Measuring BIM readiness and digitalisation in building permitting: a KPI-based framework

Smart and Sustainable Built Environment

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Abstract

Purpose – Digital building permitting (DBP) is increasingly promoted as a key instrument for improving efficiency, transparency and interoperability in public administration. Building Information Modelling (BIM) is cited as a central enabler of this transition. However, existing research offers limited support for systematically benchmarking BIM-based building permitting (BP) systems across different jurisdictions. This study addresses this gap by developing and empirically validating a multi-level Key Performance Indicator (KPI) framework to support comparative benchmarking of BIM-based BP processes.

Design/methodology/approach – The study adopts a mixed-method research design. A structured literature review was combined with qualitative content analysis and thematic synthesis to develop an initial KPI framework spanning four subsystems. The framework was validated through seven semi-structured expert interviews with public authorities involved in municipalities across six countries. Expert feedback was analysed qualitatively, while scaled KPI responses were interpreted quantitatively to support cross-country comparison and benchmarking.

Findings – The results reveal substantial variation in BP implementation across jurisdictions. While electronic submission is widely established, deeper BIM integration, interoperability and automated compliance checking remain limited. The benchmarking results suggest the presence of different implementation patterns rather than linear maturity paths, with observed differences being influenced more by factors such as legislative clarity, modelling standards and organisational capacity than by technological availability alone. Experts emphasised that procedural inefficiencies tend to originate from upstream regulatory and institutional constraints.

Originality/value – The research responds to the growing need for evidence-based instruments and offers a validated, practice-oriented framework that supports systematic benchmarking of BIM-based BP systems and provides authorities and policymakers with a structured basis for identifying bottlenecks, comparing approaches and guiding evidence-based DBP.

Keywords Building permitting, Digitalisation, BIM, Key performance indicators, Benchmarking, Regulatory compliance

Paper type Research article

1. Introduction

The construction industry has been slow to adopt digital technologies due to its fragmented nature, project complexity and reliance on conventional documentation (Vararean-Cochisa and Crisan, 2024; Musarat *et al.*, 2021; Crisan *et al.*, 2024). Recently, this has begun to change as sustainability demands, regulatory pressures and efficiency requirements drive wider adoption of digital tools such as BIM, cloud-based platforms and artificial intelligence (AI), supporting more integrated and data-driven practices across the Architecture, Engineering and

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Construction (AEC) industry (Seiß *et al.*, 2025). Building Information Modelling (BIM) is a transformative process that enhances efficiency, collaboration and sustainability across the AEC industry (USP-Research, 2024). BIM adoption continues to rise significantly, supported by standardisation efforts, national mandates and increasing technological capabilities (buildingSMART International, 2024). However, despite its growing implementation in the design and construction phases, the integration of BIM into regulatory processes, especially building permitting (BP), remains limited and inconsistent (Ullah *et al.*, 2022; Hartmann *et al.*, 2024). In this context, BIM-based BP denotes the use of structured BIM data to support or automate regulatory compliance checks within the BP process, replacing or complementing traditional document-based review practices (Noardo *et al.*, 2022; Ismail *et al.*, 2024). This gap reflects a significant challenge in the broader digital transformation of the construction industry. As highlighted by Urban *et al.* (2024), the transition to BIM adoption in Digital Building Permit (DBP) is technically feasible, but its implementation faces significant institutional, regulatory and technological challenges, as well as societal barriers such as resistance to change, varying levels of digital readiness and limited stakeholder awareness.

International standardisation efforts further underline the need for structured assessment models in DBP. ISO 19650 provides a reference framework for managing information in BIM workflows (ISO, 2018), while initiatives from the EU BIM Task Group and buildingSMART encourage municipalities to evaluate their digital readiness through clear performance criteria (EU BIM TASKGROUP, 2017). The public-sector KPI practices increasingly emphasise metrics, such as processing time, data quality and communication efficiency, illustrating that successful DBP implementation depends not only on technical solutions but also on institutional capacity and administrative performance (Fauth *et al.*, 2024a, b, c, d).

The motivation for this study draws in part from insights generated through an Erasmus + project on “Introduction to BIM and Digitalization”, which collected survey data from project applicants and industry stakeholders in Denmark, Germany, Italy, Portugal and Romania, with no direct participation from municipal BP authorities. The results revealed a notable disparity in the presence of BIM policies among companies across the selected European countries, reflecting variations in the levels of organisational maturity in BIM adoption. Denmark and Portugal reported comparatively high levels of organisational readiness (70% and 76%, respectively). However, these results should be interpreted considering the relatively small number of responses (37 in Denmark and 38 in Portugal), which were largely provided by organisations already engaged in BIM adoption. In contrast, Germany (141 responses) and Italy (27 responses) showed significantly lower readiness levels of around 20%. Romania recorded the lowest readiness rate, at just 12%, based on the largest and most diverse respondent group (131 responses), including a significant share of administrative organisations and therefore likely provides a more representative picture of current practice. The findings also highlighted that many organisations lack structured workflows, trained personnel and investment strategies to support BIM adoption (ROBIM, 2022). The survey findings indicated substantial obstacles to effective BIM adoption, many of which have direct implications for its integration into BP processes. Respondents frequently reported limited competencies, uncertainty about organisational readiness and persistent policy and investment gaps, all of which hinder the development of structured digital workflows needed for regulatory use. Software-related issues, particularly interoperability problems, costs and difficulties selecting appropriate tools, were among the most significant barriers, alongside insufficient training and resistance to shifting traditional practices. Legal and contractual uncertainties, especially concerning data rights and model ownership, further complicate the use of BIM in administrative settings. The software landscape was highly fragmented, ranging from closed systems and openBIM environments to ISO19650-aligned platforms, viewers and analysis tools, reflecting uneven digital maturity and inconsistent support for standardised data exchange. Overall, the findings highlight significant cross-country validation, limited formal BIM policies and inadequate workflow integration, indicating that BIM's role and benefits in processes such as BP remain poorly understood and insufficiently supported by current regulatory frameworks.

In response to these challenges, this study proposes a structured framework of Key Performance Indicators (KPIs) to support systematic benchmarking of BIM-based BP, reflecting different levels of implementation across regulatory, organisational and technological dimensions. The KPIs serve as measurable and comparable criteria that help authorities understand their current digital capabilities, identify operational bottlenecks and prioritise areas requiring investment or policy intervention. By incorporating stakeholder perspectives and validating the indicators through expert interviews, the framework provides practical benchmarks that can guide municipalities in monitoring progress and aligning digital transformation efforts with regulatory needs. The overall objective is to facilitate BP authorities and policymakers to make evidence-based decisions that strengthen interoperability, improve process efficiency and facilitate the wider adoption of data-driven BP practices.

The aim of this research is to establish measurable indicators for evaluating BIM readiness in BP and to bridge the gap between conceptual aspirations and operational implementation. The originality of this work lies in its integration of KPI development with empirical validation through international expert interviews from municipalities and public authorities actively engaged in BP digitalisation.

Accordingly, this study addresses the following research questions (RQs):

RQ1. Which KPIs can effectively evaluate the functioning and maturity of BIM-based BP processes?

RQ2. How do experts from different countries and institutional backgrounds evaluate their applicability and clarity in practice?

RQ3. What similarities and differences can be observed across countries leading in BIM-based BP?

Together, these research questions guide the structure of the study and frame the analyses presented in the subsequent sections.

2. Background

While digitalisation has rapidly advanced within design and construction phases, its implementation in public administrative processes, particularly in BP, remains limited. BP traditionally functions as a regulatory mechanism to ensure that construction projects comply with zoning rules, safety standards and urban development plans (Fauth *et al.*, 2024a, b, c, d; 2025), but its workflows are often fragmented, paper-based and prone to delays. Manual document handling, sequential review cycles and inconsistent communication increase processing times and reduce transparency among authorities, designers and applicants (Fauth *et al.*, 2023). DBP seeks to address these limitations by enabling digital submissions, structured data exchange and new forms of automated verification. Maturity models have become important tools in this transition, supporting public authorities in evaluating digital capabilities, identifying gaps and planning the progression from paper-based to fully DBP systems (Braholli *et al.*, 2025).

Despite considerable progress, research shows that DBP implementation remains uneven. Many initiatives focus on technical validation tasks, while administrative, legal, and coordination-intensive components as well as post-permit phases, such as inspections, remain largely unchanged (Seiß *et al.*, 2025). Bloch and Fauth (2023) emphasise that critical sub-processes such as communication, legal review and multi-agency coordination are still predominantly manual, limiting the overall impact of digitalisation. This highlights the need for structured evaluation tools that capture the full spectrum of BP performance, beyond technical model checks. BIM plays a central role in connecting technical and procedural dimensions. Its structured, information-rich models support automated compliance checking, integration with geospatial datasets, improved traceability and more consistent data reuse, while Geographic Information System (GIS) integration further supports spatial analysis, contextual assessment and interoperability between building- and urban-scale data (Oluwaseun *et al.*, 2025). Recent studies highlight that the integration of blockchain technologies within BIM environments can enhance data management, which supports BP processes where multiple stakeholders interact in complex regulatory workflows (Abrishami *et al.*, 2024). Nevertheless, BIM adoption within BP workflows remains limited and inconsistent, hindered by inadequate institutional frameworks, low public-sector expertise, interoperability issues and perceptions of high implementation cost for smaller projects (Crisan *et al.*, 2024).

Recent studies demonstrate that full DBP workflows are technically feasible. According to Urban *et al.* (2024), it is achievable to redesign the entire BP workflow within a digital, BIM-based framework, piloting automated compliance checking, streamlined neighbourhood hearings, prechecks of BIM models and augmented reality-supported consultations. In South Korea, the development of the KBIM framework integrated into the national BP platform (SEUMTER) further demonstrates the growing integration of automated code checking, BIM model pre-verification step, automated extraction of information directly from BIM models and automated code checking, reducing repetitive manual input and improving the overall process (Kim *et al.*, 2020). Pioneering examples further illustrate this potential: Rotterdam's GeoBIM system supports automated zoning and spatial checks (Hobeika *et al.*, 2022); Finland's Lupapiste platform facilitates Industry Foundation Classes (IFC) submissions (buildingSMART, 2013) and semi-automated validation across most municipalities (KIRA-digi); Estonia's e-construction platform integrates project data, rule checks and communication services (European Commission, 2024; Peet *et al.*, 2025); Singapore mandates BIM submissions for larger project (Teo *et al.*, 2016). Dubai provides an advanced example of mandatory BIM use for BP, requiring model-based submissions for high-rise buildings, large-scale developments and public-sector projects, supported by legal mandates, standardised guidelines and automated quality control procedures (Ismail *et al.*, 2024). Turkey and Slovenia are advancing national strategies to incorporate BIM into regulatory review (buildingSMART International, 2020a, b, c; e-Proje Yönetim Sistemi, 2025). Although these initiatives show the feasibility of BIM-supported BP, they also demonstrate that legal, organisational and technological conditions must evolve in parallel. The presence of a mandate alone does not ensure readiness for model-based review.

Within Europe and beyond, the landscape remains highly diverse. Countries such as Denmark, the Netherlands, Finland and the United Kingdom have developed mature policy frameworks for BIM adoption, while others, such as Italy and Romania, are in earlier stages of implementation (NBS, 2023). Differences persist not only in legislation but also in digital infrastructure, institutional capacity and the extent to which BIM is perceived as relevant to BP. The literature consistently notes that successful DBP implementation requires more than technical tools or legal requirements; it depends on institutional alignment, staff capabilities, workflow integration and measurable performance indicators that capture progress toward digital transformation. Many of the identified BIM readiness challenges also reflect broader social sustainability dimensions, including collaboration among stakeholders, their coordination, institutional capacity and readiness for the digital transformation (Radzi *et al.*, 2025; Maskil-Leitan and Reychav, 2019), which closely align with the United Nations Sustainability Development Goals (SDG) associated with effective institutions (SDG 16), innovation and infrastructure (SDG 9) and sustainable communities (SDG11) (Lavikka *et al.*, 2025).

KPIs therefore serve as essential instruments for evaluating DBP maturity. Traditional construction KPIs focused on cost, time and quality are being complemented by indicators that assess interoperability, data integrity, sustainability and stakeholder collaboration (Chan and

Chan, 2004). Several studies classify BIM-related KPIs into managerial, sustainability-oriented and policy-related domains (Al-Shamayleh *et al.*, 2024), yet research specifically tailored to BP remains scarce. Existing case studies, while informative, are often context-specific and do not provide a harmonised framework that integrates legislative, organisational, procedural and technological dimensions of DBP. Fauth *et al.* (2024a, b, c, d) show that stakeholders prioritise time efficiency and data integrity, reinforcing the need for metrics that reflect both workflow performance and the reliability of digital transformation. Despite these contributions, the literature lacks a comprehensive indicator system capable of assessing DBP readiness across jurisdictions in a comparable and structured manner.

Recent studies conceptualise DBP development as a gradual transition across four maturity levels, ranging from manual paper-based procedures to fully digital workflows supported by BIM and automated rule-checking. At the first level, BP relies entirely on printed documentation and analogue verification. The second level introduces basic electronic submission, typically through PDFs, without structured data exchange. The third level allows partial BIM integration, where models are submitted for review, but compliance checks still require human interpretation. The fourth level represents advanced DBP, characterised by machine-readable rules, automated verification and integrated BIM-based assessment (Shahi *et al.*, 2019; Bloch and Fauth, 2023). Evidence indicates that most countries currently operate within the early to intermediate stages of this spectrum, with fully automated processes still uncommon.

These limitations helped define the research gap within the current body of knowledge. While existing studies provide theoretical and technical solutions, there is still a lack of structured frameworks that municipalities and public authorities can practically use to assess and improve their processes. Many existing studies remain largely conceptual or focus on isolated technical solutions, without offering measurable guidance for addressing organisational readiness, knowledge gaps, coordination challenges or infrastructural limitations. These conditions underline the need for an empirically grounded, multi-dimensional KPI framework capable of assessing digital maturity across regulatory, organisational, procedural and technological dimensions. The present study responds to this need by developing and validating such a framework through international expert interviews, providing a structured basis for evaluating and guiding the transition toward more mature, BIM-supported BP systems.

3. Methodology

The methodology of this study adopts a mixed-methods approach (Figure 1), integrating both qualitative and quantitative research methods (Fellows and Liu, 2015) to capture interpretive depth and empirical comparability in the assessment of BIM-based BP systems (Wieringa, 2014). The qualitative component supports the exploration of institutional practices, regulatory conditions and expert perspectives, while the quantitative component allows structured benchmarking of KPIs across jurisdictions. By combining these approaches, it captures methodological triangulation between expert judgment and measurable performance indicators, strengthening the robustness and analytical validity of the findings. The research design is structured into three sequential phases:

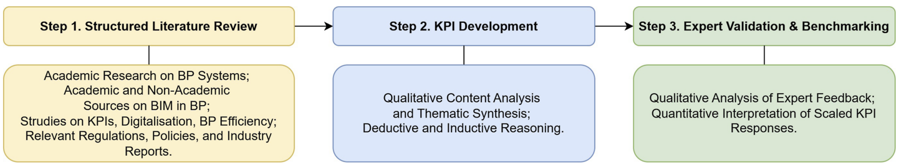

Figure 1. Methodology of the study

(1) Structured Literature Review and Preliminary Analysis;

(2) Development of the KPI Framework through qualitative content analysis and thematic synthesis of relevant literature, regulations and policy documents, complemented by preliminary analytical assessment of current BP practices;

(3) Expert-Based Validation and Benchmarking through qualitative expert interviews with key institutional and technical stakeholders involved in BIM-based BP, designed to refine and validate the identified KPIs.

These steps are illustrated in Figure 1 and further detailed in the following subsection.

The first phase consisted of a structured literature review aimed at establishing the conceptual and theoretical foundations of digital and BIM-supported BP. Academic publications, policy documents, technical reports and industry guidelines were reviewed to identify recurring challenges in BP workflows, existing digitalisation initiatives and prior approaches to performance measurement and maturity assessment. The literature review also informed a preliminary analytical synthesis (University of Illinois Springfield, n.d.; Cooper *et al.*, 2019), in which key concepts related to digital maturity, regulatory readiness, procedural efficiency and technological capability were consolidated. This synthesis provided the conceptual grounding for identifying relevant performance dimensions and informed the subsequent development of the KPI framework.

The second phase focused on developing the KPI framework, and the method followed a qualitative content analysis (Laumann, 2020) combined with thematic synthesis, an approach commonly applied in indicator and framework development research. Relevant literature, regulations and policy documents were systematically analysed to extract recurring themes, constraints and performance criteria associated with digital and BIM-based BP processes. The document analysis was guided by an earlier developed taxonomy of BP (Fauth *et al.*, 2024a, b, c, d), which categorizes the systems into four main subsystems: legislative, organisational, procedural and technological; and served as the conceptual foundation for structuring and organizing the proposed KPIs, which directly underpins the presentation of results in Section 4. The indicator development (Belcher *et al.*, 2024) combined: 1) deductive reasoning, drawing on established concepts and indicators identified in the literature (Johnson-Laird, 2010) and ii) inductive reasoning, allowing additional criteria to emerge from the document analysis and preliminary assessment of current BP practices (Hayes *et al.*, 2010). The outcome of this phase was a preliminary KPI framework, including indicator definitions, measurement logic and alignment with specific BP subsystems, which was subsequently subjected to expert validation.

The third phase consisted of qualitative expert interviews designed to refine, validate and benchmark the proposed KPIs. The expert selection criteria required participants to be representatives from a municipality, directly involved in BIM-based BP processes or to have experience with related pilot projects. All participants were directly involved in or had substantial prior experience with BIM-based BP processes or pilot projects, ensuring both practical relevance and cross-contextual comparability. However, these specific selection criteria considerably limited the number of eligible experts available for participation at a global scale, as not many municipalities have practical experience with BIM-based BP processes. A total of seven semi-structured expert interviews were conducted with representatives from municipal authorities across Vienna, Austria (VieAUT); Ontario, Canada (OntCAN); Dubai, UAE; Estonia; Helsinki and Vantaa, Finland; and Vila Nova de Gaia, Portugal. In the case of Estonia, the responses reflect the national context rather than a single municipal authority. The semi-structured interview guideline focused on the relevance and clarity of individual KPIs, their applicability in real BP contexts, the feasibility of data collection and measurement and context-specific interpretations and limitations. Experts were also asked to provide scaled assessments of selected KPIs based on their institutional context. Interview data were analysed qualitatively to capture interpretive insights, while the scaled responses were analysed quantitatively to support comparative benchmarking across countries, forming the basis of the comparison table presented in Section 5. By combining qualitative expert feedback with structured KPI scoring, this phase supported both validation of the framework and systematic comparison of BP maturity levels across jurisdictions. Following the initial interviews, a second validation round was conducted to review and confirm additional KPIs proposed by the experts, ensuring their relevance, clarity and alignment with the overall framework.

4. KPI framework development

Based on the literature review, a preliminary KPI framework was developed through qualitative content analysis and thematic synthesis, integrating deductive and inductive reasoning. The KPIs were organised into legislative, organisational, procedural and technological subsystems. Table 1 presents the indicators prior to expert validation, including definitions, measurement units and corresponding sources, distinguishing literature-based KPIs from expert-derived contributions.

Expert validation and benchmarking combined qualitative assessment of expert feedback with quantitative interpretation of scaled KPI responses. Overall, the experts confirmed the conceptual validity of the framework and supported its four-subsystem structure. However, several interviewees initially expressed uncertainty regarding whether specific indicators referred to general digitalisation or specifically to BIM-based BP. This feedback highlighted the need to clearly distinguish between administrative digital maturity and BIM integration within the KPI framework.

The first set of KPIs addresses the legislative subsystem, which captures the formal conditions required for BIM-based BP, focusing on the extent to which national and local regulations accommodate digital workflows and model-based submissions. It evaluates indicators addressing whether BIM submission is mandatory for specific project types, the presence of official regulations or guidelines explicitly referring to BIM in BP procedures and the degree to which building codes are formulated in a measurable and machine-readable manner. To reflect different levels of regulatory maturity, the archiving indicator was split into two components, distinguishing between legal provisions for digital document archiving and the legal recognition of BIM models as archivable permitting records. For example, the existence of mandatory BIM submission requirements, as implemented in initiatives such as CORENET X in Singapore (Government of Singapore, 2025), reflects an advanced level of regulatory readiness, while national guidance frameworks such as Finland's COBIM illustrate how regulatory clarity supports consistent implementation (Construction21, 2017). In addition, indicators addressing the measurability of building codes and the legal definition of model ownership highlight that technical feasibility alone is insufficient in the absence of enforceable legal structures. Together, these KPIs emphasise that regulatory maturity must precede large-scale automation and that legal clarity remains a critical prerequisite for interoperable and reliable BIM-based BP systems.

The organisational subsystem focuses on institutional readiness by focusing on governance structures, staff competencies and managerial commitment within public authorities responsible for BP. The KPIs at this level assess whether organisations have established internal BIM guidelines, invested in systematic staff training and engaged in research or pilot initiatives related to DBP. Indicators such as the implementation of institutional BIM guidance reflect whether authorities have formalised BIM requirements in their internal processes, while training-related KPIs measure the extent to which personnel are equipped with the necessary competencies to support model-based workflows. In addition, organisational involvement in DBP research and development initiatives indicates strategic commitment beyond routine operations, signalling whether digital enabling is treated as a long-term institutional objective rather than a short-term technical upgrade.

Table 1. Proposed KPI framework for assessing DBP maturity

Level	ID	KPI name	Description	Measurement unit	Reference/Source
Legislative Level	L1A	Archiving Provision for Digital Documents	Whether national/regional regulations allow/mandate long-term digital archiving of BP documents (e.g. PDFs, scanned drawings)	Binary (Yes/No)	TalEST; (Rakennusteollisuus RT, 2026)
	L1B	Archiving Provision for BIM Models (IFC or others)	Whether model-based submissions (e.g. IFC, proprietary formats) are legally recognised and archivable in digital archives	Scale (0–4); 0: Not recognised; 1: Planned; 2: Discussed; 3: IFC only; 4: Open + proprietary formats	TalEST; (Lavikka and Kallinen, 2024)
	L2	Digital Submission Enablement in Law	Whether digital submissions are accepted as valid (vs. paper)	Scale (0–4); 0 Not started; 1 Planned; 2 Initiated; 3 Partially implemented; 4 fully implemented	Ullah *et al.* (2022)
	L3A	Mandatory BIM Submission Requirement	Whether BIM is required for submission (and for which project types)	Binary/Scale	CORENET X Initiative Singapore (Urban Redevelopment Authority, 2023)
	L3B	Voluntary BIM Submission Uptake	Proportion of voluntarily submitted BIM-based permits	Scale	City of Vienna (2020)
	L4	Inclusion of BIM in official Regulations	Quality of national regulations/guidelines mentioning BIM in permitting	Scale Unit 0: not; 1: initial documents; 2: very clear guidelines	(buildingSMART Finland, 2012; buildingSMART International, 2020a, b, c)
	L5	Measurability of Building Codes	Extent to which codes contain clearly defined, checkable rules	%	Ullah *et al.* (2022), TalEST
	L6	Machine-Readable Code Availability	Percentage of building codes published in digital formats (XML, JSON, etc.)	%	Fauth *et al.* (2024a, b, c, d), EU Construction Strategy
	L7	Regulatory Flexibility Score	Extent to which legal system accommodates pilots, open standards	Scale 0–4	buildingSMART International (2025)
	L8	Legal Clarity on Model Ownership	Existence of ownership/responsibility provisions for BIM models	Scale/optional/low priority	Ardani *et al.* (2021)
	L9	Legal Validity of Automated Compliance Checks	Whether automated rule-check results are recognised in legal decision-making	Binary/Scale	TalEST
	L10	Existence of Regulatory Data Standards	Existence of national/regional regulation mandating data standards for BP, enabling interoperability and automated code checking	Scale 0–4	OntCAN

(*continued*)

Table 1. Continued

Level	ID	KPI name	Description	Measurement unit	Reference/Source
Organisational Level	O1	Implementation of Institutional BIM Guidelines	Extent to which BP institutions apply structured BIM modelling or documentation requirements	% of authorities with internal BIM guidelines	Survey data, (EU BIM TASKGROUP, 2017); Municipal BIM Guidelines (Finland) (buildingSMART Finland, 2012)
	O2	Implementation of Staff Training in BIM	Percentage of BP personnel trained in BIM methodologies, workflows, and relevant tools	% of BP staff training (basic/advanced)	Rava2/Rava 3 Pro project (KIRAHub, 2023a, b; Ullah *et al.*, 2022; SmartMarket Report, 2012; Crisan *et al.*, 2024)
	O3	Platform Availability for BIM Submission	Existence of platforms for receiving digital/BIM files	Binary	buildingSMART International; Lupapiste case Solibri (2024)
	O4	Participation in DBP R&D Initiatives	Level of organisational engagement in R&D or pilot projects for DBP development	Scale (0–3): 0: not important; 1: considering; 2: important but not participating; 3: important and participating	KIRA-digi (n.d.), KIRAHub (2023a, b), Crisan *et al.* (2024)
	O5	Performance-Based Approval through Modelling	Extent to which BP decisions rely on performance-based evaluation using modelling and simulations, rather than fixed prescriptive requirements	Scale (0–3): 0: not important, 1: considering; 2: important but not participating, 3: important and participating	OntCAN
Procedural Level	P1	Average Processing Time	Time between submission and approval	Days	Fauth *et al.* (2024a, b, c, d), Pärn *et al.* (2023)
	P2	Error Reduction Rate	Percentage reduction in errors in BIM-based vs. paper-based submissions	%	Ahmad *et al.* (2018)
	P3	Application Revision Cycles	Average number of iterations before approval	Count	Survey responses
	P4	File Format Consistency	Percentage of files in standard open BIM formats (e.g. IFC)	%	ISO (2018); Järvenpää case, online BP systems
	P5	IFC-Based Submission Rate	Proportion of submitted BP applications that include an IFC model	%	Lavikka and Kallinen (2024)
	P6	Municipal Digital Workflow Adoption	Percentage of BP bodies using online platforms for submission, review, and communication	%	(ACCORD, 2024)
	P7	Level of Automation in Regulatory Checks	Degree to which code compliance and rule verification are automated in the BP review process	Checks completed/total checks (est.)	Solibri Model Checker usage (Finland)
	P8	User Satisfaction Score	Proportion of users expressing satisfaction with DBP service (e.g. thumbs up/down)	%	TalEST

(*continued*)

Table 1. Continued

Level	ID	KPI name	Description	Measurement unit	Reference/Source
Technological Level	T1	Existence of E-BP Platform	Whether an electronic BP platform is operational	Binary	EU BIM TASKGROUP (2017)
	T2	BIM Integration Level in Platform	Degree of integration of BIM models into the permitting platform	Scale (0–5)	Pärn *et al.* (2023), Ullah *et al.* (2022)
	T3A	Data Availability: 3D Environment	Extent to which 3D city models (e.g. CityGML, mesh) are used in permitting	% of municipalities with 3D models	City-level initiatives and (Puttonen, 2021)
	T3B	Data Availability: 3D Zoning Plan	Availability of zoning/master plans in digital 3D or machine-readable format	Binary or Pilot/Partial/Full	TalEST
	T4	Automated Rule-Checking Availability	Availability of automated code compliance tools	Binary	Ismail *et al.* (2023), Al Nama and Alalawi (2023), Lee (2024), Building and Construction Authority (BCA, 2025)
	T5	Compliance with Open Formats and Interoperability	Support for open data formats in BP workflows (e.g. IFC, CityGML, XML)	Binary	ISO (2018), KuntaGML, (Kolbe, 2009)
	T6	User-Friendliness of Digital Systems	Perceived ease of use of digital systems by applicants and authorities	Scale (0–5)	TalEST
	T7	Use of AI in Permitting Tools	Use of AI-driven tools to support permitting processes	Binary/Scaled	TalEST
	T8	Availability of Municipal/Provincial Digital Twin	Availability and active use of municipal digital twin (DT) integrating GIS, and regulatory data to support BP and planning decisions	Scale (0–4) 0: No DT available 1: Pilots/partial prototypes in testing 2: DT exists but limited in scope (e.g. only zoning or environment) 3: Comprehensive DT for planning and BP (covering BIM + GIS + regulatory layers); 4: Fully operational DT	OntCAN

The procedural subsystem focuses on the operational performance of BP workflows, addressing efficiency, transparency and overall process quality. The KPIs in this category capture how digitalisation and BIM integration affect day-to-day BP handling, including application handling, internal coordination, communication efficiency and error management. Core indicators include processing time between submission and approval, frequency of application revision and the proportion of submissions that include BIM models, such as IFC-based applications. Additional measures assess the extent to which municipalities have adopted digital platforms to manage submissions, review and communication tasks. Together, these indicators facilitate systematic assessment of procedural maturity and highlight structural constraints in jurisdictions where digital transformation remains partial or uneven.

Finally, the technological subsystem addresses the digital infrastructure underpinning BP, capturing the extent to which systems support interoperability, automation and model-based workflows. The KPIs at this level examine the degree of BIM integration within BP platforms, the availability of three-dimensional spatial data such as city models and the extent to which automated rule-checking tools are deployed in practice. In addition, the indicators assess compliance with open data standards and interoperability requirements, reflecting whether BP systems are designed as closed solutions or as components of a broader digital ecosystem. By distinguishing between mere tool availability and actual operational use, this subsystem highlights the difference between nominal adoption and functional maturity in DBP implementations.

Expert validation led to targeted refinements and extensions of the KPI framework, improving its practical relevance. At the legislative level, the experts emphasised the need to distinguish archiving provisions for digital documents (L1A) from those for BIM models (L1B), highlighting differences in legal recognition of PDFs versus model-based submissions. The experts further emphasised the measurability of building codes (L5) as a prerequisite for automated compliance checking. In addition, two legal indicators were introduced: the legal validity of automated compliance checks (L9), addressing whether automated results carry binding authority in BP decisions, and the existence of regulatory data standards (L10), capturing formal preconditions for interoperability and automation. At the organisational level, performance-based approval through modelling (O5) was added to reflect a shift from prescriptive to outcome-oriented compliance. At the procedural level, user satisfaction (P8) was included to capture service quality from the applicant perspective. At the technological level, the experts highlighted user-friendliness (T6), exploratory use of AI tools (T7) and the availability of DTs (T8) as emerging indicators of operational maturity. Together, these additions demonstrate the value of expert input in capturing critical dimensions of BIM-based BP that have not yet been systematically addressed in the literature.

5. Expert-based KPI reflection and benchmarking

Building on the previously developed KPI framework, expert validation highlighted several cross-cutting issues related to indicator clarity and practical assessment. Concerns related to measurability emerged repeatedly, particularly for procedural indicators such as processing time and error reduction. Where logs, dashboards or internal monitoring systems were absent, expert responses were based on estimation rather than recorded performance data. Experts emphasised that one of the benefits of structured KPIs is precisely their ability to expose the absence of performance monitoring as an indicator of immaturity.

The resulting benchmarking values for each indicator are shown in Table 2. This section synthesises expert feedback and highlights structural patterns identified across legislative, organisational, procedural and technological dimensions. Important to note is that several responses were difficult for the interviewees to precisely quantify, and some of the provided values were therefore based on estimations. Such estimated values are indicated in the text either by the symbol "~" to represent appropriate values or by numerical ranges (e.g. X-Y) where a precise value could not be determined. In a limited number of cases, participants

Table 2. Consolidated framework of validated KPIs per subsystem

Level	ID	KPI name	Tallinn, EST	Helsinki, FIN	Vantaa, FIN	Vienna, AUT	Gaia, PRT	Dubai, UAE	Ontario, CAN
Legislative Level	L1A	Archiving Provision for Digital Documents	Yes	Yes	No	Yes	Yes	Yes	Yes
	L1B	Archiving Provision for BIM Models (IFC/ others)	3	3	2	2	3	4	0
	L2	Digital Submission Enablement in Law	4	4	4	4	4	4	4
	L3A	Mandatory BIM Submission Requirement	No	Yes, 2–3	3	No	No, 1	4	0
	L3B	Voluntary BIM Submission Uptake	Yes	Yes, 2–3	Yes, 3	Yes, 2	Yes, 4	Yes, 4	1
	L4	Inclusion of BIM in Official Regulations	1	Yes, 1	Yes, 1	Yes, 2	Yes, 1	Yes, 2	No
	L5	Measurability of Building Codes	35%	~50%	30%	58%	6%	70%	100%
	L6	Machine-Readable Code Availability	35%	–	~15%	80%	0%	70%	100%
	L7	Regulatory Flexibility Score	3	3–4	0	1–3	1	2–3	1
	L8	Legal Clarity on Model Ownership	Low priority	4	4	3	0	0	1
	L9	Legal Validity of Automated Compliance Checks	No, 0	Yes, 3	No	No	No, 0	No, 0	No, 0
	L10	Existence of Regulatory Data Standards	1	NA	NA	0–3	0	NA	0–1
Organisational Level	O1	Implementation of Institutional BIM Guidelines	10%	50%	0%	0%	0%	100%	0%
	O2	Implementation of Staff Training in BIM	>80, basic	100%, basic	10% basic	<10% advanced	~5–10%	60%	20%
	O3	Platform Availability for BIM Submission	Yes	Yes	Yes	No	Yes	Yes	No
	O4	Participation in DBP R&D Initiatives	3	3	3	3	3	2	2–3
	O5	Performance-Based Approval through Modelling	2	NA	NA	1	2	NA	2–3

(*continued*)

Table 2. Continued

Level	ID	KPI name	Tallinn, EST	Helsinki, FIN	Vantaa, FIN	Vienna, AUT	Gaia, PRT	Dubai, UAE	Ontario, CAN
Procedural Level	P1	Average Processing Time	45 days	~88 days	~31 days	~90 days	~30–90 days	3 days	NA
	P2	Error Reduction Rate	30%	NA	~0%	~20–40%	~40–50%	~50–70%	80%
	P3	Application Revision Cycles	3–4	NA	~3	1–2	4	3	6
	P4	File Format Consistency	100%	~5–10%	–	0%	1%	100%	0
	P5	IFC-Based Submission Rate	1%	~5–10%	0	0%	1%	~10%	0
	P6	Municipal Digital Workflow Adoption	100%	100%	100%	4%	100%	100%	>50%
	P7	Level of Automation in Regulatory Checks	9.7%	~5–10%	0	NA	0	70%	1%
	P8	User Satisfaction Score	planned	100%	72%	80%	80–85%	95%	90%
Technological Level	T1	Existence of E-BP Platform	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	T2	BIM Integration Level in Platform	5	5	1	0	5	4	0
	T3A	Data Availability: 3D Environment	100%	~50%	NA	100%	Yes, 10%	20–30%	0
	T3B	Data Availability: 3D Zoning Plan	Pilot	Pilot	Partial	Pilot	Pilot	Pilot	Pilot
	T4	Automated Rule-Checking Availability	Yes	Yes	No	Yes	No	Yes	Yes
	T5	Compliance with Open Formats and Interoperability	Yes	Yes	Yes	No	Yes	Yes	No
	T6	User-Friendliness of Digital Systems	4	~4	2	4	5	5	4
	T7	Use of AI in Permitting Tools	No	No	No	No	No	Yes	No
	T8	Availability of Municipal/Provincial Digital Twin	3	NA	NA	3–4	1	NA	NA

verified the information internally and provided updated responses after the interview. This also contributed to the decision to conduct a second round of validation.

5.1 Legislative reflection and benchmarking

At the legislative level, the interviews revealed moderate variation across jurisdictions (Table 2), particularly regarding the legal treatment of BIM-related processes. While digital submission (L2) is widely accepted, differences occur in the legal recognition of BIM models, archiving practices and regulatory flexibility.

Archiving provisions (L1A & L1B) exposed an early conceptual gap. Experts repeatedly distinguished between the archiving of digital documents and legal archiving of BIM models, noting that many authorities support the former without formally recognizing the latter. Separating these aspects was critical for an accurate assessment of legislative maturity.

Acceptance of digital submission (L2) showed stronger convergence. All countries reported operational digital submission channels; however, legal nuances remain. Finland continues to BP paper-based filing despite negligible use, with legislative reform planned for 2026. Experts emphasised that electronic filling does not equate to digital maturity when submissions remain limited to PDFs.

Mandatory BIM submission (L3A) revealed notable differences across countries. Estonia, Ontario, Vila Nova de Gaia and Vienna, reported voluntary submission (L3B) only. In Dubai, BIM requirements were first introduced in 2014 through Circular 196, focusing on large and high-rise projects as well as certain public sector developments (CMS, 2017). This scope was later expanded, and since January 2024 (Circular 9-1-2) BIM-based submissions have been required for BP for large and tall buildings, buildings above 20 stories, special-use facilities such as hospitals and universities and public-sector projects (buildingSMART International, 2025; CMS, 2017). Finland confirmed forthcoming national requirements under the new Construction Act (Rakennusteollisuus RT, 2026), although with concerns regarding municipal readiness. Vila Nova de Gaia confirmed postponement of national implementation to 2030 due to political change. Across jurisdictions, the experts affirmed that mandatory submission acted as the strongest accelerator of institutional adaptation.

The inclusion of BIM in official regulations and guidelines (L4) is present across nearly all jurisdictions, with Ontario representing the sole exception. Differences therefore relate primarily to the level of detail and operational clarity rather than formal inclusion. Vienna provides detailed publicly available guidelines on Level of Geometry (LoG) and Level of Information (LoI), while other contexts, including Helsinki and Vila Nova de Gaia, reported fragmented or limited documentation. The Estonian interviewee (TalEST) emphasised that the quality and precision of regulatory guidance are critical for effective BIM-based BP, noting that technical standardisation alone does not resolve ambiguity. The experts further highlighted that variations in IFC implementations across different native tools (e.g. Archicad, Revit) often contain different “dialects” complicating validation.

The measurability of building codes (L5) and machine-readable codes (L6) also highlighted major gaps. Vienna and Dubai reported higher proportions of codified rules, whereas Vila Nova de Gaia reported low formalisation. Ontario represents a distinct case: although automated checks are implemented within the BP platform, this is not based on machine-readable legislation, but on structured rule interpretation embedded in software tools such as TRAX, where regulations remain available only as PDFs. Ontario experts emphasised that the primary barrier to automation is not technical capacity but inconsistent human interpretation of codes across municipalities, which undermines trust in automated outcomes. Across interviews, experts agreed that the depth of automation is ultimately constrained by legal clarity and interpretative consistency rather than software capability alone. In the case of Helsinki (L5), the results were estimated, similarly to Vantaa (L6).

Regulatory Flexibility (L7) followed national governance models. Helsinki and Estonia reported moderate flexibility for piloting. Vila Nova de Gaia described its system as largely inflexible, as municipalities cannot impose requirements beyond national law. Vienna demonstrated flexibility through a beta phase for DBP experimentation without regulatory change. Experts stressed that legal adaptability directly affects implementation spread.

The model ownership and liability (L8) remained non-regulatory across all systems. Experts affirmed BIM ownership is contractual rather than procedural. In Finland and Vienna, ownership and usage rights are clearly regulated by intellectual-property law and contractual agreements, with IFC models generally considered low-risk for sharing. In Vila Nova de Gaia and Dubai, municipal authorities focus on archiving submitted materials and do not provide specific guidance on ownership. In Estonia, expressed "low priority", as currently the ownership is mainly a contractual matter in public procurement and is considered largely irrelevant to the BP decision itself.

The legal recognition of automated compliance checks (L9) remains limited across jurisdictions. Only Helsinki reported partial legal acceptance of automated results, while in all other cases the final BP decision continues to rest with a human authority, regardless of the level of automation applied. Automated tools are therefore primarily used as decision-support mechanisms, flagging potential non-compliance rather than producing legally binding outcomes. Interviewee from Vantaa highlighted the lack of transparency in commercial rule-checking tools and the absence of legal precedent as key barriers to granting automated checks formal legal status.

Finally, the existence of regulatory data standards (L10) emerged as a critical KPI due to their role in enabling interoperability and automated rule-checking. While most jurisdictions reported some form of structured data requirements, experts identified semantic inconsistency as a major bottleneck. Differences in naming conventions, classifications and terminology were described as limiting interoperability, even within otherwise integrated permitting platforms. Vienna's Information Delivery Specification (IDS)-based initiative defining required LoG and LoI was highlighted as a promising step toward standardisation; however, it remains voluntary and is not yet anchored in binding regulation.

5.2 Organisational reflection and benchmarking

The organisational level showed high variance across the responses. Institutional BIM guidelines (O1) represented substantial variations. Dubai reported a fully established system supported by official standards and guidelines that applies to both internal staff (BP engineers) and external users (designers and consultants). Estonia reported active ambitious targets, stressing that internal guidelines are as crucial as external legislation for ensuring that BP authorities can consistently handle BIM-based submissions. Interviewees in Ontario, Vantaa, Vila Nova de Gaia and Vienna reported no formal institutional BIM guidelines in place (0%), despite increasing internal awareness and preparatory work. Vila Nova de Gaia has been working since 2018 on developing such guidelines by analysing submitted IFC models to identify recurring issues, but no official implementation has yet been adopted.

Implementation of staff training in BIM (O2) followed similar patterns. Estonia and Helsinki reported near-universal competency. Dubai reported structured training programmes. Ontario reported limited BIM training coverage (≈20%), with a clear emphasis on navigation and model-based review skills rather than modelling or authoring capabilities. Vantaa, Vienna and Vila Nova de Gaia reported limited coverage.

The results show that while most jurisdictions reported platform support for BIM-based submissions (O3), Vienna and Ontario confirmed the absence of an operational BIM-based BP platform. Vienna confirmed transitional infrastructure via internal servers; IFC models are currently accepted via a secure internal cloud environment, but the dedicated DBP platform is still under development. Estonia reported full national coverage. The experts warned that uploading a model does not constitute a model-based workflow if no system consumes or validates the data.

The research and development initiatives (O4) are correlated with maturity. Authorities engaged in pilot projects reported higher readiness. Vila Nova de Gaia reported active involvement in the CHEK project, alongside collaborations with universities and software developers to pilot automated project-checking solutions (CHEK, 2025). Vantaa highlighted its participation in initiatives such as KiraHub and other professional development groups to remain aligned with evolving practices (KIRAHub, 2023a). Dubai indicated indirect participation mainly through buildingSMART UAE, as well as engagement in international discussions, conferences and webinars, though without involvement in major pilot projects.

Performance-based approval through modelling (O5) reflects a shift from prescriptive, rule-based compliance toward outcome-oriented evaluation. Estonia identified this approach as particularly valuable for assessment such as daylight access. Vienna recognised the potential benefits but reported no current application. Experts argued that true digital maturity evolves from perspective to performance logic.

5.3 Procedural reflection and benchmarking

At the procedural level, experts broadly agreed on the relevance of the proposed KPIs but repeatedly raised concerns about measurability. A common difficulty was estimating the average processing time (P1) from submission to approval because this is strongly influenced by the number of resubmissions, design errors and incomplete documentation provided by applicants. The most accelerated example came from Dubai, where policy requires a response to BIM-based submissions within three days. Fully compliant CAD drawings, BIM models and documents can be approved within this window, sometimes even faster. Large or complex projects typically require several correction rounds, but each resubmission is still reviewed within the same three-day timeframe. Vantaa reported a shorter average of 31 days and highlighted that from 1 January 2026 a new processing time guarantee will apply. Helsinki reported three months on average. In Vienna, approval time varies from a few days for minor alterations, to around three months for single-family houses and up to two years for large, complex projects. Ontario showed wide internal variation. Experts expressed that most delays are due to submission quality rather than review speed.

Another KPI addressed the reduction of errors (P2) achieved by moving from paper-based to digital or BIM-based submissions. The responses varied significantly. In Vienna, no formal measurements exist, but experts estimate that strict BIM requirements already reduce errors by approximately 20–40%, as many submissions are returned for correction. In Dubai, the BIM mandate is still too recent for reliable quantification, though officials anticipate potential reductions of 50–70% once automated checking is fully implemented. The Ontarian expert suggested that with fully coordinated digital submissions, error reduction could reach 80%, since many current issues arise from inconsistencies across separately submitted documents.

Given the clear link between revisions and overall processing time, the KPI Application Revision Cycle (P3) was introduced to capture the average number of iterations before final approval. Canada reported the highest figures, around six iterations on average, followed by Vila Nova de Gaia, now legally limited to prevent prolonged negotiations. Estonia reported 3–4 iterations, aiming to reduce this to 1–2 cycles for BIM-based BP. Vantaa similarly reported about three with occasional peaks up to seven. Dubai also reported three iterations, though CAD drawings remain the primary legally binding record during this transition phase. In Vienna, small projects may require no revisions, while larger ones typically involve 1–2 iterations, with the highest case reported as fewer than 10. Experts consistently highlighted the central role of revision cycles in overall processing time.

File-Format Consistency (P4) remained low in most jurisdictions. Vantaa, Vienna, Ontario and Vila Nova de Gaia reported minimal use of IFC in statutory workflows, with most submissions still provided as PDFs. Voluntary IFC pilots in Vienna account for roughly 30% of test cases but are not used for formal BP processing. In contrast, Estonia and Dubai require IFC; when BIM is used, achieving full consistency in those specific project categories.

IFC-Based Submission Rate (P3) likewise remains low across jurisdictions. Vantaa and Vienna remain effectively at zero for statutory cases, while Estonia reported about 1%, due to voluntary adoption. Dubai reported about 10%, corresponding to the limited share of projects covered by its BIM mandate.

Responses regarding Digital Workflow Adoption (P6) indicated near-complete adoption in most cases, but with notable exceptions. Ontario's large municipalities use DBP comprehensively, while smaller ones show partial adoption. Vienna's internal processing is fully digital, yet fewer than 4% of applications are submitted digitally. Vantaa classified its workflow as "electronic rather than digital", since uploaded models cannot yet be natively processed.

Automation of regulatory checks (P7) indicated the greatest gap across countries. Vantaa and Vila Nova de Gaia have no automated checks beyond basic GIS queries. In Ontario, a few municipalities have started experimenting with automatic zoning compliance checks, suggesting an emerging but still modest trend. Helsinki automates approximately 5–10% of selected rules, with expectations for growth after the 2026 decree. Estonia reported 47 automated checks out of approximately 500 regulatory items. Dubai reported the most advanced stage, with around 70% of rules implemented as automated compliance checks in the BP platform. Experts repeatedly noted that automation remains the clearest procedural marker of digital maturity.

Finally, user satisfaction (P8) provided additional insight into procedural usability. Scores ranged from relatively low in Vantaa (≈72%) to higher levels reported in Vienna (≈80%), Vila Nova de Gaia (≈80–85%), Ontario (≈90%), Dubai (≈95%) and Helsinki (≈100%). The experts agreed that satisfaction reflects not only platform usability but also reliability of communication, clarity of requirements and transparency of review stages.

5.4 Technological reflection and benchmarking

Technological indicators revealed some disparities in platform maturity, data environments, interoperability and the functional use of digital tools across jurisdictions (Table 2). Although electronic BP platforms (T1) exist across all cases, their capacity to support BIM-based workflows varies significantly. In Ontario and Vienna, BIM integration remains indirect, relying on external file exchange rather than platform-native processing. In contrast, Helsinki, Estonia and Vila Nova de Gaia reported more advanced technical integration, with Estonia emphasizing the combined use of reference BIM models and national GIS-based DT data. Integration of BIM into BP platforms (T2) showed clear stratification. Dubai, Helsinki and Estonia ranked highest, with direct BIM-based review, while Helsinki and Vila Nova de Gaia showed technical readiness with limited operational use. Ontario, Vienna and Vantaa remain reliant on indirect exchange or basic storage. Experts emphasised that platform availability alone does not constitute effective BIM integration.

Availability of 3D city models (T3A) further illustrated uneven technological maturity. Estonia and Vienna reported operational 3D environments linked to BP, while Dubai applies city-scale models mainly for visualisation. Finnish cities have advanced models but limited regulatory use, and Ontario currently does not use 3D city models in BP processes. Similarly, 3D zoning and master plans (T3B) remain largely experimental. Estonia and Vienna reported pilot uses but emphasised limits in translating zoning rules into 3D. Vila Nova de Gaia relies on a 2D regulatory portal, and Dubai's zoning data are not machine-readable. Experts consistently identified planning instruments, not technology, as the primary constraint.

Automated rule-checking (T4) was widely reported as available, although implementation was not universal, with two jurisdictions indicating that such functionality is not currently in place. Vila Nova de Gaia and Vantaa reported no automated compliance verification beyond simple GIS checks, while Helsinki and Vienna remain at partial or pilot stages. Estonia has implemented a limited set of automated checks (47 out of roughly 500), while Dubai leads with large-scale rule automation, combining a fully automated Quality Assurance (QA)/Quality Control (QC) tool for BIM data with an e-checking service that automates approximately 70% of building code rules, all supported by IFC-based interoperability. Across contexts, experts identified automated rule-checking as a key indicator of technological maturity, while also highlighting its strong dependence on legal and data readiness.

Interoperability and compliance with open formats (T5) showed partial convergence. Estonia applies IFC for submissions and CityGML for the DT, representing the most consistent use of open standards. Vila Nova de Gaia and Dubai rely primarily on IFC as their main exchange format. Vienna still relies largely on PDFs but plans to introduce IFC, BIM Collaboration Format (BCF) and IDS. In Finland, technical readiness exists, but practical adoption remains limited.

Several additional technological KPIs emerged inductively from expert input, reflecting practical priorities not fully captured in the initial framework. User-friendliness of digital systems (T6) was highlighted as a critical success factor influencing both applicant uptake and authority efficiency. Ratings were highest in most jurisdictions, only Vantaa reported significantly lower satisfaction due to interface complexity. Vienna noted continuous usability improvements based on user feedback.

The use of AI BP tools (T7) was reported in only a single jurisdiction, indicating that such applications remain exceptional rather than established within current BP practices. Dubai reported piloting an AI-driven chatbot for regulatory queries but has not integrated it into the BP process. Helsinki and Vantaa are exploring funding options for small-scale automated assessments. Vienna previously tested AI in its BRISE project but is revising its approach in response to rapid technological advances.

Finally, availability of municipal or national DTs (T8) was recognised as a supporting condition for future integration rather than a current determinant of maturity. Estonia's national DT is already integrated within BIM-based BP, while Vienna has a highly developed twin and plans to incorporate IFC in the next phase. Vila Nova de Gaia remains at an early stage. Across all contexts, respondents agreed that DTs have strong potential to improve planning approvals and decision-making if combined with interoperable data standards.

The findings align with previously reviewed studies, which identified technological, organisational and regulatory readiness as a major barrier to BIM adoption and BP implementation. However, beyond technical interoperability aspects frequently emphasised in the literature, the validation of the framework highlights the importance of institutional coordination, governance structure and broader technological and societal aspects influencing the implementation.

6. Discussion

The objective of this research was to develop and empirically validate a multi-level KPI framework capable of benchmarking BIM-based BP systems across different institutional and national contexts. The objective was achieved through a mixed-methods approach combining literature-based KPI development with expert validation and cross-country benchmarking, integrating qualitative expert judgment with quantitative interpretation of scaled KPI responses to ensure both conceptual robustness and practical relevance. The findings demonstrate that systematic benchmarking of BIM-based BP systems is both necessary and currently underdeveloped. While existing research addresses isolated aspects of DBP, such as BIM adoption, automated rule checking or platform design, integrated benchmarking frameworks that support structured cross-country comparison remain scarce (Ullah *et al.*, 2022). The proposed KPI framework responds to this gap by operationalising digital development across four interdependent subsystems, while expert feedback confirms its value for identifying strengths, bottlenecks and development priorities despite contextual differences between jurisdictions.

These results align with the previous literature that emphasizes the fragmented and uneven progress of DBP (Fauth *et al.*, 2024a, b, c, d; Noardo *et al.*, 2022). Previous studies have identified similar barriers, particularly inconsistent data standards, limited interoperability and the absence of common terminologies. However, by applying measurable KPIs, this study moves beyond descriptive assessments, allowing a more systematic evaluation of readiness and performance across subsystems and countries, while also supporting a better understanding of the organisational and societal implications related to the digital transformation.

In line with prior studies highlighting fragmented and uneven DBP progress, the benchmarking results reveal persistent structural constraints across jurisdictions. Legislative findings show that interoperability challenges often originate from inconsistent terminology and weak regulatory standardisation. Interviewees noted that identical building types may be classified differently across authorities, undermining data exchange even within similar software environments. While some jurisdictions, such as Estonia, have introduced national submission requirements and Vienna has developed IDS-based modelling specifications, these initiatives remain largely voluntary. Other jurisdictions, such as Canada and Vila Nova de Gaia, are still at early stages of addressing semantic consistency. Overall, the findings reinforce the previously identified research gap, namely the absence of legally binding, machine-readable regulatory data standards which continue to constrain automation and cross-system interoperability.

Organisational benchmarking further demonstrated that the findings are consistent with literature, emphasising that regulatory ambition alone is insufficient without institutional capacity. Experts from Vila Nova de Gaia emphasised that many planning rules are formulated at a strategic level and lack the precision required for machine interpretation. In parallel, Finnish interviewees highlighted structural fragmentation, where small municipal units lack the staffing and training capacity needed to sustain digital workflows. These findings support the argument that DBP implementation depends not only on digital tools, but also on administrative scale, governance structures and long-term capacity building. All of these carry broader societal implications for digital transformation within the public sector.

Procedural benchmarking revealed distinct maturity profiles rather than a linear progression. Estonia and Dubai exhibit higher procedural integration supported by clearer submission requirements and automation strategies. Helsinki combines strong e-government infrastructure with emerging automation, while Vienna demonstrates advanced internal digitalisation alongside limited digital intake. Vila Nova de Gaia and Ontario retain hybrid procedures characterised by manual intervention and inconsistent standards. Across all cases, experts emphasised that procedural inefficiencies rarely emerge in isolation, but are typically rooted in upstream legislative ambiguity, missing modelling standards or limited organisational readiness. This reinforces the systemic interdependence of the four KPI subsystems.

Technological benchmarking similarly revealed a stratified landscape. Estonia and Dubai combine integrated platforms with functional BIM-based checks, whereas Helsinki and Vienna possess strong technical foundations that are not yet fully integrated in routine permitting workflows. Vila Nova de Gaia, Ontario and Vantaa remain in transitional states marked by partial integration and fragmented automation. Importantly, experts did not interpret these differences as purely technical shortcomings. Instead, technological maturity was consistently linked to upstream legislative clarity, organisational capability and procedural alignment, reinforcing the interdependence of the four KPI subsystems.

In response to the research questions, the findings directly address the research questions. Firstly, the study demonstrates that effective evaluation of BIM-based BP maturity requires KPIs spanning all four subsystems, confirming that no single dimension sufficiently captures system performance (RQ1). Secondly, expert validation confirmed the relevance of the indicators, while also revealing challenges related to clarity and measurability, particularly for procedural KPIs where performance is influenced by applicant behaviour and contextual variability (RQ2). Thirdly, the benchmarking highlights substantial cross-country variation not only in maturity levels but also in the balance between subsystems, confirming that technological advancement alone is insufficient without regulatory and organisational readiness (RQ3).

The primary contribution of this study lies in shifting the focus from isolated digital capabilities toward a systematic understanding of BP maturity. Rather than portraying digitalisation as linear progression, the benchmarking results reveal differentiated maturity profiles shaped by institutional, legal and organisational conditions. By providing a validated, practice-oriented KPI framework, the study offers public authorities and policymakers a structured tool to benchmark readiness, identify bottlenecks and prioritise targeted interventions.

Several limitations should be acknowledged. The sample size was constrained by the expert selection criteria, which required participants to have direct experience with BIM-based BP processes or involvement in related pilot projects. While this ensured a high level of expertise, it limited the number of eligible participants available for the study. The expert interviews reflect institutional perspectives from specific municipalities and agencies rather than comprehensive national representations. Some of the responses provided during the interviews were based on estimations rather than exact values, reflecting the difficulty of quantifying certain aspects. Additionally, participation in the second validation round was lower, which may have reduced consistency in responses for newly introduced KPIs. Nevertheless, the direct involvement of interviewees in BP practice ensures that the findings are grounded in operational realities and retain strong institutional relevance.

7. Conclusion

The study developed and empirically validated a structured set of KPIs for benchmarking BIM-based BP systems across legislative, organisational, procedural and technological dimensions. Through expert validation and cross-country comparison, the framework translates abstract notions of digital transformation into measurable, practice-oriented indicators that support systematic comparison across institutional contexts.

The benchmarking results reveal substantial variation across countries and subsystems, demonstrating that BIM-based BP performance cannot be evaluated solely through technical indicators alone. While electronic submission is widely adopted, deeper integration of BIM, interoperable data standards and automated compliance checking remains uneven. Experts consistently emphasised that legal clarity, regulatory structure, organisational capacity and staff competencies are decisive factors determining BP performance and scalability.

The primary implication of this study lies in the development and validation of a practice-oriented KPI benchmarking framework that supports evidence-based and measurable evaluation of BIM integration in BP processes. The proposed framework may support municipalities and policymakers through practical implications in evaluating their current level of digital maturity, identifying areas requiring additional investment or organisational support and prioritising implementation strategies according to their local capacities. Academically, the study contributes to addressing the identified research gap by offering a reusable analytical, measurable tool for comparative studies of DBP systems. For practitioners, it clarifies that effective BIM-based BP requires coordinated regulatory, organisational and technical alignment rather than isolated technological adoption, while also highlighting broader societal implications related to institutional capacity and stakeholder collaboration. From a broader societal perspective, the framework contributes to supporting municipalities through identifying and comparing BIM-based BP practices across different jurisdictions, through lessons learned and identifying effective implementation strategies to be adopted. In the long term, such improvements may contribute to supporting broader challenges related to the housing crisis and sustainable urban development. Future research should aim to extend this framework through large-scale quantitative validation across a wider range of municipalities and national contexts to strengthen its generalisability and applicability. As soon as BIM-based BP becomes more widely implemented across different countries, broader datasets may support cross-jurisdictional comparisons. The longitudinal analysis could further investigate how KPI performance evolves over time and how it changes across different levels of readiness and influences the implementation of BIM-based BP. Further investigation should also address the integration of additional sustainability-oriented KPIs, data governance models, automation in compliance checking and interoperability performance. Furthermore, research could investigate the application of the framework beyond BP submission and approval stages could be investigated, by considering broader lifecycle and post-permit processes. Finally, future research may examine how improvements identified through KPI benchmarking translate into broader societal outcomes, including institutional development and sustainability integration and progress toward SDG-related objectives. These additions would strengthen the framework's applicability and support the ongoing shift toward fully integrated BIM-based BP systems.

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This research titled *"Measuring BIM Readiness and Digitalisation in Building Permitting: A KPI-Based Framework"*, was conducted in accordance with applicable ethical standards and relevant institutional and international guidelines. All participants were informed about the purpose of the research and the voluntary nature of participation. Written informed consent was obtained prior to data collection. No personal or sensitive data were collected. All interview data were anonymised, handled confidentially and used solely for research purposes, in line with principles of responsible data management. The authors thank the interviewees for their valuable insights.

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