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MANDATORY IMPLEMENTATION OF BUILDING INFORMATION MODELING AS A MECHANISM FOR DIGITAL TRANSFORMATION OF THE CONSTRUCTION INDUSTRY IN THE REPUBLIC OF KAZAKHSTAN

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Abstract. *The digital transformation of the construction industry requires a shift from fragmented voluntary technology adoption to structured regulatory implementation. This study examines the mandatory implementation of Building Information Modeling (BIM), referred to in Kazakhstan as TIMSO (Technology of Information Modeling of Construction Objects), as a pre-implementation case of regulatory-driven digital transformation in the construction sector of the Republic of Kazakhstan. Using a comparative document-based analysis and drawing on institutional theory, innovation diffusion, and international BIM mandate experience, the study analyzes the regulatory design of mandatory BIM adoption in Kazakhstan in relation to three reference jurisdictions: the United Kingdom, Singapore, and Finland. A three-level analytical framework is developed, comprising normative, organizational, and technological dimensions of implementation. The study introduces the concept of computable regulation readiness (CRR) to distinguish between the formal adoption of BIM mandates and the broader regulatory conditions required for automated compliance checking (ACC). The findings show that Kazakhstan's mandate already establishes the formal basis for structured information delivery and phased implementation, but that digital submission infrastructure, interoperability enforcement, and institutional authorization of computational verification remain underdeveloped. The study demonstrates that mandatory BIM adoption should not be equated with computable regulation readiness and argues that regulatory digitalization depends on the combined development of structured data requirements, standardized exchange procedures, and formalized regulatory knowledge. The findings contribute to the literature on regulatory-driven BIM adoption in transitional economies and provide practical implications for digital construction governance.*



Keywords: *Building Information Modeling; mandatory BIM adoption; digital construction governance; Common Data Environment; automated compliance checking; regulatory transformation; lifecycle information management; open standards; ontological formalization.*

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ҒЫЛЫМИ МАҚАЛА

АҚПАРАТТЫҚ МОДЕЛЬДЕУ ТЕХНОЛОГИЯСЫН МІНДЕТТІ ҚОЛДАНУ – ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ ҚҰРЫЛЫС САЛАСЫН ЦИФРЛЫҚ ТРАНСФОРМАЦИЯЛАУ МЕХАНИЗМІ РЕТІНДЕ

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²Қазақстан Республикасы Өнеркәсіп және құрылыс министрлігі Құрылыс және тұрғын үй-коммуналдық шаруашылық істері комитетінің «Жобаларды мемлекеттік ведомстводан тыс сараптау» шаруашылық жүргізу құқығындағы республикалық мемлекеттік кәсіпорны («Мемсараптама» РМК), 010000, Астана, Қазақстан

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Аңдатпа. Құрылыс саласын цифрлық трансформациялау технологияларды фрагментарлы ерікті енгізуден оларды құрылымдалған нормативтік бекітуге көшу қажеттігін туындатады. Мақалада Қазақстан Республикасында құрылыс объектілерін ақпараттық модельдеу технологиясын (ҚОАМТ) міндетті қолдану құрылыс саласындағы реттеуші тұрғыдан айқындалған цифрлық трансформацияның іске асыру алдындағы жағдайы ретінде қарастырылады. Институционалдық теорияға, инновациялар диффузиясы тұжырымдамасына және BIM-мандаттарын енгізудің халықаралық тәжірибесіне сүйене отырып, Қазақстандағы BIM-ді міндетті енгізудің нормативтік құрылымы Ұлыбритания, Сингапур және Финляндиямен салыстырмалы құжаттық талдау негізінде зерттеледі. Іске асырудың нормативтік, ұйымдастырушылық және технологиялық деңгейлерін қамтитын үш деңгейлі аналитикалық құрылым ұсынылған. Автоматтандырылған сәйкестікті тексеруге қажетті кеңірек реттеуші алғышарттарды BIM-мандатын формальды енгізуден ажыратуға мүмкіндік беретін есептелетін реттеуге дайындық (computable regulation readiness, CRR) ұғымы енгізіледі. Зерттеу нәтижелері Қазақстандағы мандат құрылымдалған ақпаратты ұсыну мен кезең-кезеңімен енгізудің нормативтік негізін қалыптастырғанын, алайда цифрлық тапсыру инфрақұрылымы, интероперабельділікті қамтамасыз ету тетіктері және есептеу арқылы верификациялауды институционалдық тану деңгейі әлі де жеткіліксіз дамығанын көрсетеді. BIM-ді міндетті енгізу есептелетін реттеуге дайындықпен тепе-тең емес екені негізделеді, ал реттеуді цифрландыру құрылымдалған деректерге қойылатын талаптардың, стандартталған алмасу рәсімдерінің және формалданған нормативтік білімнің қатар дамуына тәуелді екені айқындалады. Алынған нәтижелер өтпелі экономика жағдайындағы елдерде BIM-ді реттеуші тұрғыдан енгізу жөніндегі зерттеулерге үлес қосады және құрылыс саласын цифрлық басқару үшін практикалық мәнге ие.





Түйін сөздер: ғимараттарды ақпараттық модельдеу; BIM-ді міндетті енгізу; құрылысты цифрлық басқару; ортақ деректер ортасы; автоматтандырылған сәйкестікті тексеру; реттеуді трансформациялау; өмірлік цикл ақпаратын басқару; ашық стандарттар; онтологиялық формализация.

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НАУЧНАЯ СТАТЬЯ

ОБЯЗАТЕЛЬНОЕ ПРИМЕНЕНИЕ ТЕХНОЛОГИИ ИНФОРМАЦИОННОГО МОДЕЛИРОВАНИЯ КАК МЕХАНИЗМ ЦИФРОВОЙ ТРАНСФОРМАЦИИ СТРОИТЕЛЬНОЙ ОТРАСЛИ РЕСПУБЛИКИ КАЗАХСТАН

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Аннотация. *Цифровая трансформация строительной отрасли требует перехода от фрагментарного добровольного внедрения технологий к их структурированному нормативному закреплению. В статье обязательное применение технологии информационного моделирования строительных объектов (ТИМСО) в Республике Казахстан рассматривается как предварительный кейс регуляторно обусловленной цифровой трансформации строительной сферы. На основе сравнительного документального анализа с опорой на институциональную теорию, концепцию диффузии инноваций и международный опыт BIM-мандатов исследуется нормативная конструкция обязательного внедрения BIM в Казахстане в сопоставлении с тремя референтными юрисдикциями: Великобританией, Сингапуром и Финляндией. Разработана трехуровневая аналитическая рамка, включающая нормативный, организационный и технологический уровни реализации. Введено понятие готовности к вычислимому регулированию (computable regulation readiness, CRR), позволяющее различать формальное введение BIM-мандата и более широкий набор условий, необходимых для автоматизированной проверки соответствия. Результаты показывают, что казахстанский мандат уже формирует нормативную основу для структурированной передачи информации и поэтапного внедрения, однако инфраструктура цифровой подачи, механизмы обеспечения интероперабельности и институциональное признание вычислительной верификации остаются недостаточно развитыми. Показано, что обязательное внедрение BIM не тождественно готовности к вычислимому регулированию, а цифровизация регулирования зависит от совместного развития требований к структурированным данным, стандартизированных процедур обмена и формализованного нормативного знания. Полученные результаты вносят вклад в исследования регуляторно обусловленного внедрения BIM в странах с переходной экономикой и имеют практическое значение для цифрового управления строительной отраслью.*

Ключевые слова: *информационное моделирование зданий; обязательное внедрение BIM; цифровое управление строительством; среда общих данных; автоматизированная проверка соответствия; трансформация регулирования; управление информацией жизненного цикла; открытые стандарты; онтологическая формализация.*

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1 INTRODUCTION

The construction industry remains one of the least digitized sectors of the global economy, despite long-standing pressures to improve productivity, quality assurance, and regulatory efficiency [22]. In this context, Building Information Modeling (BIM) has become the central technological paradigm of the architecture, engineering, and construction (AEC) sector, enabling the generation, coordination, and lifecycle management of structured digital information about built assets [10].

However, international experience indicates that voluntary BIM adoption alone rarely produces sector-wide transformation [8]. Earlier studies demonstrated that without institutionalized implementation mechanisms, BIM diffusion tends to remain fragmented across individual projects and organizations, limiting interoperability and preventing systemic change [11; 21; 31]. This has led many jurisdictions to move from incentive-based promotion toward mandate-based implementation, using regulatory instruments to standardize information requirements, align industry practices, and accelerate digital transition.

The United Kingdom's BIM Level 2 mandate, introduced in 2016 for centrally procured public projects, is widely recognized as a landmark example of regulatory-driven transformation in construction [15]. Comparable approaches have also been pursued in Singapore, the European Union, and several Nordic countries, where BIM requirements were progressively linked to public procurement, interoperability standards, and digital submission procedures [4; 7; 12]. These experiences suggest that the significance of a BIM mandate extends beyond software adoption: it restructures the regulatory and organizational conditions under which construction information is produced, exchanged, and verified.

In the Republic of Kazakhstan, this transition has been formalized through the Concept for the Implementation of Information Modeling Technology in Industrial and Civil Construction, approved by Order No. 33-NQ of the Committee for Construction and Housing Affairs on 20 February 2025 [14]. The Concept establishes the strategic basis for the phased introduction of mandatory TIMSO/BIM, with the first phase of mandatory application entering into force on 1 July 2026 in accordance with the implementing orders of the authorized body adopted in 2025 (Orders No. 161 and No. 114). In regulatory terms, this marks a shift from viewing the information model as an optional project tool toward recognizing it as a formally required element of the construction process.

Such a transition has implications that go beyond design digitization. Mandatory BIM implementation presupposes changes in information management practices, including the use of Common Data Environments (CDE), structured exchange requirements, interoperable data formats, and alignment with ISO 19650 principles [16–17]. It also raises a broader regulatory question: under what conditions can a BIM mandate serve as a foundation for automated and computable forms of compliance assessment? This question is increasingly relevant in light of the growing body of research on Automated Compliance Checking (ACC), semantic technologies, and machine-readable regulatory knowledge [3; 35].

Although BIM mandates have been extensively discussed in relation to developed economies, less attention has been devoted to how such mandates are structured in developing and transitional contexts, where regulatory modernization, institutional capacity, and digital infrastructure evolve unevenly [1]. There remains a need for analytical approaches that distinguish between the formal introduction of BIM obligations and the broader regulatory conditions required for data-driven and computational governance.

This study addresses that gap by examining the Kazakhstani BIM mandate as a pre-implementation case of regulatory-driven digital transition. It asks not only how mandatory BIM is formally structured, but also which regulatory conditions determine whether such a mandate can evolve into a computable compliance environment. To answer this question, the study applies a comparative document-based analysis and develops an analytical framework that integrates normative, organizational, and technological dimensions of implementation.

Accordingly, the study addresses two research questions. RQ1: How is the Kazakhstani mandatory TIMSO/BIM framework structured at the normative, organizational, and technological levels

in comparison with established mandate jurisdictions? RQ2: To what extent does the current regulatory environment in Kazakhstan satisfy the conditions of computable regulation readiness, and which of these conditions remain underdeveloped?

Research novelty. The novelty of this study lies in four elements. First, it develops a structured comparative framework for examining mandatory BIM implementation across jurisdictions using predefined analytical criteria. Second, it conceptualizes mandatory BIM not simply as a policy requirement, but as a three-level institutional mechanism comprising normative, organizational, and technological dimensions. Third, it introduces the concept of computable regulation readiness (CRR) as an analytical construct for distinguishing between formal BIM mandate adoption and actual readiness for automated compliance checking. Fourth, it applies this framework to Kazakhstan as a transitional pre-implementation case, identifying the specific combination of existing mandate elements, missing infrastructure, and unresolved regulatory conditions.

The remainder of the paper is structured as follows. Section 2 describes the materials and methods, including the comparative analytical procedure. Section 3 presents and discusses the findings of the document-based comparison together with their theoretical and policy implications. Section 4 concludes by summarizing the scientific contribution of the study and outlining directions for future research.

1.1. BIM Adoption: From Voluntary Initiatives to Regulatory Mandates

The trajectory of BIM adoption in the global construction industry exhibits a consistent pattern: voluntary, market-driven adoption is insufficient for achieving sector-wide penetration and standardization. Succar's [31] seminal framework for BIM adoption identified three fields (technology, process, and policy) whose coordinated development is essential for industry-level transformation. Empirical evidence from multiple jurisdictions confirms that without regulatory intervention, BIM adoption remains heterogeneous, creating information silos and interoperability barriers [21; 34].

The concept of BIM maturity, advanced by Succar and Kassem [32], provides a granular taxonomy of adoption stages, ranging from object-based modeling to network-based integration, that informs the design of mandate strategies. Jurisdictions that have implemented BIM mandates demonstrate accelerated progression through maturity stages compared to those relying solely on market forces [11].

1.2. International BIM Mandate Experiences

The UK BIM Level 2 mandate [15] established the requirement for collaborative 3D BIM with structured data exchange on all centrally procured public construction projects. The mandate was supported by a comprehensive ecosystem of standards (BS 1192, PAS 1192-2/3), tools (BIM Toolkit, Digital Plan of Work), and capacity-building programs. Evaluations indicate that the mandate achieved significant improvements in information management maturity, reduced project delivery times, and enhanced cost predictability [24].

The European Union's approach, articulated through Directive 2014/24/EU on public procurement, encourages, without strictly mandating, the use of BIM in public works. The EU BIM Task Group [12] published a handbook providing policy recommendations for member states, emphasizing the importance of graduated mandates, pilot projects, and stakeholder engagement. Scandinavian countries, notably Finland, Norway, and Denmark, have implemented national BIM requirements that predate the EU directive and have achieved relatively high levels of digital maturity in construction [7].

Singapore's Building and Construction Authority (BCA) implemented mandatory BIM submission for architectural plans in 2013, subsequently extending the requirement to structural and mechanical, electrical, and plumbing (MEP) disciplines. Research demonstrates that the Singaporean model's success derives from the integration of regulatory requirements with digital submission infrastructure, automated rule checking capabilities, and sustained investment in workforce development [33].

1.3. Information Management Standards and Interoperability

The ISO 19650 series [16–17] represents the international consensus on information management principles for the built environment using BIM. Part 1 establishes concepts and principles, while Part 2 specifies requirements for the delivery phase. The standard introduces key constructs, including the Common Data Environment (CDE), Exchange Information Requirements (EIR), and the distinction between Project Information Models (PIM) and Asset Information Models (AIM), that structure information flows across the asset lifecycle [10].

Interoperability, defined as the ability of diverse systems and organizations to exchange and utilize information effectively, remains a critical challenge in BIM implementation. The Industry Foundation Classes (IFC) schema, maintained by buildingSMART International [5], provides a vendor-neutral data model for describing built environment objects and their properties. The Information Delivery Specification (IDS), introduced by buildingSMART [6], enables the definition of machine-readable information requirements that can be validated against IFC models, establishing a bridge between contractual requirements and digital deliverables.

1.4. Automated Compliance Checking (ACC)

Automated Compliance Checking represents the computational verification of building designs against regulatory requirements using structured data from BIM models. The field has evolved over more than five decades, from early rule-based approaches [9] to sophisticated systems incorporating natural language processing, semantic analysis, and knowledge representation techniques. Recent reviews have documented both the growing commercial viability of ACC tools and the persistent challenges that impede their widespread adoption, including data quality issues, the complexity of regulatory language, and the limited interoperability between rule-checking engines and BIM platforms [2; 25].

Zhang and El-Gohary [35] developed methods for automated information extraction from construction regulatory documents using semantic NLP, demonstrating the feasibility of converting textual regulations into executable computational rules. Nawari and Ravindran [23] explored the integration of blockchain technology with BIM processes, highlighting the potential for decentralized compliance verification and transparent information exchange in construction. Beach et al. [3] provided a comprehensive state-of-the-art review, establishing a taxonomy of ACC approaches and identifying open research challenges including scalability, multi-jurisdictional applicability, and integration with evolving BIM standards.

The realization of ACC depends critically on the availability of semantically rich, standardized building data, precisely the type of data that mandatory BIM implementation is designed to produce. This relationship between regulatory mandates and ACC readiness constitutes a key theoretical link explored in the present study.

1.5. Ontological Formalization of Regulatory Knowledge

The transition from document-centric to data-centric regulation requires the formalization of normative requirements in machine-readable formats. Ontological approaches provide structured representations of domain knowledge that enable automated reasoning, semantic interoperability, and knowledge reuse [27].

In the construction domain, ontological formalization has been applied to building codes, safety regulations, and construction standards, with promising results in reducing interpretive ambiguity and enabling automated verification. Kabzhan et al. [18] demonstrated the transition pathway from thesaurus-based knowledge organization to formal ontological models in construction, establishing the methodological foundations for representing regulatory knowledge as computable structures. Furthermore, research on controlled natural language (CNL) in construction regulatory documents has shown that constrained linguistic structures can bridge the gap between human-readable norms and machine-processable rules [19].

Recent work on semantic and ontology-based analysis of regulatory documents has advanced the integration of BIM data with formalized regulatory knowledge, providing empirical evidence for the feasibility of computable regulation in the construction domain [20].

2 MATERIALS AND METHODS

2.1. Research Design and Analytical Framework

This study employs a qualitative comparative document analysis of regulatory and institutional instruments governing mandatory BIM implementation. The Republic of Kazakhstan is examined as the focal case, with the regulatory framework for mandatory TIMSO/BIM adoption serving as the primary object of analysis. The documentary corpus for the focal case includes: (a) the Concept for the Implementation of TIMSO/BIM in Industrial and Civil Construction of the Republic of Kazakhstan, approved by Order No. 33-NQ of 20 February 2025 [14]; and (b) associated normative and methodological documents defining implementation scope, timelines, information requirements, and institutional responsibilities.

To contextualize the Kazakhstani case, the study incorporates three reference jurisdictions selected for structured comparison: the United Kingdom, Singapore, and Finland. These jurisdictions were selected purposively because they represent distinct and well-documented models of BIM mandate development. The United Kingdom was selected as a mature case of national mandate implementation supported by a broad evaluative literature base [15; 24]. Singapore was selected because it combines BIM mandate requirements with operational digital submission infrastructure and documented automated rule-checking mechanisms [4]. Finland was selected as an early public-sector adopter of IFC-based requirements and as a relevant reference case for permit automation and interoperability-oriented implementation [7; 30].

The source selection followed explicit inclusion criteria. Documents were included if they met three conditions:

- (1) they had formal regulatory, institutional, or officially recognized guidance status;
- (2) they directly addressed TIMSO/BIM implementation, interoperability requirements, digital submission processes, or compliance-related infrastructure; and
- (3) they provided sufficient information for coding at least one of the predefined comparison criteria.

Draft documents, informal commentaries, and sources without formal adoption or institutional standing were excluded from the core analytical corpus. For the international jurisdictions, peer-reviewed evaluative publications were used as supplementary interpretive sources to contextualize official documents, but not as substitutes for them.

The analytical procedure consisted of five stages. First, the Kazakhstani regulatory corpus was reviewed to identify the formal structure of the mandate, including its legal basis, phased implementation logic, scope of application, and references to information management and interoperability requirements. Second, a documentary corpus was assembled for each reference jurisdiction using the same inclusion principles. Third, all materials were coded using seven predefined analytical criteria: legal trigger mechanism, scope of application, phasing strategy, interoperability standards, digital submission infrastructure, ACC integration, and institutional support mechanisms. Fourth, the coded data were synthesized into a comparative matrix to identify patterns of similarity, difference, and implementation asymmetry across the four jurisdictions. Fifth, the comparative findings were interpreted through the combined lens of institutional theory [26; 29], innovation diffusion theory [28], and the multi-level perspective on socio-technical transitions [13].

To improve analytical transparency, each comparison criterion was operationalized in advance. “Legal trigger mechanism” referred to the formal regulatory or institutional instrument through which BIM implementation was imposed or required. “Scope of application” referred to the

categories of projects or assets subject to mandatory requirements. “Phasing strategy” referred to the temporal or disciplinary sequencing of mandate expansion. “Interoperability standards” referred to formally referenced data exchange or information management standards, including IFC, ISO 19650, IDS, and related frameworks. “Digital submission infrastructure” referred to the documented existence and maturity of formal digital environments for regulatory or procedural submission, coded in descriptive terms such as absent, under development, pilot-stage, or operational. “ACC integration” referred to the degree to which automated rule checking or computational compliance mechanisms were formally recognized or embedded in implementation practice. “Institutional support mechanisms” referred to documented organizational structures, guidance systems, training instruments, or state-supported implementation programs accompanying the mandate.

In addition, the three conditions of computable regulation readiness introduced in Section 3.6 – data structuredness, exchange standardization, and institutional authorization of computational verification – were assessed for each jurisdiction using the same documentary corpus and a three-value descriptive scale: established, emerging, or absent. A condition was coded as established where it was formally embedded in binding regulatory or procedural instruments; emerging where it appeared in pilot programs, draft instruments, or partially adopted requirements; and absent where no documentary evidence of formal recognition was identified. As with the seven comparison criteria, these codings are analytical characterizations of documented mandate design, not independent performance audits.

The comparison was designed as analytical rather than benchmark-based. Table entries do not constitute independent performance audits and should not be interpreted as quantitative measures of implementation success. Instead, they represent a structured comparison of mandate design characteristics as documented in formal sources and supporting evaluative literature. This distinction is especially important in the Kazakhstani case, where the mandate remains at a pre-implementation stage and therefore cannot yet be assessed through outcome-based indicators.

Building on this comparative procedure, the study uses a three-level analytical framework comprising normative, organizational, and technological dimensions of mandatory BIM implementation. This framework structures the interpretation of the findings and provides the basis for examining how formal BIM obligations relate to broader conditions of regulatory digitalization. Table 1 presents the analytical framework used in the study.

Table 1 – Multi-Level Analytical Framework for Mandatory BIM Implementation

№	Level	Key Components	Functional Purpose	Expected Outcomes
1	Normative (Institutional)	Taxonomy of construction objects; phased timelines; regulatory enforcement instruments	Establishment of mandatory requirements and regulatory pressure mechanisms	Industry-wide BIM adoption scaling; baseline compliance
2	Organizational (Process)	CDE; EIR; PIM/AIM; information management protocols	Organization of structured information management and stakeholder coordination	Process coherence; traceability; inter-organizational alignment
3	Technological (Infrastructure)	Open data formats (IFC); exchange specifications (IDS); structured data models; ontological frameworks	Ensuring machine-readability, interoperability, and computational verifiability of building data	ACC readiness; cross-platform data exchange; computable regulation foundations

The seven comparison criteria were interpreted through a three-level analytical framework comprising normative, organizational, and technological dimensions. Sections 2.2–2.4 describe how each level was examined.

2.2. Normative Level Analysis

The normative level examines the formal institutional conditions through which mandatory BIM implementation is introduced and structured. At this level, the analysis focuses on regulatory instruments that establish compulsory requirements, define the scope of application, determine the sequencing of implementation, and assign institutional responsibilities. For the Kazakhstani case, particular attention is given to the Concept for the Implementation of Information Modeling Technology, which functions as the principal mandate-setting instrument and defines object categories, implementation phases, and governance responsibilities [14].

The normative analysis was conducted using four guiding questions:

- (1) What formal instrument establishes the mandate?
- (2) To which categories of projects or assets does the mandate apply?
- (3) How is the implementation timeline structured?
- (4) Which public or institutional actors are assigned implementation or oversight functions?

Using these questions, the Kazakhstani mandate was compared with the selected reference jurisdictions in order to determine whether its regulatory design follows patterns of immediate imposition, staged expansion, or differentiated application by sector, project type, or implementation phase. This level of analysis also identifies gaps in mandate design, particularly where formal obligation is introduced without corresponding precision regarding enforcement mechanisms, submission procedures, or downstream compliance processes.

2.3. Organizational Level Analysis

The organizational level examines how mandatory BIM requirements are translated into structured information management practices and inter-organizational coordination mechanisms. The analysis is anchored in the ISO 19650 framework [16–17], which provides the conceptual basis for assessing whether a mandate is supported by procedures governing information creation, exchange, review, and continuity across the project lifecycle.

At this level, the analysis focuses on the presence or absence of three organizational components:

- (1) Common Data Environment (CDE) arrangements as the shared environment for storing, reviewing, and exchanging project information;
- (2) formally defined information requirements, including Exchange Information Requirements (EIR) or analogous structured specifications; and
- (3) the use of Project Information Models (PIM) and Asset Information Models (AIM) as mechanisms for maintaining information continuity between project phases.

The purpose of this level is not to evaluate the actual organizational maturity of specific firms or agencies, but to determine whether the regulatory and institutional framework contains the procedural foundations necessary for coordinated information management under mandatory BIM conditions. In comparative terms, this level makes it possible to distinguish between mandates that impose BIM as a submission obligation only and those that also restructure the process environment in which digital information is generated and governed.

2.4. Technological Level Analysis

The technological level examines whether the mandate environment is supported by the digital and semantic infrastructure required for interoperable, machine-readable, and potentially computable implementation. The analysis focuses on three interrelated dimensions:

- (1) data continuity through open and interoperable exchange formats, principally IFC [5];
- (2) information validation through machine-readable requirement structures, including IDS or functionally similar specification mechanisms [6]; and

(3) the existence of enabling conditions for automated compliance checking, including formalized regulatory logic, ontological knowledge structures, and rule-oriented semantic representations [20; 35].

This level was used to assess not whether full automated compliance checking is already operational in each jurisdiction, but whether the technological preconditions for such a transition are present, emerging, or absent. Accordingly, the analysis distinguishes between:

- (a) simple digitalization of design deliverables,
- (b) interoperability-oriented digital infrastructure, and
- (c) environments in which computational verification becomes institutionally and technically plausible.

Taken together, the normative, organizational, and technological levels provide the analytical structure for interpreting differences in mandate design across jurisdictions. Rather than treating mandatory BIM as a single regulatory act, the framework allows it to be examined as a layered implementation environment in which legal obligation, process organization, and computational infrastructure may evolve unevenly. The three-level framework is illustrated in Figure 1.

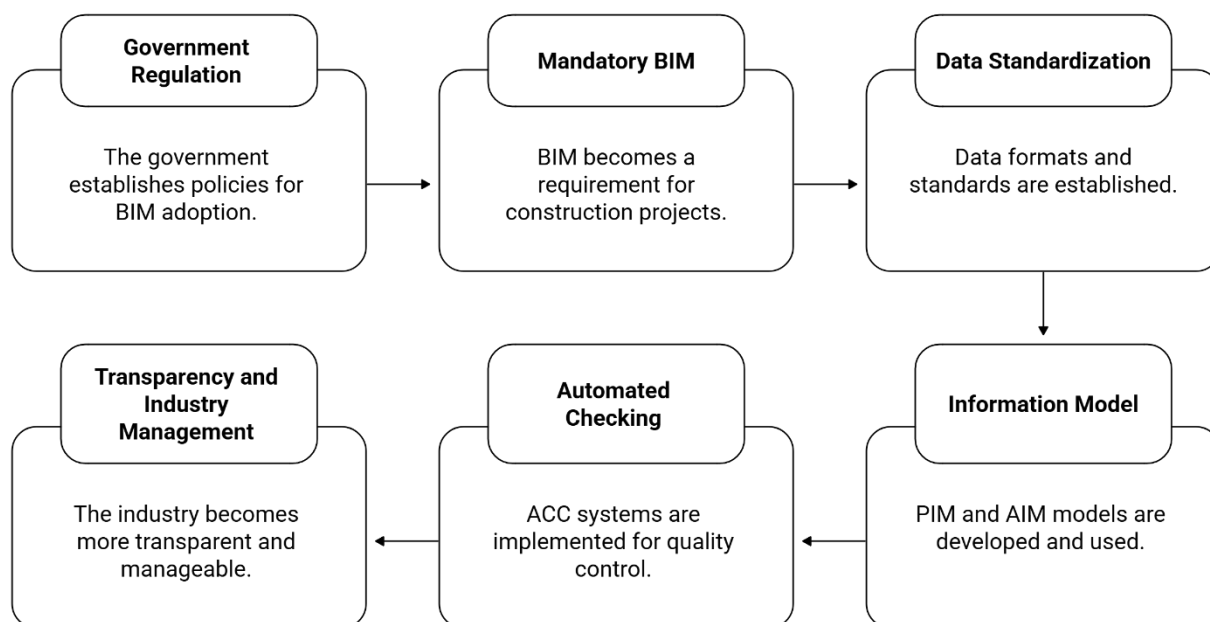


Figure 1 - Multi-level model of mandatory TIMSO/BIM implementation, illustrating the transition from document-oriented regulation to data-driven governance across normative, organizational, and technological dimensions. [Authors' material]

3 RESULTS AND DISCUSSION

3.1. From Document Submission to Information-Based Regulatory Control

The comparative analysis indicates that mandatory BIM frameworks alter the formal object of regulatory control. In document-centered regulatory environments, compliance is primarily assessed through textual and graphical project documentation, which is typically fragmented across multiple formats and depends on expert interpretation at the point of review. In contrast, BIM-based mandate environments shift regulatory attention toward structured information deliverables, in which project data are organized as digital models capable of supporting parameter-based verification, information consistency checks, and cross-disciplinary coordination.

In the Kazakhstani case, this shift is reflected at the level of mandate design rather than implementation outcomes. The TIMSO/BIM Concept formalizes the information model as a required element of the construction process and links mandatory adoption to phased categories of construc-

tion objects and institutional implementation mechanisms. This distinguishes the emerging Kazakhstani model from a purely document-based regulatory approach, even though the supporting infrastructure for digital submission and computational verification remains incomplete.

The cross-jurisdictional comparison further shows that this transition is not uniform in depth. In the United Kingdom, Singapore, and Finland, mandatory or quasi-mandatory BIM environments are associated not only with structured model-based deliverables, but also with broader procedural arrangements for information management and, in some cases, digital submission and rule-based verification. By contrast, the Kazakhstani case currently reflects an earlier stage of transition in which the regulatory object is being redefined in formal terms, while the downstream mechanisms required for full data-centric regulation are still under development.

Accordingly, the main finding at this stage is not that regulatory governance has already become computational, but that the formal basis for moving beyond document-centered control has been established unevenly across jurisdictions. Table 2 summarizes the principal differences between document-centered and information-based regulatory logic.

Table 2 – Comparative Analysis of Regulatory Paradigms

№	Parameter	Document-Centric Model	Data-Centric Model (TIMSO/BIM)
1	Regulatory object	Textual/graphical documentation	Structured information model
2	Data format	Unstructured, heterogeneous	Structured, standardized (IFC/IDS)
3	Verification timing	Post-hoc (ex post facto)	Continuous, integrated into lifecycle
4	Verification method	Manual expert review	Automated + expert hybrid
5	Transparency	Limited, document-dependent	Enhanced, audit-trail enabled
6	Interoperability	Low (format-dependent)	High (open standards-based)
7	Scalability	Constrained by human capacity	Computationally scalable

The structured comparison of BIM mandate parameters across four jurisdictions shows that the Kazakhstani model already incorporates several elements characteristic of established mandate frameworks, most notably phased scope expansion and formal orientation toward ISO 19650-based information management principles. At the same time, the comparison identifies clear asymmetries in implementation infrastructure. Unlike Singapore, where BIM requirements are linked to the operational CORENET X environment, and Finland, where permit automation initiatives have created pathways toward automated verification, Kazakhstan does not yet have an operational digital submission platform and has not introduced formal ACC-related mechanisms into the regulatory workflow. These findings indicate that, in the Kazakhstani case, the formal structure of the mandate has developed more rapidly than the procedural and technical environment required for information-based regulatory implementation.

Table 3 – Comparative Analysis of BIM Mandate Parameters Across Jurisdictions

№	Parameter	United Kingdom	Singapore	Finland	Kazakhstan
1	2	3	4	5	6
1	Legal trigger	Government Construction Strategy mandate (2016)	BCA regulatory requirement (2013, extended 2015)	Senate Properties BIM requirement (2007); national guidelines (2012)	TIMSO/BIM Implementation Concept (Order No. 33-NQ, 20.02.2025)
2	Scope of application	All centrally procured public projects	New building projects > 5,000 sq.m.	Government-owned buildings and infrastructure	Phased: priority/social objects (2026), expanded categories (2028), broad coverage (2030)

Table 3 (continued)

1	2	3	4	5	6
3	Phasing strategy	Single threshold (Level 2 by 2016)	Staged by discipline: architecture (2013), structural (2014), MEP (2015)	Incremental since 2007; IFC submission requirement	Three-phase expansion by object type over 4 years
4	Interoperability standards	BS 1192, PAS 1192-2/3, ISO 19650, COBie	Singapore BIM Guide v2.0, IFC, CORENET X IFC-SG	Common BIM Requirements (COBIM), IFC	ISO 19650 (adopted), IFC (adoption in progress)
5	Digital submission infrastructure	Operational: CDE-based workflows integrated with procurement	Operational: CORENET e-submission since 2008, CORENET X since 2023	Operational: IFC-based building permit pilots	Under development: no operational digital submission platform
6	ACC integration	Available via third-party tools (Solibri); not mandated for regulatory use	Integrated: automated rule checking within CORENET X	Pilot deployments for building permit automation	Not yet initiated; conceptual-stage planning only
7	Institutional support mechanisms	BIM Task Group, NBS guidance, university integration, industry certification	BCA Academy, Built Environment Industry Transformation Map, funding programs	buildingSMART Finland, KIRA-digi program, university curricula	Kazakh Research and Design Institute of Construction and Architecture, initial workforce training programs

Note: All entries are based on document analysis of published regulatory instruments, official guidelines, and evaluative literature. ACC integration levels reflect the status reported in published sources as of 2025 and do not represent independent benchmarking by the authors. Principal documentary sources by jurisdiction: United Kingdom [15; 24]; Singapore [4; 33]; Finland [7; 25; 30]; Kazakhstan [14].

3.2. Preconditions for Automated Compliance Checking (ACC)

The comparative analysis identifies three conditions that are recurrently associated with the possibility of Automated Compliance Checking (ACC) in BIM-based regulatory environments. The first is the formal requirement for structured and machine-readable project information rather than solely textual or graphical documentation. The second is the use of interoperable exchange standards, particularly IFC and related specification frameworks, which enable model-based information transfer across systems and actors [5–6]. The third is the presence of institutional arrangements that allow digital information to be used not only for submission, but also for review, verification, and compliance-related procedures [2–3].

Across the examined jurisdictions, these conditions are present to different degrees. Singapore demonstrates the most integrated configuration, combining structured BIM submission with digital review procedures and documented rule-based verification pathways [4]. Finland reflects a partial but technically relevant configuration through interoperability-oriented implementation and permit automation initiatives [7; 25]. The United Kingdom demonstrates strong standardization and information management maturity, although formal regulatory use of automated checking remains less integrated [15; 24]. In Kazakhstan, the first condition is being introduced through the TIMSO/BIM mandate and the formal orientation toward structured information management, while the second and especially the third remain only partially developed [14].

These findings indicate that mandatory BIM adoption does not in itself constitute ACC readiness. Rather, ACC-related potential emerges where structured data requirements, interoperability mechanisms, and procedurally recognized forms of digital verification are combined within the same implementation environment [3; 27; 35].

3.3. Transparency and Project Governance Effects

The document-based comparison shows that BIM mandate environments are associated with a

shift toward more traceable information management arrangements, particularly where Common Data Environment (CDE) principles and formal information exchange procedures are embedded in implementation practice [10; 16–17]. In such settings, project information is not treated as a set of isolated deliverables, but as a versioned and coordinated information flow that can be reviewed across stages and actors.

This distinction is important for regulatory governance. In document-centered environments, control is concentrated at discrete review points and depends heavily on manual interpretation of fragmented submissions. In more information-based environments, the use of coordinated digital information creates the conditions for traceability of revisions, clearer attribution of information responsibility, and earlier identification of inconsistencies [3; 10]. The comparative materials show that these effects are strongest where BIM mandates are linked to operational submission environments and standardized process protocols, as illustrated most clearly by Singapore and, to a lesser extent, Finland [4; 25]. In Kazakhstan, this direction is visible at the level of formal design, but the corresponding procedural infrastructure remains incomplete [14].

3.4. Standardization and Scalability Effects

The comparative analysis also shows that standardization is a central feature of mature BIM mandate environments. Across the examined cases, mandatory implementation is associated with the formalization of data formats, information exchange rules, and procedural expectations governing the production and coordination of digital deliverables [16–17; 21; 31]. This standardization is particularly evident in jurisdictions where BIM requirements are supported by recognized information management frameworks and interoperability standards [4; 15].

In analytical terms, standardization performs two functions. First, it reduces variation in how project information is structured and exchanged, thereby improving cross-organizational consistency. Second, it creates the conditions under which digital regulatory procedures can be expanded beyond isolated projects, since repeatable compliance logic depends on predictable information inputs [11; 21]. The comparison suggests that this second function is especially important: scalability depends not simply on the existence of digital models, but on the standardization of the information environment in which those models are created and assessed.

For Kazakhstan, the findings indicate that the normative basis for such standardization is emerging, particularly through phased mandate design and reference to international information management principles [14; 16–17]. However, the comparison also shows that standardization at the regulatory level does not automatically imply standardization in implementation practice, especially where model content conventions, submission procedures, and interoperability enforcement remain under development.

3.5. Implementation Challenges and Constraints

The analysis identifies several constraints that may limit the effective realization of mandatory BIM implementation. These include uneven organizational readiness across market participants, shortages of qualified personnel, incomplete adaptation of the regulatory framework to digital information requirements, limited integration capacity of legacy systems, and the absence of clearly institutionalized benchmarks for assessing compliance quality beyond formal submission [2–3; 21]. These constraints are not unique to Kazakhstan, but their significance is amplified in pre-implementation environments where formal requirements are introduced before supporting infrastructure is fully stabilized.

A central risk identified in both the comparative literature and the present analysis is the divergence between formal compliance and substantive capability. In this situation, organizations may produce BIM deliverables that satisfy mandatory submission requirements without embedding information modeling into actual design and coordination processes [21]. This risk is particularly relevant where deadlines are compressed, workforce readiness is uneven, and implementation support mechanisms remain limited, as is currently the case in Kazakhstan's transition phase [14].

The comparison also points to four recurring implementation failure modes. The first is com-

pliance decoupling, in which BIM outputs function as regulatory artifacts rather than operational project instruments. The second is capacity asymmetry, in which larger organizations adapt more readily while smaller firms face disproportionate burdens in software acquisition, training, and workflow restructuring. The third is regulatory absorption deficit, in which authorities require digital submissions but lack the institutional and technical means to review or use them effectively. The fourth is standards fragmentation, in which nominal interoperability is undermined by inconsistent property definitions, classification systems, or information specifications [3; 21; 25].

In the Kazakhstani case, these risks are especially relevant because the mandate is entering force within an environment where digital submission infrastructure is still developing, ACC-related mechanisms are not yet embedded, and industry-wide conventions for model content and interoperability are not fully stabilized [14]. Taken together, these findings show that the effectiveness of a BIM mandate depends not only on the existence of formal obligation, but on the alignment between legal requirements, organizational capacity, and technical implementation conditions.

3.6. Mandatory BIM as a Catalyst for Computable Regulation

The findings of this study suggest that mandatory BIM should be interpreted not only as a mechanism for scaling digital technology adoption, but also as a regulatory condition that may enable the transition toward computable forms of compliance assessment. This distinction is important. The formal introduction of BIM requirements does not automatically produce a computational regulatory environment. Rather, it creates the possibility of such a transition only where structured data requirements, standardized exchange protocols, and recognized procedures for digital verification develop in combination [2–3; 9].

To interpret this relationship, the present study introduces the concept of computable regulation readiness (CRR). CRR is defined here as the degree to which a regulatory environment supports the progressive formalization and computational application of normative requirements. It is structured by three interrelated conditions:

(i) data structuredness, meaning that regulated entities are required to produce building information in standardized, machine-readable formats such as IFC rather than solely in textual or graphical documents;

(ii) exchange standardization, meaning that information flows are governed by explicit information management and interoperability rules, including frameworks such as ISO 19650, EIR, or IDS; and

(iii) institutional authorization, meaning that computational or rule-based verification is formally recognized, anticipated, or procedurally embedded within the compliance environment [5–6; 16–17].

This concept is analytically distinct from BIM maturity. BIM maturity describes the extent to which organizations and markets have adopted modeling tools, collaborative workflows, and digital delivery practices [31–32]. CRR, by contrast, refers to the regulatory environment's readiness to transform digital information into a basis for computable compliance procedures. A jurisdiction may therefore display relatively advanced BIM use while remaining only partially prepared for automated compliance checking if its regulatory instruments do not authorize or incorporate computational verification.

CRR should also be distinguished from recent assessments of digital building permit (DBP) progress [25]. DBP studies primarily evaluate the operational state of permit digitalization – the tools, platforms, and procedures through which digital review is conducted. CRR, by contrast, addresses a prior regulatory question: whether normative requirements and compliance procedures are structured in a way that makes computational verification institutionally possible at all. Similarly, whereas macro-BIM adoption models [21; 32] capture market- and policy-level diffusion dynamics, CRR isolates the readiness of the regulatory environment itself, which may diverge significantly from market maturity, as the Kazakhstani case illustrates.

From this perspective, the comparison undertaken in this study shows a differentiated pattern across the four jurisdictions. Singapore most closely approximates a high-CRR environment be-

cause structured BIM submission, interoperability requirements, and rule-based review procedures are linked within the same regulatory system [4; 25]. The United Kingdom demonstrates strong alignment with the first two conditions through mandate-driven standardization and information management maturity, but computational verification remains less formally embedded in regulatory procedure [15; 24]. Finland occupies an intermediate position, where interoperability-oriented implementation and permit automation pilots indicate movement toward computational review, but not full institutionalization [7; 25; 30].

Table 4 summarizes the assessment of the three CRR conditions across the four jurisdictions, applying the descriptive scale defined in Section 2.1.

Table 4 – Assessment of CRR Conditions Across Jurisdictions

№	CRR condition	United Kingdom	Singapore	Finland	Kazakhstan
1	Data structuredness	Established	Established	Established	Emerging (mandate adopted; phased entry into force from 2026)
2	Exchange standardization	Established	Established	Established	Emerging (ISO 19650 adopted; IFC adoption in progress)
3	Institutional authorization of computational verification	Emerging	Established	Emerging	Absent

Note: Codings follow the descriptive scale defined in Section 2.1 and reflect the documentary status reported in published sources as of 2025.

The Kazakhstani case is particularly instructive because it demonstrates the analytical value of distinguishing between mandatory BIM adoption and computable regulation readiness. The current mandate design addresses the first condition through formal demand for structured information and partially addresses the second through alignment with ISO 19650 principles and the progressive adoption of interoperable information practices [14; 16–17]. However, the third condition remains absent. No current regulatory instrument formally authorizes computational verification as a component of compliance assessment. In this sense, Kazakhstan can be interpreted not as a fully computable regulatory environment, but as a case of partial CRR, in which the legal architecture of mandate implementation is developing faster than the institutional procedures required for automated compliance.

The broader theoretical implication is that ACC should not be understood as an isolated technological add-on to BIM. Rather, as the findings of this study indicate, it emerges where regulatory design, information standardization, and institutional procedure converge within the same implementation environment [3; 27; 35]. This interpretation extends prior research by situating automated compliance not only within the evolution of BIM tools, but within the transformation of the regulatory conditions under which those tools become actionable.

The findings of this study indicate that the transition from document-centered regulation to information-based regulatory control creates a structural need for the formalization of regulatory knowledge. Even where BIM models are available, automated or rule-based compliance assessment cannot be realized if normative requirements remain embedded exclusively in natural-language texts characterized by terminological variation, implicit assumptions, and context-dependent interpretation. In this sense, the problem is not only digitalization of design information, but also the computability of the regulatory knowledge against which that information is assessed [3; 35].

3.7. The Role of Ontological and Semantic Models

Ontological and semantic approaches are relevant in this context because they provide a means of representing regulatory concepts, relations, and constraints in explicit and machine-processable form. Prior research has shown that ontology-based representations can support semantic interoperability, automated reasoning, and the linking of regulatory logic with BIM-based design data [27]. For the present study, this is important not as an abstract technological possibility, but as a

necessary complement to mandatory BIM implementation: structured design information alone is insufficient unless the normative side of the compliance environment is also progressively formalized.

The relevance of this transition is particularly visible in the Kazakhstani context. Recent work on the development of domain knowledge structures in construction has demonstrated a methodological pathway from thesaurus-based organization toward formal ontology models [18]. Related studies on controlled natural language in regulatory and technical documents suggest that constrained linguistic formulation can function as an intermediate layer between conventional normative drafting and computational rule formalization [19]. In addition, empirical work on semantic and ontology-based analysis of regulatory documents has shown the feasibility of linking structured regulatory knowledge with BIM-oriented digitalization processes, while also identifying persistent difficulties related to cross-referencing, ambiguity, and scalability across regulatory domains [20].

Taken together, these considerations suggest that ontological and semantic models should be interpreted not as optional extensions to BIM implementation, but as part of the knowledge infrastructure required for computable regulation. If mandatory BIM changes the form of design information, ontological formalization changes the form of regulatory knowledge. The transition to computable compliance depends on the convergence of both.

3.8. Limitations of the Existing Regulatory Framework

The comparative and interpretive analysis undertaken in this study indicates that the existing regulatory framework still contains several limitations that constrain movement toward computable regulation. These limitations include terminological ambiguity, insufficient distinction between mandatory and advisory provisions, the absence of machine-processable regulatory structures, and inadequate parametric specificity for computational verification. As a result, even where structured BIM information becomes formally required, the regulatory environment may remain only partially capable of supporting automated or semi-automated compliance procedures.

These limitations are consistent with broader findings in the literature on regulatory digitalization and automated compliance checking, which repeatedly identify ambiguity, implicit semantics, and weak formalization as major barriers to machine-applicable regulation [2–3; 35]. They are also consistent with recent analyses of Kazakhstani construction regulations, which show that the linguistic and conceptual structure of normative documents remains insufficiently aligned with the needs of formal knowledge representation and computable interpretation [19–20].

From this perspective, the problem is not limited to the absence of software tools or digital platforms. Rather, it lies in the continued dominance of drafting practices oriented toward human interpretation alone. The transition to computable regulation therefore requires not only digital submission infrastructure, but also a gradual restructuring of normative documents themselves, including clearer semantic distinctions, explicit parameterization of requirements, and the use of forms that are simultaneously human-readable and machine-processable.

3.9. Policy Implications

The findings of this study have several implications for construction governance policy in Kazakhstan. First, the current phased approach to mandatory BIM implementation appears structurally consistent with international mandate trajectories, particularly in its use of staged scope expansion and reference to internationally recognized information management principles [12; 14–15]. However, the comparison also indicates that the effectiveness of such a mandate depends on whether supporting infrastructure develops in parallel with formal obligation. This includes not only training and organizational adaptation, but also digital submission environments, procedural integration, and implementation-ready information standards.

Second, the analysis suggests that mandatory BIM creates a strategic opening for the gradual incorporation of ACC-related functions into the regulatory system. This does not imply that full automation should be treated as an immediate implementation target. Rather, it indicates that once structured information requirements and interoperable procedures are in place, the regulatory envi-

ronment becomes more receptive to hybrid forms of digital verification. In this sense, the value of the BIM mandate extends beyond model production: it can establish the procedural conditions under which compliance checking may become progressively more data-driven and less dependent on fragmented documentary review [2–3].

Third, the study indicates that the formalization of regulatory knowledge should be treated as a policy priority rather than a purely academic exercise. If BIM implementation is to contribute to regulatory transformation rather than to digitalized document submission alone, then ontological frameworks, controlled drafting logic, and semantically structured regulatory formulations must be developed alongside technical mandate instruments [19–20; 27].

More broadly, the integration of BIM mandates with state information systems could improve the analytical capacity of regulatory institutions by enabling more consistent tracking of submissions, clearer monitoring of compliance patterns, and a more evidence-based allocation of oversight resources. However, the findings of the present study also caution that such benefits depend on institutional readiness and cannot be assumed as an automatic consequence of mandate adoption.

3.10. Theoretical Contribution

The theoretical contribution of this study lies in the analytical distinction it establishes between mandatory BIM adoption and computable regulation readiness. Existing BIM adoption literature has primarily examined mandates as instruments for accelerating diffusion, improving standardization, and increasing the maturity of digital practices across the construction sector [21; 31]. The present study extends this perspective by showing that mandate adoption should also be examined in relation to the regulatory conditions under which digital information may become actionable for computational compliance purposes.

Within this perspective, mandatory BIM is interpreted not simply as a policy requirement, but as a multi-level implementation environment comprising normative, organizational, and technological dimensions. This framing makes it possible to analyze why jurisdictions with formally similar BIM obligations may nevertheless differ significantly in their readiness for digital verification and computable regulation. The concept of computable regulation readiness (CRR) contributes to this distinction by identifying three conditions that must converge for such a transition to become plausible: structured data requirements, standardized information exchange, and institutional recognition of computational verification.

A second theoretical contribution lies in the positioning of transitional economies within the broader literature on digital construction governance. Much of the existing research has focused on advanced mandate jurisdictions in which digital infrastructure and institutional support mechanisms are already relatively mature. By examining Kazakhstan as a pre-implementation case, the study demonstrates that the most analytically significant question is not whether a BIM mandate exists, but which elements of the wider regulatory environment are already in place and which remain underdeveloped. This makes it possible to treat transitional mandate environments not as incomplete versions of mature systems, but as distinct analytical cases with their own regulatory sequencing, institutional asymmetries, and trajectories of digital transformation.

Taken together, these contributions support a broader reinterpretation of ACC. Rather than viewing automated compliance as a downstream technological application of BIM, the study positions it as an emergent property of regulatory environments in which legal obligation, process standardization, and knowledge formalization converge. In this sense, the study contributes to the literature not only by proposing a conceptual framework, but by showing how comparative analysis can distinguish between formal digital mandate adoption and the deeper institutional conditions required for computable regulation.

3.11. Limitations of This Study

Several limitations of this study should be taken into account when interpreting its findings. First, the research is based primarily on comparative document analysis and theoretical interpretation rather than on primary empirical data collection. No interviews, surveys, or implementation-

stage observations were undertaken. As a result, the study does not provide direct evidence on stakeholder perceptions, organizational behavior, or the operational dynamics of mandate implementation. These dimensions should be examined in future research through qualitative fieldwork and post-implementation assessment.

Second, the study examines the Kazakhstani BIM mandate at a pre-implementation stage. Because the first phase of mandatory application begins in August 2026, the analysis necessarily addresses mandate design and regulatory readiness rather than observed implementation outcomes. The study therefore does not evaluate realized effects of the mandate in practice, but rather interprets the conditions under which such effects may or may not emerge [14].

Third, the comparative analysis is limited by variation in the availability, depth, and evaluative character of published materials across jurisdictions. Although the comparison was structured using predefined analytical criteria, the underlying documentary bases are not fully symmetrical. Some parameters, particularly those related to ACC integration and institutional support, are documented more extensively in certain jurisdictions than in others [4; 15; 25]. The comparison should therefore be understood as analytically structured rather than metrically standardized.

Fourth, the findings are shaped by the specific regulatory and institutional context of Kazakhstan as a transitional economy. While the analytical framework developed in this study may be applicable beyond the present case, its transferability to other jurisdictions requires separate validation. The patterns identified here should therefore be treated as context-sensitive analytical findings rather than universally generalizable regularities.

4 CONCLUSIONS

This study examined the mandatory implementation of BIM technology in the Republic of Kazakhstan as a pre-implementation case of regulatory-driven digital transformation in the construction sector. Its main scientific contribution lies in demonstrating that mandatory BIM adoption should be analyzed not only as a policy instrument for accelerating digital uptake, but also as a regulatory condition whose significance depends on the wider institutional, organizational, and technological environment in which it is embedded. Based on the conducted analysis, the following conclusions can be drawn.

1. Mandatory BIM adoption and computable regulation readiness (CRR) should be treated as analytically distinct phenomena. The formal introduction of BIM requirements does not in itself create a computable regulatory environment. Such a transition becomes plausible only when three conditions converge: structured and machine-readable building information, standardized exchange procedures, and institutional authorization of computational verification.

2. The Kazakhstani case demonstrates a configuration of partial CRR. The current mandate establishes the formal requirement for structured information and signals movement toward standardized information management aligned with international principles. However, the institutional and procedural conditions required for computational compliance assessment remain underdeveloped. The principal gap in the current transition therefore lies not only in digital infrastructure, but also in the absence of a fully established regulatory environment capable of transforming digital information into actionable compliance procedures.

3. Mandatory BIM implementation changes the regulatory logic of construction governance. The transition is not limited to replacing paper-based documentation with digital models. Rather, it redefines the formal object of regulatory control by shifting the focus from fragmented documentary submission toward coordinated information-based regulation. At the same time, the comparative findings show that this transition develops unevenly across jurisdictions and depends on the maturity of submission environments, interoperability practices, and implementation support mechanisms.

4. The transition toward computable regulation cannot be achieved through BIM mandate instruments alone. If design information becomes structured and machine-readable while regulatory requirements remain linguistically ambiguous and semantically unformalized, the compliance envi-

ronment remains only partially digitalized. In this sense, ontological and semantic formalization of regulatory knowledge should be understood as a necessary counterpart to mandatory BIM implementation rather than as a separate technical add-on.

5. The findings indicate that the development of a national ontology-oriented framework for construction regulatory knowledge should be treated as a strategic priority. The computability of regulation depends not only on the quality of information models, but also on the formal structure of normative requirements, including their semantic clarity, logical consistency, and suitability for digital interpretation.

6. Digital submission infrastructure and CDE-oriented integration with state information systems should be developed in parallel with the mandate. This is necessary to ensure that structured information can be received, processed, validated, and used within regulatory workflows rather than remaining limited to formal model submission.

7. ACC-related functions should be introduced gradually as a medium-term regulatory objective. At the initial stage, hybrid digital-expert verification appears more realistic than immediate full automation. Such an approach would allow computational tools to support expert review while institutional, semantic, and procedural foundations for automated compliance checking continue to mature.

8. Implementation quality should be assessed through benchmarks that go beyond formal submission compliance. Evaluation should capture the substantive use of BIM information in project delivery, design coordination, state expertise, data exchange, and regulatory review processes.

9. Sustained investment in workforce development is required. The effective implementation of the mandate depends on competencies in BIM processes, information management, interoperability standards, CDE workflows, digital submission procedures, and digital regulatory practice.

Future research should extend this study in three directions: empirical assessment of implementation outcomes after the launch of mandatory application, development of domain-specific ontology models for Kazakhstani construction regulations, and comparative investigation of BIM mandate trajectories across other transitional and Central Asian jurisdictions.

In conclusion, mandatory BIM adoption should not be equated either with digital maturity or with computable regulation. It establishes an important regulatory threshold, but not a complete digital governance environment. The transition from mandate to computable compliance depends on whether legal obligation, process standardization, and knowledge formalization develop together. For Kazakhstan, the most consequential unresolved issue is therefore not the existence of the mandate itself, but the institutionalization of the conditions under which digital information can become a legitimate basis for compliance assessment.

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

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