rule control report.

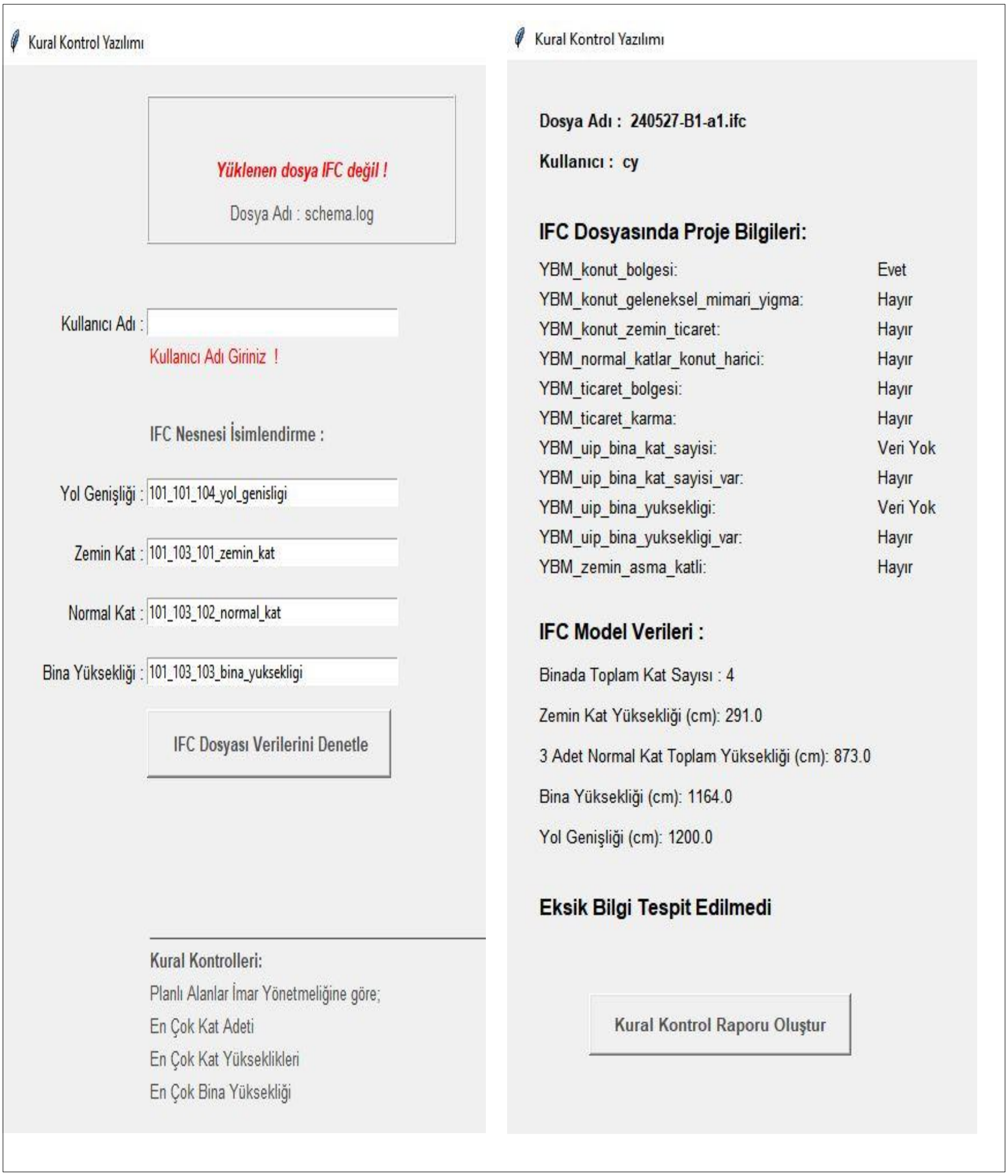


Figure 8. Error message on the software startup interface and user interface after IFC file validation (interface in Turkish)

In cases where missing information is found, a separate screen displays the incomplete fields, and report generation is disabled (see Figure 9). If all required data is present, the "Create Rule Control Report" tab becomes active, allowing the user to export the report in HTML format. Upon completion, the software automatically terminates.

With the sample model used, which contains 956 elements, a file size of 6.38 MB, and approximately 197,000 words, the rule control report is generated in approximately 3 seconds. This demonstrates the software’s ability to perform efficiently, even when handling large-scale data.

Figure 9. Warning screen when missing information is detected in the IFC file (interface in Turkish)

The results of the software tests with four different models are shown in Table 1.

Table 1. Software testing with four different models and results

Model Name	Project Construction Information	Comparison Value	Road Width (cm)	Suitable Results	Unsuitable Results
240527-B1-a1	Number of floors and floor height not specified in the zoning plan	Building height to be determined according to regulations	1200	6	0
240527-B1-a2	Number of floors and floor height specified in the zoning plan	Building height: 950 cm and number of floors: 3 floors according to regulations	1200	4	2
240527-B1-a3	Number of floors and floor height not specified in the zoning plan	Building height to be determined according to regulations	900	4	2
240527-B1-a4	Number of floors and floor height specified in the zoning plan	Zoning plan missing building height information	-	-	-

For the model named "240527-B1-a1," the zoning plan does not specify the number of floors and floor height. The number of floors will be determined based on the road widths in the model, and the building height will be calculated according to the floor heights and the number of floors. The project is located in a residential area. The data for this model are shown in Table 2, and the comparison values are shown in Table 3. According to the result report, all 6 rules were found to be suitable for the "240527-B1-a1" model (Table 4).

Table 2. Model data for "240527-B1-a1" from the IFC file

Model Data	Value
Road Width (cm)	1200
Number of Floors	4
Building Height (cm)	1164
Ground Floor Height (cm)	291
1st Normal Floor Height (cm)	291
2nd Normal Floor Height (cm)	291
3rd Normal Floor Height (cm)	291

Table 3. Comparison values for the "240527-B1-a1" model

Comparison Name	Value
Max Number of Floors	4
Max Building Height (cm)	1440
Max Ground Floor Height (cm)	360
Max Normal Floor Height (cm)	360

Table 4. Rule compliance results for the "240527-B1-a1" model

Compliance Name	Status
The number of floors is equal to the maximum number of floors	Suitable
Building height complies with the maximum allowable height	Suitable
Ground floor height	Suitable
1st normal floor height	Suitable
2nd normal floor height	Suitable
3rd normal floor height	Suitable

For the model named "240527-B1-a2," the zoning plan specifies the number of floors, and the condition for the number of floors in the zoning plan is valid. The zoning plan also specifies the building height, which is valid. The project is located in a residential area. The data for this model are shown in Table 5, and the comparison values are shown in Table 6. According to the result report, 4 out of the 6 rules were suitable, and 2 were unsuitable for the "240527-B1-a2" model (Table 7).

Table 5. Model data for "240527-B1-a2" from the IFC file

Model Data	Value
Road Width (cm)	1200
Number of Floors	4
Building Height (cm)	1164
Ground Floor Height (cm)	291
1st Normal Floor Height (cm)	291
2nd Normal Floor Height (cm)	291
3rd Normal Floor Height (cm)	291

Table 6. Comparison values for "240527-B1-a2" model

Comparison Name	Value
Max Number of Floors	3
Max Building Height (cm)	950
Max Ground Floor Height (cm)	360
Max Normal Floor Height (cm)	360

Table 7. Rule compliance results for "240527-B1-a2" model

Compliance Name	Status
The number of floors is equal to the maximum number of floors	Not Suitable
Building height complies with the maximum allowable height	Not Suitable
Ground floor height	Suitable
1st normal floor height	Suitable
2nd normal floor height	Suitable
3rd normal floor height	Suitable

For the model named "240527-B1-a3," the zoning plan does not specify the number of floors. The number of floors will be determined based on road widths, and the building height is not specified in the zoning plan. The height and number of floors will be determined based on the floor heights and the number of floors, and the project is located in a residential area. The data for this model are shown in Table 8, and the comparison values are shown in Table 9. According to the result report, 4 out of the 6 rules were suitable, and 2 were unsuitable for the "240527-B1-a3" model (Table 10).

Table 8. Model data for "240527-B1-a3" from the IFC file

Model Data	Value
Road Width (cm)	900
Number of Floors	4
Building Height (cm)	1164
Ground Floor Height (cm)	291
1st Normal Floor Height (cm)	291
2nd Normal Floor Height (cm)	291
3rd Normal Floor Height (cm)	291

Table 9. Comparison values for "240527-B1-a3" model

Comparison Name	Value
Max Number of Floors	3
Max Building Height (cm)	1080
Max Ground Floor Height (cm)	360
Max Normal Floor Height (cm)	360

Table 10. Rule compliance results for "240527-B1-a3" model

Compliance Name	Status
The number of floors is equal to the maximum number of floors	Not Suitable
Building height complies with the maximum allowable height	Not Suitable
Ground floor height	Suitable
1st normal floor height	Suitable
2nd normal floor height	Suitable
3rd normal floor height	Suitable

For the model named "240527-B1-a4," the model was created with missing information, and therefore, no report was generated. The software detected that although the building height in the zoning plan was valid, the zoning plan was missing the building height information, and the user was informed via a warning message.

5. Discussion and Recommendations

This study provides an original contribution to the relatively underdeveloped field of BIM–regulation integration in Turkiye by proposing a software-based solution that enables automated compliance checking. However, some critical issues and development opportunities remain for wider implementation.

5.1. Discussion

- Lack of Data Standardization: The absence of standardized BIM practices and consistent IFC data structures in Turkiye results in data variation depending on the software used [8, 9]. This may limit the reliability and compatibility of the proposed rule-checking mechanism.
- Ambiguity in Legal Texts: Zoning regulations often include vague language, exceptions, and non-technical expressions. These characteristics can hinder the precise formalization of rules and reduce the software's ability to interpret them consistently [36].
- Limits of Propositional Logic: While propositional logic is effective for simple rule modeling [42], it lacks the capacity to handle more advanced relational inferences. First-order logic or ontology-based reasoning might be necessary for more complex rule hierarchies.
- Institutional Readiness: The success of such a system depends on whether public agencies are digitally prepared and whether their personnel can use these tools. In Turkiye, the level of digital maturity in public-sector approval workflows specifically related to construction projects remains limited [7].

5.2. Recommendations

- Develop a National BIM–Regulation Integration Guide: Similar to Singapore's "BIM Guide" and initiatives like CORENET [45], Turkiye should develop a national guideline that outlines how BIM data should be structured and linked with legal provisions.

- Adopt NLP and AI for Regulatory Modeling: Legal texts can be automatically translated into formal rules using NLP and machine learning techniques [37, 38], reducing the burden of manual rule definition.
- Pilot Implementation through Public–Private Collaboration: The developed software should be tested in municipalities, building inspection firms, and architecture offices to collect feedback and refine the model.
- Standardize BIM Parameters and Naming Conventions: BEP (BIM Execution Plan) documents should include standardized property naming, classification systems, and IFC usage protocols [24, 25].
- Develop an Open API for Integration: To facilitate interoperability with e-permit systems and other platforms, an open-source API should be created for wider institutional adoption.
- The prototype software developed for testing purposes can be further enhanced. It is possible to improve the system both by expanding data input capabilities and by enabling multi-user access, allowing multiple users to utilize the software collaboratively.

6. Conclusions

This study presents a comprehensive framework and a functional software application for the automatic digital verification of BIM-based design data in line with current zoning regulations in Turkiye. Specifically, Articles 9 and 28 of the Regulation on Planned Areas Construction were selected as the basis for developing and testing rule-checking mechanisms that involve multi-variable rule structures [41]. The developed software parses IFC-format BIM models to extract architectural parameters such as road width, number of floors, building height, and floor heights. These are then compared with reference values derived from the regulation. The system successfully functioned in both complete and inconsistent data scenarios, producing user-friendly reports and guiding the user in each step. Test results from four different models demonstrated the system's accuracy, speed, and operational stability. A significant methodological contribution of the study is the successful implementation of propositional logic for translating regulatory rules into machine-readable formats [42]. Unlike traditional systems that rely solely on fixed comparison values, the proposed approach allows for the dynamic evaluation of derived values based on multiple interrelated parameters using an "If–Then" logic structure.

The study offers both theoretical and practical contributions. Theoretically, it proposes a logic-based mechanism for integrating legal rules with BIM data; practically, it demonstrates how this mechanism can be converted into a functioning digital system. Unlike conventional control tools, the software provides scalable and adaptable logic-based validation, which enables broader use across different regulatory conditions. The findings emphasize that automatic rule-checking software can significantly improve efficiency, early error detection, and transparency in both design and public approval processes. For public authorities, such systems may help to accelerate permitting, streamline inspections, and strengthen accountability. For private sector professionals, it offers the opportunity to test compliance before submission, reducing the likelihood of legal obstacles.

In the future, the system can be extended beyond 3D modeling by incorporating 4D (schedule), 5D (cost), 6D (energy and sustainability), and 7D (operation and maintenance) dimensions [19, 20]. This would make it possible to evaluate regulatory compliance not only in terms of geometry but also across the entire project lifecycle. Moreover, the integration of AI and natural langu age processing (NLP) may allow complex, vague, and exception-based regulations to be interpreted automatically [36, 38]. This would eliminate the need for manual logic translation and broaden the applicability of the system in large-scale regulatory frameworks.
In conclusion, this research introduces an original and applicable model for the automated, regulation-based control of BIM data in Turkiye. Both its software infrastructure and logical framework present a transformative potential for digitalization in the construction industry, offering benefits to both public institutions and private stakeholders.

7. Author Contribution Statement

Author 1 contributed to the design, analysis of the data, interpretation of the results, spelling check and content. Author 2 contributed to the creation of the idea, interpretation of the results, and checking the paper in terms of content.

8. Ethics Committee Approval and Conflict of Interest

There is no need to obtain ethics committee permission for the prepared article. There is no conflict of interest with any person/institution in the prepared article.

9. Ethical Statement Regarding the Use of Artificial Intelligence

During the writing process of this study, the artificial intelligence tool "ChatGPT" developed by "OpenAI" was used only for limited purposes for linguistic editing. The scientific content, analysis and results belong entirely to the authors.

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