



BRI Research Series

DIGITAL TRANSFORMATION OF BUILDING PERMITTING

Edited by

Judith Fauth, Dogus Guler, Rita Lavikka,
Francesca Noardo, Peter Nørkjær Gade
and Silvia Mastrolembro Ventura



Digital Transformation of Building Permitting

This book represents an initiative to amalgamate research findings from a diverse array of international perspectives on building permits, addressing their innovation and digital evolution. With a comprehensive approach, the publication endeavours to encapsulate global scientific advancements, practices, and takeaways within the realm of digital building permit systems. Ranging through a diverse set of disciplines, related to the different systems and aspects of digital building permitting, it provides stakeholders and researchers with a comprehensive overview, which should be grasped as a whole to allow for real progress in digitalisation of building permit procedures.

Central to the narrative of the book is the theme of the digital transformation reshaping building permit systems globally. By undertaking an in-depth exploration and examination of best practices, it seeks to furnish readers with a nuanced understanding of the opportunities and challenges inherent in this digital transformation. In consolidating a wealth of knowledge, including best practices and case studies from multiple countries, the book aims to demystify the complex domain of building permit systems. It serves as a comprehensive guide, starting from bothersome tasks, such as breaking down intricate regulations and technicalities into digestible information, thereby facilitating greater accessibility and understanding.

This book significantly contributes to understanding digital building permits from a global perspective. Advancements, projects, and experiences are considered globally to provide the reader with an overview of opportunities and relevant methods to approach building permit digitalisation and innovation (regulations, process, organisational adjustments, legal aspects, 3D data, and software architectures, among others). The book is an essential reading for researchers and professionals with interests in different sectors encompassing the built environment.

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This book series shares similar aims and scope to the journal, *Building Research & Information*, but allows for a deeper discussion, together with more practical material.

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If you wish to contribute to the series then contact the series editor Stephen Emmitt at se394@bath.ac.uk with a short note about your ideas.

Digital Transformation of Building Permitting

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Series Preface

***Building Research & Information* – Research Series** **Series Editor: Stephen Emmitt**

Building Research & Information (BRI) is a leading international refereed journal focused on the entire life cycle of buildings, from inception to designing, engineering, construction and assembly, through the building in use phase, to disassembly and recovery. Unique to *BRI* is a holistic and interdisciplinary approach to a sustainable built environment, centred on the building and its context. This book series shares the journal's philosophy and commitment to high-quality research, providing the space for a more detailed and nuanced exploration of a particular theme. Each book in the series aims to explore the complex and inter-related nature of our sustainable built environment, embracing what? why? how? and when? questions in relation to a specific research theme.

The content of the journal, except for Special Issues, is very much determined by what is submitted to the journal for consideration; and what gets through a rigorous anonymous peer review process. Thus, the content is wonderfully varied, and individual Issues are rarely themed in the way that an edited book can be. The journal content does, however, often suggest the need for further enquiry and exploration that lends itself a little better to a research book format. This research book series is a mechanism that allows the curation of chapters as a themed anthology and builds on the content of the journal. Like any edited collection, difficult decisions must be made about what to include and what to exclude to create books that are integrated around a specific topic. The rationale is to provide unbiased peer-reviewed content by expert authors, championed by the book editor and supported by the book series editor. In this way the book series aims to be fresh and engaging, and by design, not formulaic. We believe that these books will be a valuable starting point for early career academics and readers wanting to discover more about a specific topic. With this book series we hope to further inform and stimulate rapid advances in the performance of our buildings.

The theme of this edited book is the digitalisation of building permit processes for a sustainable built environment. The aim is to amalgamate research findings from a diverse array of international perspectives, addressing a crucial

aspect of digital innovation and transformation in construction. With a comprehensive approach, the contributors have encapsulated global scientific achievements, current practices, and challenges within the realm of building permit systems. Ranging through a diverse set of disciplines, related to the different systems and aspects of digital building permits, the book provides readers with a comprehensive overview of the subject.

The book draws on research conducted around multiple projects in Europe and beyond. Through meticulous examination of research conducted by international experts the book offers unique insights into the intricacies of planning and building permit processes, regulatory frameworks, and the global adoption of digital technologies. Case studies and comparative analyses are used to illuminate different approaches adopted by regulatory authorities. Chapters furnish readers with a nuanced understanding of the opportunities and challenges associated with this digital shift. Collectively, the book functions as a catalyst for international knowledge exchange and collaboration, fostering dialogue among policymakers, urban planners, industry professionals, and researchers from diverse cultural and geographical backgrounds.

In consolidating a wealth of knowledge from many countries, the book aims to demystify the complex domain of building permits. It serves as a comprehensive guide, breaking down intricate regulations and technicalities into digestible information, thereby facilitating greater accessibility and understanding. By providing detailed insights into navigating digital systems and understanding regulatory nuances, the book equips stakeholders with the necessary tools and references to obtain digital building permits effectively. Beyond its informative value, the book also serves as a platform for the dissemination of groundbreaking research to a wider audience. Its broad reach facilitates knowledge transfer and encourages dialogue and collaboration among stakeholders, thereby fostering continuous improvement in the field of building permits globally.

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Foreword to ‘Digital Transformation of Building Permitting’

Rafael Sacks

30 October 2025

Editors Judith Fauth, Dogus Guler, Rita Lavikka, Francesca Noardo, Peter Nørkjær Gade, and Silvia Mastrolembo Ventura, and their international team of authors, have collectively produced this exceptionally informative book on one of the most daunting challenges at the nexus of Building Information Modelling (BIM), Geographic Information Systems, and Artificial Intelligence. Coincidentally, I have recently had the informative yet frustrating experience of procuring a building permit to build a new duplex house in my hometown of Kiryat Tivon, in the north of Israel. Although we have a nation-wide standard digital, online permit application management system, the quantity, complexity, variety, and inconsistency of design requirements rendered the process exceptionally inefficient and dependent on a multitude of people making decisions that at times appeared irrational and arbitrary. There is no doubt that building permitting is in dire need of disruptive innovation.

Yet this is not a simple problem. Digitalisation and innovation of building permit processes was recognised as a target for application of computers to building design and construction since the very early days of BIM. In his landmark 1975 article in the journal of the American Institute of Architects, Chuck Eastman described a future ‘Building Description System’ (BDS) (Eastman, 1975). He wrote:

Designing would consist of interactively defining elements... It should be possible, then, to derive sections, plans, isometrics or perspectives from the same description of elements... Thus BDS will act as design coordinator and analyzer, providing a single integrated database for visual and quantitative analyses, for testing spatial conflicts and for drafting. ... Later, one can conceive of a BDS supporting automated building code checking in city hall or the architect’s office.

This was an incredibly prescient article, and almost all the specific functions that he imagined and described are now available in the plethora of BIM software on the market. Indeed, in many jurisdictions around the world, BIM models are used to support ‘building code checking in city hall or the architect’s office’. However, the word ‘automated’ as an adjective for ‘building code

checking', defines a functionality that we have not achieved 50 years later, neither in industry nor in academic research (Sacks et al., 2025, Chapter 3).

Despite the rich legacy of research efforts with methods such as Case-Based Reasoning, Expert Systems, the Semantic Web, Natural Language Processing, Neural Networks, BIM, Geoinformatics, 3D Cadastre, Graph Representations, and Machine Learning, we still have no comprehensive commercial solutions for generic automated building design and code conformance checking for use in digital permitting processes, neither in city hall nor in the architect's office. It turns out that the complexities of building codes and building designs require forms of intelligent cognition and judgement that remain beyond the scope of our current tools, notwithstanding the impressive recent progress in application of Large Language Models to the problem. Indeed, the Introduction chapter of this book explains the context of modern building permit systems – a mix of legislative, organisational, procedural, and technological issues – that collectively and combinatorially make this such a daunting task for digitalisation and automation.

Thus, this book is timely and an essential resource that establishes the current state of the art in digitalisation and innovation of building permit processes. The editorial and author team is the 'A List' of this subject. Strongly rooted in the European Network for Digital Building Permits (EUnet4DBP) and with collective experience on all major EU research projects dealing with DBP (CHEK – *Change toolkit for digital building permit*, ACCORD – *Automated Compliance Checks for Construction, Renovation or Demolition Works*, and DigiChecks – *Digital environment for management of permits and compliance in building and construction*), the editors have brought together a diverse team of authors from multiple organisations and professional roles (academia, public, and government agencies and the BIM software industry) and from many countries (including Europe and the UK, the Middle East, North America, South America, and Australia) all of whom are at the forefront of efforts to realise innovative digital building permit systems, including the core challenge of automated design and code conformance checking.

Lastly, the Conclusions chapter lays out a prospective research agenda for the coming years. Researchers and software system developers will find this a 'must-read' resource for defining their own work plans.

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1 Introduction

Embracing the Complexity of Building Permit Systems

*Judith Fauth, Rita Lavikka, Dogus Guler,
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Land is an essential resource for humans since the beginning of life. For as long as humans have built shelters and cities on the land, societies have sought to ensure that construction serves the public good. One of the earliest written laws, the Code of Hammurabi (Law 229, circa 1750 BCE) (Hammurabi, 1904), already set forth specific provisions for builders and their responsibility towards occupants: “If a builder builds a house for someone, and does not construct it properly, and the house which he built falls and kills its owner, then that builder shall be put to death”. This underlines the ancient recognition of accountability in the built environment (Richardson, 2004). Its intent was not to burden citizens with regulation but to protect lives, ensure trust, and maintain societal order through clear accountability. More than three millennia later, this original purpose remains at the heart of what we today call building permits (Roth, 1995).

In the centuries since Hammurabi’s decree was carved into stone, the means of regulation have evolved in tandem with social, technological, and architectural progress. Medieval guild systems codified craftsmanship, industrialisation introduced standardised building code, and the twentieth century brought comprehensive zoning and environmental regulations. Natural disasters are one of the main reasons to set these regulations, as the deficiency in the buildings might result in catastrophic consequences. Today, another turning point has been reached: the digitalisation of building permit processes, including the automation of compliance checking (Hettiarachchi et al., 2025; Seiß et al., 2025). This innovation is considered a key enabler for the digital transformation of the construction industry and for the enhancement of its international competitiveness (European Commission, 2023). It should not be limited to the conversion of physical documentation into static digital formats, a process known as dematerialisation that constituted the initial phase of transition to electronic documentation. Instead, there is a need for digitalisation to evolve into a data-driven strategy designed to promote enhanced transparency and effective collaboration across the entire value chain (European Commission, 2024). In this context, the integration of data models, digital twins, and artificial intelligence (AI) possesses the potential to fundamentally redefine the

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conceptualisation, design, and regulatory framework of the built environment. Yet the fundamental question remains unchanged: how can societies best and efficiently ensure that the built structures are resilient, lawful, and sustainable?

The Nature of Complexity

Modern building permit systems represent complex administrative ecosystems. These systems function at the intersection of legislative, organisational, and technological strata, with a substantial reliance on human agency for decision-making processes. The presence of multiple governance levels, encompassing municipal, regional, national, and supranational entities, establishes an intricate network of interdependencies. This complexity is frequently associated with redundant procedural steps, reliance on legacy systems, and fragmented information flows (Fauth et al., 2025).

The observed complexity is not exclusively bureaucratic, but rather systemic (Meacham et al., 2021). Building permits are representative of what is denoted as a socio-technical system, or even a system of systems (Fauth et al., 2024), where the legal complexity inherent to authorisation processes interacts dynamically with the insufficient understanding of the organisational and technological implications of digitalisation (Ullah et al., 2022). The building permit process, in fact, is simultaneously a legal act, a managerial workflow, a technical data exchange, and a social negotiation. Understanding it, requires perspectives that cross disciplinary boundaries—from civil engineering, architecture, and computer science to law, public administration, and social sciences.

Understanding the System through Taxonomy

Building permit systems operate at the intersection of several intertwined dimensions—legislative, organisational, procedural, and technological. Together, they form a taxonomy that helps to grasp their inherent complexity (Fauth et al., 2024). The legislative dimension provides the normative framework of rules and standards that safeguard public interests but also generate overlaps across governance levels. The organisational dimension reflects how authorities, professionals, and citizens interact within institutional hierarchies, shaping whether procedures function collaboratively or bureaucratically. The procedural dimension translates these norms into workflows, revealing the balance between transparency, efficiency, and discretion in everyday practice. Finally, the technological dimension acts as a fundamental driver and accelerator for the preceding aspects, facilitating the embedding of regulatory requirements into data as computable rules. This capability enables automation and streamlines information flows through technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS), their combined application (GeoBIM), and, more recently, AI.

Rethinking Digitalisation: Beyond Acceleration

Digitalisation is undeniably the way forward. It inherently provides transparency, efficiency, and traceability, thereby enhancing collaboration through the implementation of a data-driven approach. These attributes are recognised as essential requirements for building permit systems and are considered key actuators in promoting a more sustainable methodology for construction works. On the other hand, given that the building permit is defined as a socio-technical ecosystem, digitalisation, while valuable and necessary, is insufficient to resolve all the underlying systemic challenges. The conversion of an inefficient or fragmented manual process into a digital format may only yield marginal improvements and does not constitute an actual transformation. To achieve sustained enhancement, the process must be critically re-evaluated in its entirety, requiring a fundamental reassessment of its purpose, underlying logic, and interdependencies.

Equally important is clarity about what is actually aimed to be achieved. Acceleration in terms of time optimisation, for instance, is often presented as the key performance indicator. However, faster procedures without reflection may come at the cost of quality, safety, and trust. The question is whether it is truly desirable to prioritise faster approvals if it risks weakening oversight and responsibility. Pushed to the extreme, such reasoning could imply transferring all accountability to applicants and abolishing the role of public authorities altogether. Would such a system be trustworthy, or would it merely shift the burden to law enforcement and the courts, dealing with the aftermath of non-compliance?

The more realistic and desirable path lies between extremes: less bureaucracy but not less governance, and greater efficiency without abandoning collective responsibility. Digital tools can and should support this balance, but they cannot replace the institutional and societal foundations on which the legitimacy of the building permit process rests. Nor must everything be forced into automation; sometimes, the human dimension of the building permit process, including careful judgement and professional discretion, could resolve issues more effectively. The most important consideration is that processes, digital or otherwise, are designed to serve the broader goal: a safe, fair, and sustainable built environment. On the other hand, enabling digital tools to serve the building permit purposes and model-based checking can open significant new possibilities in terms of increasing the quality checking of the resulting built environment, without being merely a simple servant of traditional, although refurbished, processes, but rather revolutionising the practice of design and urban planning itself. In fact, BIM- and GIS-based tools enable a huge range of new analyses (e.g., energy, microclimate, noise, accessibility, city-wide assessments, cross-checking with societal, cultural, economic datasets and so on) that can become object of a new generation of regulations, conceived in three or more dimensions and aiming at a new holistic quality of the built environment. For example, underground space planning, which can be

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mentioned as an unresearched topic regarding building permits (Guler, 2024), can efficiently exploit the mentioned advancements, as design and decisions require the integrated and multidimensional utilisation of these tools. In this sense, considering the interdisciplinary structure of building permit processes, digitalisation is taking a role in reshaping the procedures from different fields, such as digital planning.

The Purpose and Structure of This Book

As previously discussed, the sustainable innovation of building permit systems is recognised as being contingent upon not only technological advancements but also on an enhanced comprehension of organisational behaviour, legislative structures, and effective stakeholder collaboration (Noardo et al., 2022). This book embraces this inherent complexity of the building permit process, resisting the simplification often associated with digitalisation efforts. This perspective serves as the conceptual backbone of this book, which underscores that innovation in building permitting cannot be achieved through isolated interventions in a single domain. Accordingly, the structure systematically examines both the digital tools and technologies, as well as the legal, organisational, and cultural conditions necessary for meaningful transformation to occur. This book is structured into three principal parts. Each part addresses a distinct facet of the building permitting process, ranging from a foundational conceptual understanding of the topic (Part I) to an analytical review of technical developments in the field (Part II), concluding with a selection of operational case studies and actual implementations (Part III).

In the following Parts I–III, the chapters are briefly introduced in the order they appear in this book.

Part I. Transitioning to Innovative Building Permit Processes: Foundational Understanding

The first part of this book brings together a series of chapters that collectively deepen the foundational understanding of building permit processes and introduce key innovations shaping their future.

The journey begins with “What Is a Building Permit Process? – An International Review” by Judith Fauth and Peter Nørkjær Gade. This chapter offers a comprehensive, interdisciplinary exploration of building permitting as a socio-technical system. Drawing on decades of international research, it unpacks the complexity of building permitting processes, emphasising the interplay between formal regulations, informal practices, and local contexts. The authors highlight that permitting is not a linear administrative task, but a dynamic negotiation shaped by legal, technical, and organisational factors. Their review of global process modelling approaches and empirical studies provides essential lessons for future research and reform, advocating context-sensitive, interdisciplinary perspectives.

Building on this foundation, “Maturity Models for Digital Building Permits” by Orjola Braholli, Mariana Ataide, and Dietmar Siegele introduces the concept of digital maturity in permitting systems. The work is intended to support public authorities, and a structured framework for assessing and guiding the digital transformation of municipal building permit processes is presented. By mapping out key maturity areas across process, organisation, technology, and information, the authors provide municipalities, which are the key stakeholders for promoting this innovation, with actionable roadmaps to advance the transparency, efficiency, and sustainability of the procedure. This work bridges the gap between technological innovation and procedural governance, offering a validated tool for strategic digitalisation.

The narrative then turns to the nuanced realities of decision-making in “Complexity in Building Permit Decisions – Beyond Pass and Fail” by Judith Fauth, Nicholas Nisbet, Peter Nørkjær Gade, and Eilif Hjelseth. Challenging the conventional binary framing of permit outcomes, this chapter introduces a layered framework that recognises conditional approvals, tolerances, exceptions, and the role of uncertainty. The authors argue for hybrid decision-support systems that combine rule-based automation with human judgement, reflecting the true complexity of regulatory practice. Their conceptual model lays the groundwork for more explainable and resilient digital building permitting ecosystems.

Sustainability emerges as a central theme in “Sustainability in Building Permitting” by Stefanie-Brigitte Deac-Kaiser, Judith Fauth, Thomas Beach, and Nicolae-Andrei Crisan. This chapter systematically maps how environmental, social, and economic dimensions of sustainability intersect with building permit systems. Through a structured taxonomy, the authors reveal both the embeddedness and fragmentation of sustainability goals across legislative, organisational, procedural, and technological subsystems. Their analysis highlights opportunities for more integrated and impactful sustainability practices, positioning building permits as strategic levers for climate resilience, social inclusion, and economic adaptability.

The integration of digital tools is further explored in “Logbook and Permits Interconnection – Realisation, Common Data, and Added Value” by Pedro Mêda, Judith Fauth, and Silvia Mastrolembo Ventura. This chapter investigates the synergies between digital building logbooks and digital building permits, emphasising the potential for unified data-driven processes. The authors demonstrate how linking data-driven building logbooks and building permits can enhance efficiency, transparency, and lifecycle management, advocating for a holistic approach that benefits stakeholders across the construction value chain.

Finally, “Legal Reasoning for Interpreting Requirements” by Eilif Hjelseth delves into the transformation of legal requirements into computable rules for automated compliance checking (ACC). The chapter addresses the interpretative challenges posed by performance-based regulations and introduces frameworks such as the Fairness, Accountability, and Transparency, the European Interoperability Framework, and the Tx3 methodology. By bridging legal science and engineering, the author provides practical methods for trustworthy

interpretation and implementation of requirements in digital systems, fostering innovation and sustainable solutions.

Together, these chapters offer a tapestry of foundational insights and innovative approaches, setting the stage for the technical developments and case studies that follow. They invite readers to rethink building permits not as bureaucratic hurdles, but as dynamic instruments for advancing public good, digital transformation, and sustainable development.

Part II. Evolving Technology: Technical Developments Serving Digital Building Permits

The second part of this book brings together diverse chapters that showcase the technical innovations driving the digital transformation of building permitting. These contributions span from foundational technologies to cutting-edge applications of AI, the semantic web, and immersive environments, collectively illustrating how technical advances are reshaping regulatory processes, data integration, and stakeholder engagement.

The part opens with “Putting Automated Compliance Checking in Context” by Tanya Bloch and Nicholas Nisbet, which provides a comprehensive overview of ACC, where computer languages are used to represent building regulatory sentences as computable rules in the building permitting landscape. The authors trace the evolution of ACC from early rule-based systems to contemporary BIM-enabled workflows, highlighting both the opportunities and the persistent challenges of integrating ACC into real-world building permitting processes. They emphasise the importance of accuracy, trust, and human oversight, setting the stage for the technical developments that follow.

Building on the theme of digital transformation, “AR, VR and XR in Building Permitting” by Harald Urban, Gabriel Pelikan, Alexander Gerger, and Christian Schranz explores how immersive technologies, whose adoption in interactive design review is already discussed in literature, are revolutionising the building permitting process. The chapter details practical use cases for augmented, virtual, and extended reality from citizen engagement and plan checking to on-site inspections and emergency response. Through real-world examples, particularly from the municipality of Vienna, the authors demonstrate how these technologies enhance transparency, spatial understanding, and collaboration among stakeholders.

The integration of semantic technologies is addressed in “Semantic Web Technologies for Building Permitting” by Jeroen Werbrouck, Philipp Hagedorn, Alex Donkers, and Judith Fauth. This chapter introduces the reader to the fundamentals of the semantic web and linked data, illustrating how ontologies, knowledge graphs, and validation languages like SHACL can be leveraged to automate compliance checking and streamline information exchange. The authors present practical cases and discuss the potential of semantic web approaches to enable scalable, interoperable, and transparent building permitting systems.

The narrative then turns to the integration of emerging technologies in “Integrating Emerging Technologies to Streamline Urban Planning, Cadastral Registration, and Building Approvals” by Davood Shojaei, Soheil Sabri, and Abbas Rajabifard. Here, the authors propose a holistic framework that unifies cadastre, planning, and building permitting through digital twins, AI, and the metaverse. They demonstrate how these technologies can break down silos, automate assessments, and create a single source of truth for urban development, ultimately enabling more responsive and efficient governance.

Spatial data and 3D modelling are at the forefront in “Integrating 3D Geodata-Based Spatial Plans into 3D Land Administration for Digital Building Permits” by Dogus Guler. This chapter presents a CityJSON extension for modelling 3D spatial plans, illustrating how standardised, interoperable 3D geodata can support urban simulations, compliance checking, and the integration of land use planning with digital building permitting.

The role of open standards in compliance checking is explored in “Using Information Delivery Specification for Compliance Checking in Building Permitting” by Anshika Karn, Simon Fischer, and Jernej Tekavec. This chapter examines the Information Delivery Specification (IDS) as a bridge between regulatory requirements and BIM-based Automated Compliance Checking (ACC). Through real-world examples from the municipality of Vienna and from Nepal, the authors demonstrate how IDS can automate information availability checks and logical dependencies, while also discussing its current limitations and the need for complementary tools.

Standardisation and interoperability are further advanced in “XPlanung and the Digital Transformation of Urban Planning in Germany: Standards, Practice, and Perspectives” by Kai-Uwe Krause and Carsten Pieper. The authors provide an in-depth look at German XPlanung and XBau standards, which enable machine-readable, legally binding planning data and seamless integration across federal, state, and municipal levels. Through case studies from Hamburg and Niedersachsen, they highlight the practical value and challenges of implementing national digital planning ecosystems.

“Data Profiling and Validation through Linked Data Technologies” by Rob Atkinson, Francesca Noardo, Nataliya Keberle, Arkadiusz Chadzynski, Alejandro Villar, Mayte Toscano, and Vladimir Alexiev delves into the use of linked data and knowledge graphs to harmonise, validate, and profile diverse datasets, such as BIM, GIS, and regulatory information, across the building permitting workflow. The authors highlight the importance of modular, machine-readable profiles and present methodologies for semantic uplift and automated validation, drawing on recent European research projects.

The integration of AI in permitting is discussed in “AI for Building Permitting – Balancing Speed, Flexibility, and Trust” by Tanya Bloch, Stefan Fuchs, Judith Fauth, and Robert Amor, which analyses different AI-driven approaches for transforming the building permitting process, from phased and hybrid models to “one-shot” decision-making. The authors discuss the trade-offs between automation, transparency, and trust, emphasising the need for human-centred, explainable AI systems.

Finally, this theme is extended in “AI-Driven Interpretation of Regulatory Documents Using NLP & LLMs” by Hansi Hettiarachchi, Edlira Vakaj, Dhoyazan Al-Turki, and Mohamed Medhat Gaber. The chapter presents state-of-the-art methods for converting regulatory text into machine-executable rules using NLP and large language models, highlighting both the promise and the challenges of responsible AI in regulatory contexts.

Together, these chapters present a comprehensive panorama of technical developments that are redefining the landscape of building permitting. They demonstrate how automation, interoperability, interactive and semantic technologies, as well as AI are not only increasing efficiency and accuracy but also enabling more transparent, inclusive, and future-proof regulatory processes.

Part III. Implementing Digital Building Permits: International Experiences and Case Studies

The third part of this book presents a collection of case studies that illuminate the practical realities, challenges, and achievements of digital transformation in building permitting across diverse governance levels and geographic contexts. These chapters offer grounded insights into how digitalisation unfolds in practice—at municipal, provincial, national, and federal scales—revealing both common patterns and unique local adaptations.

The part opens with “Finland’s Digital Leap in Building Permits: Journey through Hands-on BIM-Piloting and Cross-sectoral Collaboration” by Rita Lavikka, Anna-Riitta Kallinen, Antero Hirvensalo, Tomi Henttinen, and Tiina Talvitie. This chapter chronicles Finland’s national journey towards digital building permitting, emphasising the importance of cross-sectoral collaboration and iterative piloting. The authors detail how national-level initiatives, supported by government programmes and standards, have enabled municipalities to experiment with BIM-based permitting, gradually building a shared digital infrastructure and culture of innovation.

From the national to the municipal level, “BIM-Based Building Permit: Semi-automated Code-Compliance Checks in Estonia” by Christopher-Robin Raitviir, Pille-Riin Peet, Irene Lill, and Raido Puust explores Estonia’s pioneering efforts to integrate BIM and automated compliance checks into the building permitting process. The chapter highlights how national strategies and legislative frameworks have empowered local authorities to implement semi-automated checks, thereby increasing efficiency and transparency. The Estonian experience demonstrates the value of strong national leadership combined with local experimentation.

Also at the city level, “Digital Building Permit Service at the Municipality of Rotterdam” by Rolf Jonker and Wouter Streefkerk provides a detailed account of the digital permitting service of the municipality of Rotterdam. The authors describe how the city has leveraged digital tools to streamline workflows, improve data quality, and enhance communication with applicants. This case illustrates the potential for municipal innovation within broader

national and European regulatory frameworks and underscores the importance of local leadership and user-centred design.

The complexities of federal governance are addressed in “Implementing Nationwide Public Service Software in Federal Systems: A Case Study of the ‘One for All’ Approach in Germany” by Ronny Weinkauff and Christoph Vollmer. This chapter examines how the German federal structure, comprising national, state (Länder), and municipal authorities, shapes the implementation of digital building permitting solutions. The authors analyse the “one for all” approach, in which a single software solution is developed for nationwide use but adapted to local requirements. The case highlights both the opportunities and challenges of harmonising digital services across multiple levels of government.

Municipal innovation is further exemplified in “Driving Digital Transformation in Building Permits: BIM and Automated Checks in Vila Nova de Gaia” by Carla Pires, Ana Patricia Baptista, and Marco Lima Carvalho. This chapter presents the experience of Vila Nova de Gaia, a Portuguese municipality, in adopting BIM and automated compliance checks. The authors detail the practical steps taken to digitise building permitting processes, the benefits realised in terms of efficiency and transparency, and the ongoing challenges of change management and stakeholder engagement at the local level.

A provincial perspective is offered in “The Status of Digitalisation of the Planning and Building Permissions System in Ontario, Canada” by Mark Whitell, Saeid Emamgholian, Arash Shahi, and Mojgan Jadidi. This chapter surveys the digitalisation landscape across the municipalities of the Province of Ontario, highlighting the role of provincial policy, funding, and coordination in shaping local initiatives. The authors identify both leading practices and persistent barriers, illustrating the interplay between provincial leadership and municipal autonomy in the Canadian federated system.

The national context of the United States is explored in “Permitting System Digitalization in the United States” by Dan Puerling. This chapter provides an overview of the diverse and decentralised landscape of building permitting digitalisation across American states and municipalities. The author discusses the drivers of innovation, the role of federal and state agencies, and the challenges of achieving interoperability and consistency in a highly fragmented system.

Turning to South America, “Brazilian Scenario for Digital Building Permits: Initiatives from Pioneering Municipalities” by Douglas Malheiro de Brito, Dayana Bastos Costa, and Emerson de Andrade Marques Ferreira examines the emergence of digital building permitting in Brazilian cities. The chapter highlights how municipal governments, often in the absence of strong national frameworks, have taken the lead in piloting digital solutions, adapting international standards, and fostering local innovation. These pioneering efforts underscore the potential for bottom-up transformation even in complex regulatory environments.

Together, these case studies provide a nuanced, multi-level perspective on the digital transformation of building permitting. They reveal how innovation emerges through the interplay of municipal initiative, provincial coordination, national strategy, and federal harmonisation. By highlighting both the diversity

of local contexts and the shared challenges of digitalisation, this part offers valuable guidance for practitioners, policymakers, and researchers seeking to advance the future of building permitting worldwide.

Finally, the conclusions, by the editors, bring together lessons from diverse case studies, highlighting the intricate interplay between technological innovation, organisational behaviour, legislative frameworks, and stakeholder collaboration in building permitting systems.

The authors emphasise that digitalisation is a vital enabler, but not a panacea; genuine transformation requires rethinking processes and governance structures, not just digitising existing workflows. Success lies in digital tools and institutional reforms evolving in tandem, supported by clear responsibilities, transparent rules, and cross-disciplinary collaboration. Building permitting reflects societal priorities, balancing efficiency, quality, and accountability, and serves as a daily manifestation of democratic values.

This volume arises from a shared conviction among the editors and contributors that the transformation of building permits is one of the most consequential and still under-researched phenomena in the built environment. Despite the ubiquity of permit systems across countries, few comprehensive international references exist that address their modernisation from a multi-disciplinary perspective.

This book therefore brings together 62 researchers and practitioners from across five continents and more than 20 countries, representing expertise in civil and architectural engineering, computer science, geoinformation, law, management, and public administration. Together, they document not only how building permit processes differ globally but also how they converge towards digital and sustainable futures.

Ultimately, this book invites readers to rethink building permits not as bureaucratic hurdles but as *levers of innovation*. The move from analogue paperwork to digital ecosystems opens unprecedented opportunities: for evidence-based policy, for citizen engagement, for data reuse across the building lifecycle, as well as for an efficient city management, and for measurable progress towards the UN Sustainable Development Goals (SDGs), particularly SDG 7 (*Affordable and Clean Energy*), SDG 9 (*Industry, Innovation and Infrastructure*), and SDG 11 (*Sustainable Cities and Communities*), but also SDG 16 (*Peace, Justice and Strong Institutions*).

Just as the Code of Hammurabi once codified the social contract between builders and society, the digital building permits of today can encode our collective responsibility for a sustainable and resilient built environment.

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Part I

Transitioning to Innovative Building Permit Processes

Foundational Understanding



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2 What Is a Building Permit Process?

An International Review

Judith Fauth and Peter Nørkjær Gade

Introduction

Processes in General

A process consists of a series of coordinated activities or functions aimed at accomplishing a specific task, typically associated with the delivery of a service. Processes have a start and an end and involve the transformation, i.e., the actual processing of input data into output data and can be interconnected through various types of connectors (Allweyer, 2005). In some process theories (Bishop, 2015), they also include control and mechanism function. The control function governs the constraints of the process. For example, the national building code or a project deadline. The mechanism is what performs or enables the process and can be both humans and systems. For example, an administrator or a digital rule-checking system. In organizational contexts, processes represent operational activities that generate services for the entity, commonly referred to as business processes. This concept also extends to public institutions, which can be regarded as enterprises in a broader sense. Here, administrative tasks are carried out to provide services either to the authority itself or to citizens.

The level of detail is crucial when analysing processes. They can be examined at various levels of abstraction or subdivided into subprocesses, which in themselves may be considered processes. Moreover, while we often think of processes as separate from each other, they often intermingle directly or indirectly. This can create hierarchies and networks of processes (Allweyer, 2005). Identifying such processes and mapping their structures is a fundamental aspect of process management. However, this is often a complex and resource-intensive task, as employees typically only possess knowledge of their own responsibilities and adjacent workflows, which rarely represent the full picture. An external perspective can be particularly helpful in achieving a more objective view. Importantly, process hierarchies must be respected, as combining processes from different hierarchical levels should be avoided (Allweyer, 2005). This complexity is further compounded by the existence of different types of processes. Criteria such as degree of structuring, knowledge and data intensity, frequency of repetition,

scope and duration, as well as the distinction between routine and exception processes, are essential when classifying and analysing them (Allweyer, 2005).

The process of applying processes into organizations is often very difficult. These processes are often defined to form an “universally applicable” process. However, the problem of creating an “universal applicable” process entails that considerations are made to the process users if it is suitable for their context. For example, when an international construction firm imposed a standardized project-startup process across all offices. However, misalignments in permitting procedures, workforce stability, and technology access lead to delays and inefficiencies. Efforts to standardize elements like personnel, objectives, or technical components often distort the actual process structures, thereby hindering the optimization of value creation within institutions (König, 2015). Consequently, processes need to be tailored to the specific context in which they are implemented.

It is also important to differentiate between a process and a workflow. While a business process defines *what* needs to be done, a workflow specifies *how* it is to be executed, usually through full or partial automation. A key distinction lies in the level of detail considered in each (Gadatsch, 2017). A process outlines what needs to be accomplished to achieve a specific objective, such as completing a project, processing an application, or managing procurement. It defines the overall sequence of activities, roles, and decision points without prescribing the exact execution method. In contrast, a workflow specifies how those activities are to be carried out in practice, often detailing task sequences, system interactions, approvals, and handovers. Workflows typically operate at a lower level of abstraction and often incorporate partial or full automation through digital platforms or business process management systems. For example, while a process may define the need for contract approval before project initiation, the workflow determines the routing of the digital document, notification triggers, and escalation mechanisms. The key distinction lies in the granularity and operational detail: processes focus on strategic structure and alignment with organizational goals, whereas workflows focus on execution logic and efficiency. Understanding this distinction is crucial when implementing digital tools or redesigning operational models, as confusing the two can lead to either excessive rigidity or lack of actionable guidance.

Building Permit Processes

A process-oriented perspective on building permits offers a structured lens for understanding their complexity. Contrary to linear or purely technical conceptions, building permits involve formal and informal practices. Formal structures articulated through codes, planning laws, and administrative guidelines prescribe procedural steps with varying specificity. These frameworks establish standardized procedures for administrators, applicants, designers, and consultants, ensuring decisions follow a recognizable sequence intended to secure compliance, transparency, and accountability. However, adherence

varies, shaped by contextual demands, institutional routines, and professional discretion (Fauth & Soibelman, 2022).

In practice, this logic is neither uniform nor deterministic. Permitting is embedded within administrative contexts shaped by resource limitations, organizational cultures, and local political priorities. While formal rules define the “what” and “when” of compliance, the “how” emerges through iterative assessments and professional judgement. Deviations from prescribed sequences often reflect adaptive capacity rather than failure. Informal practices, such as pre-application consultations and discretionary decisions, intersect with formal structures, adding flexibility while introducing opacity that complicates modelling and automation. Understanding building permits therefore requires attention to the interpretive, contextual, and relational work embedded within administrative practice (Fauth et al., 2024).

The Administrative Act of Building Permitting

Legally, a building permit authorizes construction. Yet, it functions as an operational interface across legal, technical, architectural, and planning disciplines. What appears as a sequential procedure – submission, review, consultation, decision – is in reality a negotiated process shaped by disciplinary interdependencies. Legal mandates provide procedural architecture, establishing timelines, documentation requirements, and appeals processes. Administrators interpret these mandates within organizational routines and resource constraints. During review phases, technical disciplines contribute through expert reports and certifications, each following distinct standards that may diverge from legal frameworks. For example, a fire engineer’s performance-based proposal may meet safety objectives but fall outside prescriptive codes, requiring negotiation and conditional acceptance (Fauth et al., 2023). Urban planning introduces additional complexity, with spatial analysis, neighbour consultations, and policy concerns such as climate adaptation and heritage preservation influencing outcomes, often requiring compensatory measures.

Digitalization efforts reveal these complexities. Compliance-checking algorithms rely on rule formalization but struggle with provisions requiring spatial judgement or interpretive reasoning. Automated tools act not only as validators but also as triage mechanisms, routing standard cases for automation while flagging complex ones for interdisciplinary review. Each phase becomes a site where disciplinary logics converge with varying degrees of formality and contextual sensitivity.

Viewing permitting as an interdisciplinary process explains outcome variations, timeline fluctuations, and the limits of automation. It underscores that effective process improvements require more than workflow optimization; they demand integrative coordination across legal, technical, architectural, and planning domains. Although building permit processes balance public and private interests, they are often misunderstood through overly linear or technical models that fail to capture real-world complexity. Standardization and digitalization

efforts frequently overlook informal, discretionary, and interdisciplinary dynamics, limiting policy effectiveness and innovation. Research often underrepresents how negotiation, interpretation, and contextual adaptation shape permitting, leaving gaps in understanding these systems as flexible socio-technical infrastructures.

This chapter explores the question: *What Is a Building Permit Process?* Rather than viewing it as a simple administrative sequence, the chapter examines permitting as a complex socio-technical system shaped by regulation, professional judgement, and institutional context. Drawing on 25 years of research which is presented in the upcoming section, it synthesizes how processes are structured, modelled, and interpreted across jurisdictions, using tools such as Business Process Model and Notation (BPMN) and Integration Definition for Function Modelling (IDEF0) to reflect differing analytical lenses. Finally, the chapter distils key lessons learned, revealing common challenges and innovations on understanding and managing building permit processes.

Previous Research on Building Permit Processes

This section illustrates previous efforts from the past decades on building permit process studies across the globe. It is worth mentioning that publications are considered that truly discuss process steps in detail. Through illustrations we aim to give the reader an understanding of:

- 1 The countries where building permit processes have been studied,
- 2 The years of the publications of these studies,
- 3 Which modelling and description techniques and languages have been used to illustrate and communicate the processes,
- 4 Whether or not the studies have been an individual process investigation or a comparative study of multiple countries or jurisdictions,
- 5 Differentiate between as-is process studies (how the process exists today) and future process study (how the process could look like in future),
- 6 What subprocess steps have been identified.

It needs to be noted that the building permit process of these studies mainly focusses on the process steps within the building permit authorities, although not exclusively.

A growing body of literature has examined the structure and transformation of building permit processes, highlighting the sequence, coordination, and digitization of procedural steps across diverse jurisdictions. Early work by Kettner and Diaz (2000) and Meijer et al. (2002) emphasized the need for workflow and regulatory alignment, showing how sequential tasks such as application intake, review, and issuance could be digitalized to improve traceability. Sonntag and Wimmer (2003) analysed Austria's one-stop government initiative, identifying legal ambiguities and institutional fragmentation that disrupted integrated process flows. Similarly, Yaakup et al. (2007) detailed the

staged implementation of a computerized planning approval system in Malaysia, with steps including online submission, inter-agency referrals, and approval tracking. Meijer and Visscher (2006) and Pedro et al. (2011) extended this inquiry to the European level, comparing the degree to which submission, review, and decision-making have been digitalized across member states. In Ghana, Kpamma and Adjei-Kumi (2013) and Tengan et al. (2018) showed how fragmented responsibilities and bypassed procedural steps cause delays and enforcement gaps. Refvik et al. (2014) identified similar challenges in Norway's ByggNett initiative, where technical and institutional misalignments hindered effective workflow automation.

Comparative studies from Southeast Europe (Jovanoviat et al., 2016), North America (Shahi et al., 2017), and the U.S. (Lee & Chiang, 2017) have further unpacked how delays and inefficiencies arise from unclear sequencing and coordination among actors during rezoning, negotiation, and appeals. Omorog et al. (2018) and Karoui and Sassi (2016) emphasized the need for end-to-end digital traceability by analysing the integration, or lack thereof, of review and enforcement steps in Nigeria and Tunisia. Efforts to standardize and model permit processes have been proposed by Fauth and Bargstädt (2019), Piazza et al. (2019), and Guler and Yomralioglu (2021, 2022), who outlined frameworks linking legal, cadastral, and compliance stages. This focus on structuring sequential stages – submission, validation, and multi-agency review – has been echoed in technological efforts such as OpenBIM e-submission systems (Kim et al., 2020) and rule-based smart permitting tools (Eirinaki et al., 2016). At the regional level, Whitell et al. (2020) illustrated how inconsistent application, plan checking, and approval steps across Ontario municipalities undermine digital adoption. Likewise, Fawzy and Magdi (2020) mapped Egypt's multi-step permit process and proposed digital interventions to streamline inspection and fee processing.

The complexity of real-world permitting workflows has been further illustrated by Fauth and Soibelman (2022) and Fauth et al. (2023), who used BPMN 2.0 models and interviews in South Tyrol to show how informal practices and discretion intersect with formal digital steps. Broader harmonization efforts, such as the CHEK project's modular "To-Be" process map (Braholli et al., 2023) and the ACCORD project's ontology-based review (2023), have aimed to align process steps across jurisdictions. Recent comparative research by Fauth et al. (2024) reinforced the need to account for national legal logics and administrative cultures when designing permit workflows, as detailed further in a follow-up report covering 19 European countries. Additional cases from Scotland (Belkouri et al., 2024) and Vienna (Urban et al., 2024) demonstrate how structured data environments and OpenBIM integration are reshaping the technical and institutional sequencing of permit approval processes.

Figure 2.1 shows a world map and highlights the countries where the building permit processes have been investigated. The darker the country, the more studies have been published. It becomes clear that there is strong focus on the



Figure 2.1 World map illustrating studied countries.

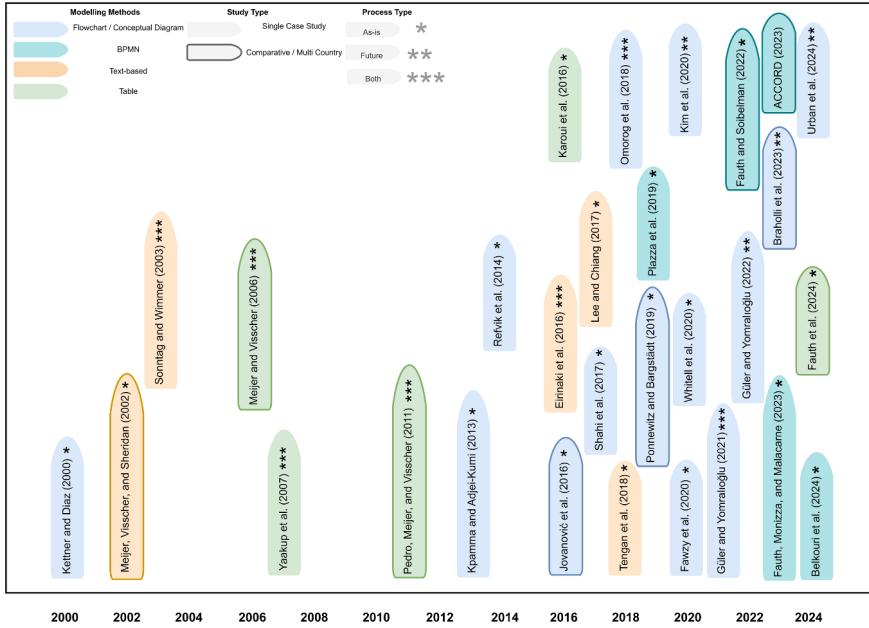


Figure 2.2 Timeline of published outputs.

European countries while countries in Asia, South America, and Africa are very limited or at least unpublished from a scientific view.

Figure 2.2 represents a timeline and illustrates known published scientific outputs on building permit process investigations. As can be seen from the legend, in addition to the year of publication, it also shows the type of study (single case or comparative/multi-country study), the modelling method applied, and the type of process (as-is, future study, or both).

Figure 2.3 illustrates the actual process steps identified in Fauth et al. (2024) and in the review by Bloch and Fauth (2023) in a schematic diagram. The figure summarizes the building permit process structured into three main phases: Pre Phase, Review Phase, and Post Phase. In the Pre Phase, applicants prepare and submit documents, undergo zoning checks, and may participate in pre-consultation or zoning amendments. The Review Phase includes administrative checks, involvement of agencies and the public, and detailed content reviews such as planning, technical, and legal assessments. The Post Phase covers site inspection, approval of construction conformity, and the issuance of the occupancy permit. Each phase contains multiple, interdependent process steps involving various authorities and stakeholder interactions.

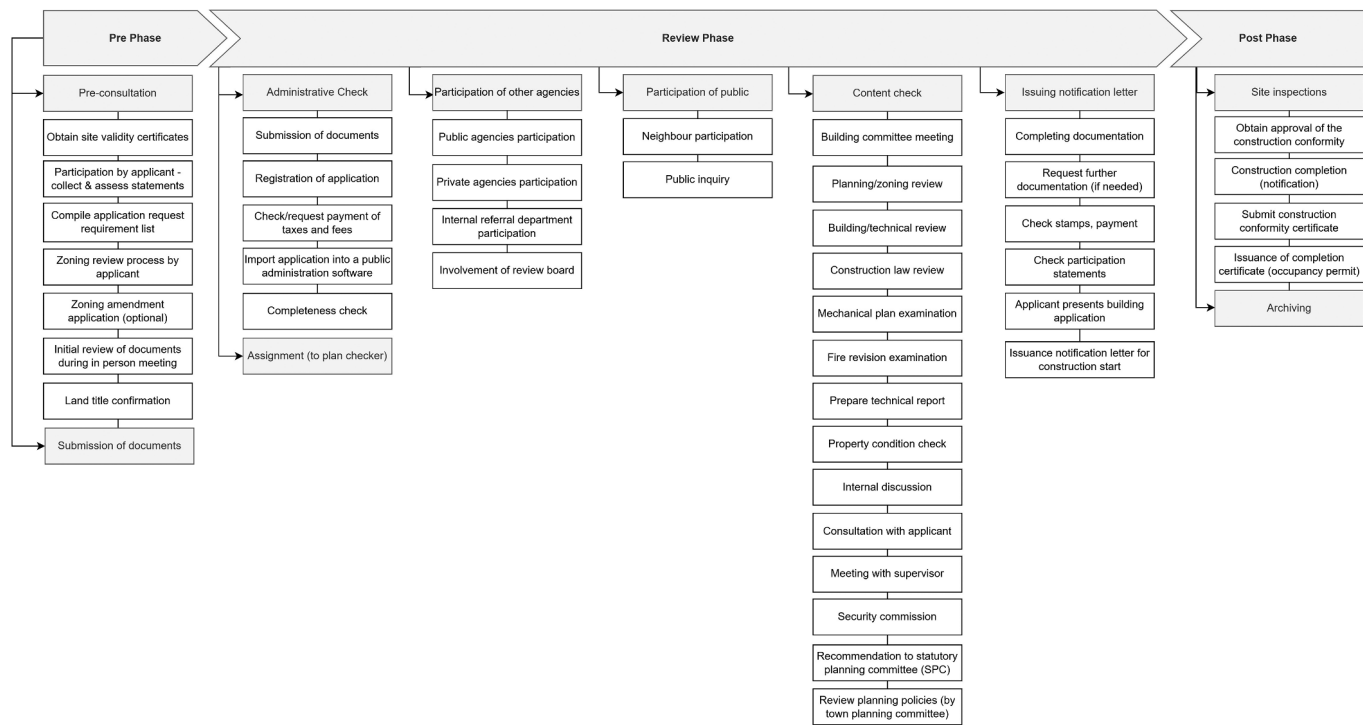


Figure 2.3 Building permit process steps.

Modelling and Representation Techniques for Building Permit Processes

Understanding building permit processes requires more than mapping linear sequences from application to approval. Stepwise progress often oversimplifies these processes, overlooking their multidimensional and discretionary nature. Theories from systems engineering, informatics, and social science reveal contrasting assumptions about structure, agency, and coordination within permitting. As illustrated in Figure 2.4 processes (Fauth & Soibelman, 2022), effective modelling of building permit processes must respect three core elements: the hierarchical structuring of processes at different granularities, the involvement of inter-organizational and targeted stakeholders such as plan checkers and external agencies, and the presence of authority-specific business rules that shape implicit alternatives and discretionary actions. Effective modelling must address hierarchical structuring at varying granularities, the involvement of multiple stakeholders, and jurisdiction-specific rules that guide discretionary decisions.

Process Modelling Theories: BPMN 2.0, IDEF0, Petri Nets, and ANT

Building permit processes demand frameworks that capture layered, complex workflows rather than reducing them to linear steps. BPMN 2.0, IDEF0, Petri Nets, and Actor-Network Theory (ANT) offer complementary lenses for analysing and redesigning these processes. BPMN 2.0 utilizes graphical elements to map workflows, supporting human readability and machine execution. It clarifies temporal sequences and stakeholder roles, making it suitable for compliance and digitalization efforts. In contrast, IDEF0 emphasizes functional decomposition. It structures processes using Inputs, Controls, Outputs, and Mechanisms, facilitating high-level diagnostics and clarifying interdependencies. Petri Nets extend analysis by modelling concurrency, system dynamics, and state transitions. They reveal potential deadlocks and synchronization

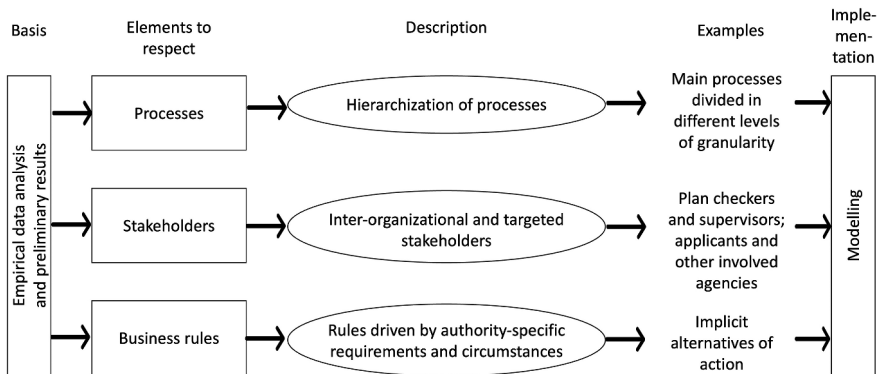


Figure 2.4 Building permit modelling framework.

issues within workflows, providing analytical rigour for environments with parallel approvals. ANT shifts focus to socio-material negotiations shaping regulatory work. It highlights how technologies, documents, and human actors co-constitute processes, emphasizing interpretation and informal practices often missed by formal modelling.

This theoretical plurality is essential. While BPMN 2.0 clarifies execution paths, it assumes predictability. IDEF0 supports functional logic but may overlook interpretive judgement. Petri Nets capture concurrency but can lack context sensitivity. ANT challenges reductionism, demonstrating how informal negotiations and discretionary practices critically shape regulatory outcomes. Embedding these models uncritically within digital permitting systems risks institutionalizing narrow perspectives, sidelining informal coordination and local discretion as inefficiencies. Recognizing the assumptions each modelling approach carries is vital. It enables stakeholders to interrogate their tools and refine models to reflect lived complexity rather than suppressing it through oversimplification.

IDEF0 – A Functional Decomposition

IDEF0 has proven effective in modelling complex construction processes, including risk management and project delivery workflows (Alizadehsalehi & Hadavi, 2023). Within permitting, IDEF0 facilitates a top-down decomposition of workflows into functional blocks, enabling clear representation of activities with defined inputs, outputs, controls, and mechanisms (Baoyin & Bo, 2009). This methodology creates a top-down decomposition where the overall permit process is systematically divided into manageable subprocesses.

This method exposes interface requirements and clarifies data flows between process stages, aiding in risk reduction and identifying bottlenecks. For example, IDEF0 can separate permit functions such as intake, compliance checks, consultations, and issuance, structuring them systematically while retaining interdependencies (Tserng et al., 2021). Chen et al. (2008) applied IDEF0 to construction lifecycles, showing its suitability for domains requiring coordination among discrete yet interdependent functions. Transposing this to permitting, IDEF0 clarifies control structures and outputs across review stages while supporting risk-focused diagnostics for fragmented systems (see Figure 2.5).

BPMN 2.0 – Workflow Integration and Stakeholder Collaboration

BPMN 2.0 has gained traction in modelling construction workflows involving multiple stakeholders. It excels in capturing iterative, collaborative processes, supporting BIM integration and automated compliance systems (Ren & Zhang, 2021). The notation system provides superior comprehensibility and system features for construction process mapping (Ali, 2019). For instance, the South Tyrol case (Fauth et al., 2023) applied BPMN 2.0 to map five subprocesses in permitting: formal review, assignment, participation, content review,

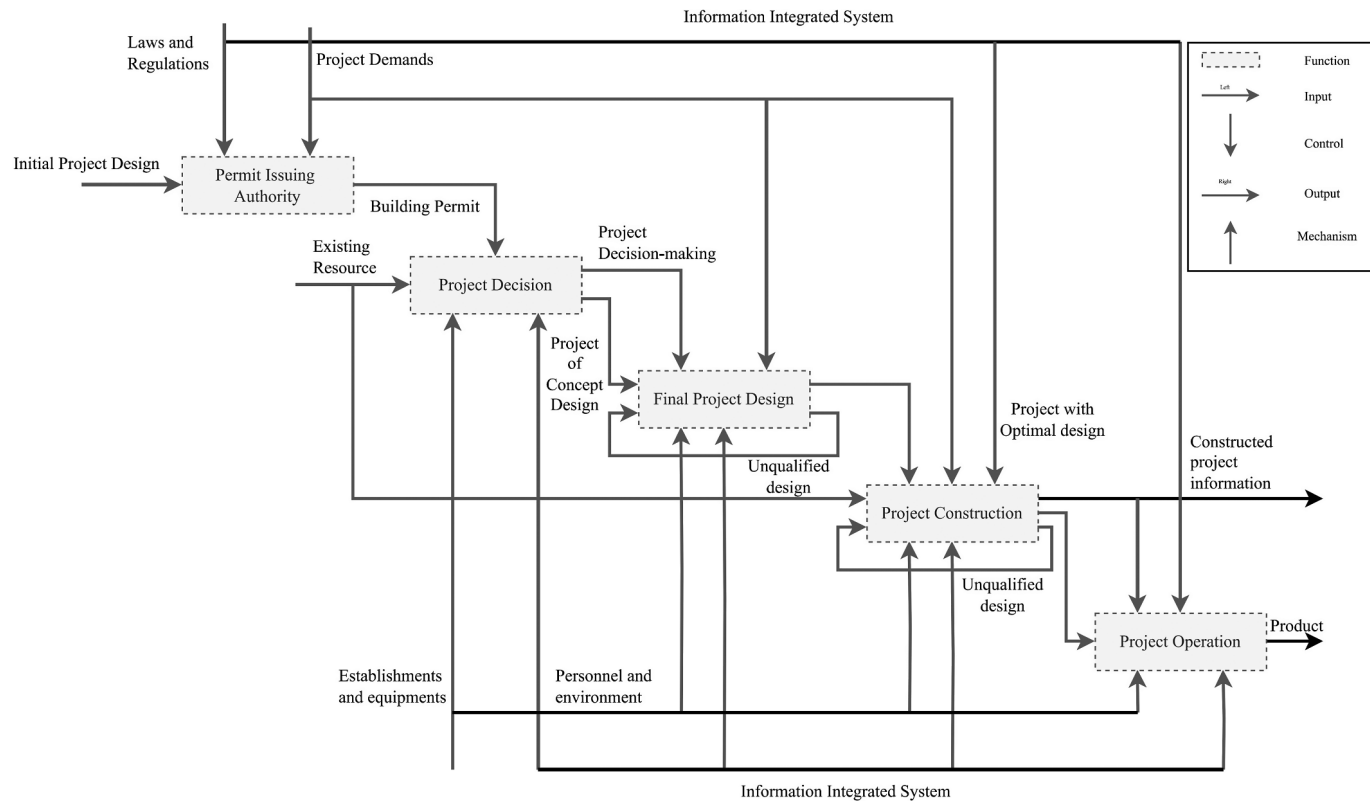


Figure 2.5 An illustration of the process-oriented construction project integrated management model. Adapted from Dikbas and Ercoskun (2006).

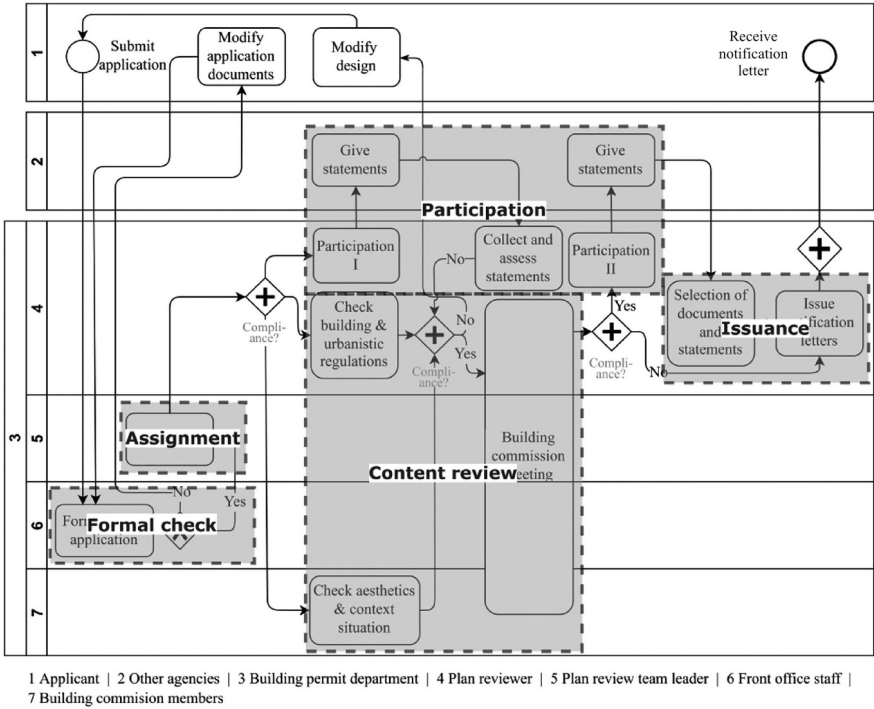


Figure 2.6 BPMN 2.0 illustration of a building permit process in the case study municipality in South Tyrol. Based on Fauth et al. (2023).

and issuance. This model visualized stakeholder actions, including plan reviewers, front-office staff, and external agencies, using parallel gateways and message flows to represent consultations and conditional branches for iterative reviews. BPMN 2.0 clarified the coordination required for BIM-integrated processes and compliance checks while enhancing stakeholder comprehension of complex workflows. It also provided a foundation for developing IT tools aligned with digital transformation objectives. The numbers illustrating the different roles involved in the process are shown in Figure 2.6.

Petri Nets: Capturing Concurrency

Petri Nets provide a formal mathematical framework for analysing concurrency and dynamic behaviours within workflows. They identify synchronization challenges, conflicts, and potential deadlocks often hidden in static representations. For permitting, Petri Nets can model parallel compliance checks by zoning, fire safety, and environmental agencies, ensuring workflow designs accommodate concurrency without system failures. This capability is critical in digital permitting, where parallel processes dominate operational realities (see Figure 2.7).

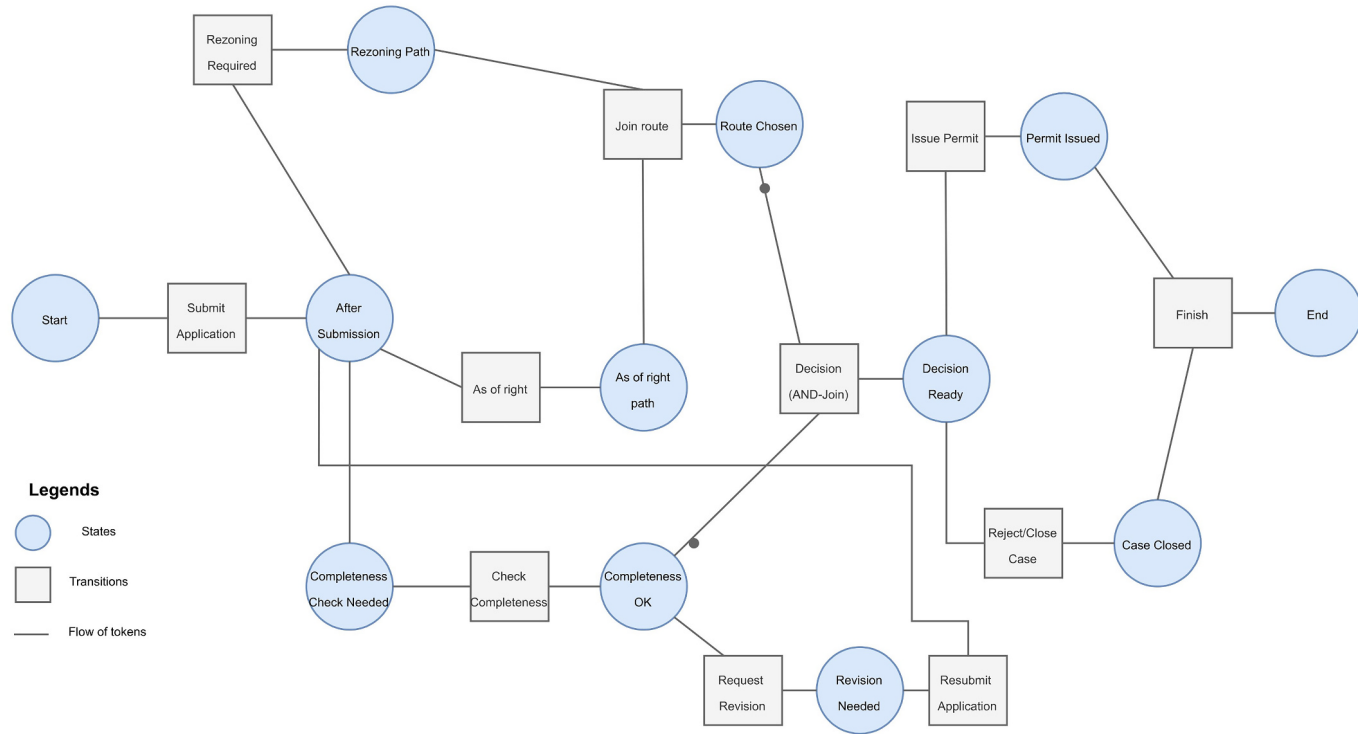


Figure 2.7 A simple graph representation of a Petri Net. Adapted from Peterson (1977).

ANT: Negotiation and Socio-Material Dynamics

ANT offers a different analytical lens by focusing on how human and non-human actors co-produce regulatory processes. ANT traces interactions among planning officers, digital rule-checking tools, legal documents, and applicants, emphasizing negotiations that redefine compliance and authority. For instance, introducing a digital checking tool does not simply automate steps; it reconfigures interpretive practices and documentation standards through interactions among system actors. ANT illuminates the influence of informal practices, such as verbal clarifications or pre-application consultations, particularly where regulatory ambiguity prevails. In Figure 2.8, a network diagram based on ANT shows how social networks are formed in the process of self-help houses.

The choice of modelling approach structures what stakeholders see, value, and improve within building permit processes. These models should not be viewed as interchangeable but as complementary, each addressing different facets of the permitting process. BPMN and IDEF0 support structured, system-oriented process improvements, while Petri Nets and ANT expand understanding to concurrency and interpretive dynamics. Selecting a modelling approach is not neutral; it directs focus towards specific elements while excluding others, shaping governance and digitalization efforts within building permitting. A critical awareness of these dynamics enables practitioners and researchers to develop models that reflect the complexity of regulatory practice, ensuring digitalization supports practical realities rather than imposing reductive structures.

Lessons Learned on Building Permit Processing

In the following, eight lessons learned observed from the previous sections are listed, with examples as key takeaways for practitioners and future research.

#1 – There Is No Single, Universal Process

Building permit logic is heavily shaped by local law, organizational culture, and politics; assuming a “standard” workflow almost always hides crucial variations. We have to acknowledge diversity but should work towards a common understanding.

Example: In Municipality A, applicants must attend a mandatory pre-application meeting, obtain advisory sign-offs from, for example the fire department. In Municipality B, staff are prohibited from giving pre-filing advice, and applicants must collect sequential approvals from separate departments.

#2 – Informal and Tacit Practices Are as Influential as Written Rules

Verbal clarifications, personal networks, and unwritten expectations routinely steer decisions that are invisible in official records.

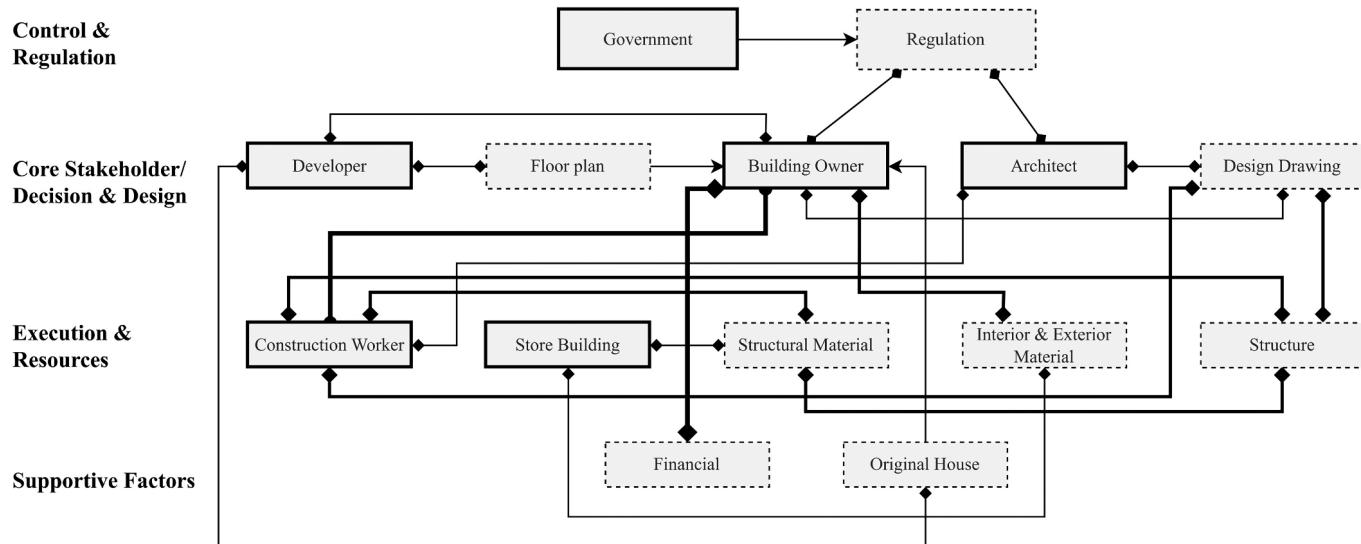


Figure 2.8 Network diagram in self-help house source. Adapted from Khalis (2022).

Example: A case officer phones the engineer to reconcile stormwater coefficients that the form does not capture, agreeing on an interpretation that never enters the file. Experienced firms also receive informal completeness checks at the counter, avoiding the “reject and resubmit” loop.

#3 – Permitting Is an Iterative Negotiation between Private and Public Goals

Drawings, conditions, and compromises are revised repeatedly until safety, legal, and urban-quality objectives align with developer needs.

Example: A developer proposes an extra floor to reach financial viability. Planning requests step-backs to limit overshadowing, and fire services require an additional stair. The final approval trades gross floor area for better daylight, adds evacuation capacity, and conditions facade materials, an explicit compromise aligning safety, legality, urban quality, and the pro forma.

#4 – “Where Does the Process Begin and End?” – Everyone Has Its Own Definition

Some jurisdictions see it spanning from land purchase to occupancy; others stop at the approval letter. Comparing systems requires stating those boundaries explicitly.

Example: Region X treats concept plan advice, rezoning, and environmental screening as part of “the permit process,” and it ends only at the occupancy certificate. Region Y starts the clock at building-permit intake and ends at the approval letter, leaving inspections to a separate regime.

#5 – Formality, Certainty, and Granularity Sit on Sliding Scales

A step may be highly prescriptive in one place yet discretionary in another; micro-level tasks that matter for automation are often omitted from high-level maps.

Example: Setbacks are fixed at 5 meters in City A, enabling deterministic checks; City B allows “contextual alignment,” requiring discretion. At the micro level, automation needs explicit tasks, count risers, measure nosing projections, test headroom, yet high-level process diagrams omit them. Without this granularity and its connection to the higher levels, digital tools appear unreliable where discretion actually drives outcomes.

#6 – Many Actors, Many Viewpoints

Planners, fire departments, environmental agencies, neighbours, and digital tools each read the same case through different lenses; coordination, not mere sequence, is critical.

Example: Planning endorses an active ground floor, but fire services reject the same plan due to egress of bottlenecks during peak occupancy. Environmental protection mandates tree-root zones that conflict with proposed stormwater tanks, while a BIM clash checker flags duct-beam conflicts unrelated to any legal rule. Progress depends less on sequence than on orchestrating these simultaneous, discipline-specific readings.

#7 – Interdisciplinary Understanding Is Non-negotiable

Legal, technical, and spatial logics collide in every file; improvement efforts fail if they privilege only one domain.

Example: Legal due-process rules require neighbour notification that triggers design changes; acoustics demand higher facade performance; urban design seeks transparency for street life. A purely legal fix grants compliance yet yields unbuildable HVAC layouts, while a purely engineering solution breaches privacy limits. Only a coordinated reading of legal, technical, and spatial logics resolves the case.

#8 – Digitalization Helps – and Can Hurt – If It Ignores the Above Points

Rule-checking algorithms cope well with routine cases but fall short where spatial judgement or negotiated trade-offs are needed, sometimes even reshaping codes for the worse.

Example: A rules engine rapidly validates floor-area ratios, parking counts, and ramp slopes for simple lots, cutting weeks from routine approvals. However, it is hard to code case-based discretionary decisions (yet). In some cases, a machine might not be faster and not more accurate than a human. Also, from a cost-benefit perspective, it might not be worth it to code a single case decision when a human is able to make the decision in seconds.

Conclusions

The exploration of building permit processes across diverse jurisdictions and theoretical lenses has revealed a set of critical insights into how these systems function and why they often defy simplification. Central among these is the realization that no single, universal process exists. Instead, building permitting systems are deeply embedded in legal traditions, institutional arrangements, administrative cultures, and political economies. What emerges as a “process” is not merely a sequence of steps, but a socio-technical configuration shaped by informal practices, discretionary decisions, and dynamic negotiation between public mandates and private interests.

This complexity poses significant challenges to both scholars and practitioners seeking to model, compare, or reform building permit systems. The modelling frameworks analysed in this chapter (BPMN 2.0, IDEF0, Petri Nets, and ANT) each illuminate different dimensions of process logic. The chapter’s comparative and empirical foundation also underscores the importance of understanding where a process begins and ends. Some jurisdictions consider pre-application negotiations or post-approval responsibilities as integral to permitting, while others narrowly define it from submission to decision. These boundary definitions matter for comparative research, digital tool development, and policy design. Furthermore, tacit and informal elements, such as verbal agreements, pre-checks, and stakeholder expectations, are not marginal quirks but central features of how permits are processed and outcomes determined. Recognizing these as legitimate parts of the process is crucial for system improvement.

The findings have several implications. First, for researchers, this chapter challenges reductive models and calls for interdisciplinary, multi-method approaches that account for both formal and informal dimensions. Theoretical pluralism is necessary to grasp the richness of building permitting processes and avoid process “blindness.” Second, for practitioners and administrators, the lessons highlight the importance of context-sensitive reforms and the risks of one-size-fits-all digitalization. Automation can support efficiency but must be calibrated to preserve discretion, coordination, and professional judgement. Finally, for policymakers, process reform should not aim for universal templates but foster adaptive standards that acknowledge local institutional capacity, legal culture, and planning needs.

Despite the breadth of this study, limitations remain. The reviewed models and case studies, while diverse, still reflect a Eurocentric and Global North bias. Building permit processes in much of Asia, Africa, and South America remain under-investigated in scholarly literature. Moreover, while this chapter draws on rich empirical work, further research is needed to explore how digital tools, regulatory reforms, and organizational shifts co-evolve in practice, particularly in the face of sustainability transitions, housing pressures, and post-pandemic governance challenges.

In sum, this chapter argues that building permitting must be understood as more than administrative compliance. It is a complex, situated process of interdisciplinary negotiation, framed by rules but enacted through judgement, tools, and networks. Future research should continue to unpack these socio-technical dynamics, embracing methodological diversity and comparative insight. For innovation in permitting to succeed, whether technical, organizational, or legal, it must begin from a grounded understanding of how processes are actually lived, structured, and transformed.

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Data Availability

Not applicable

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3 Maturity Models for Digital Building Permits

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Introduction

Municipal building permit processes constitute a critical interface between regulators, developers, and the public, shaping the pace and quality of urban development. Traditionally, these processes have relied on paper-based submissions, manual verifications, and dispersed documentation that slow application reviews and add ambiguity to procedural transparency (Ataide et al., 2023; EuroSDR 2020 report). Applicants often face repeated requests for missing documents, while municipal staff must navigate fragmented workflows and parallel data repositories. Such inefficiencies not only inflate administrative costs but also hinder timely decision-making, undermine public trust, and interfere with the achievement of broader sustainability objectives (Fauth et al., 2024; Shahi, 2018).

Digital permit systems promise to alleviate these burdens by centralising data, automating rule checks, and providing real-time status updates (Noardo et al., 2022). However, successful digital transformation requires more than the implementation of information technology. It entails reengineering workflows, aligning organisational structures, standardising data formats, and ensuring that technological platforms are reliable, secure, and interoperable (Ochoa-Urrego & Peña-Reyes, 2021; Wendler, 2012). These multi-dimensional changes are further complicated by legacy constraints, such as paper archives and incompatible IT systems, as well as by the need to balance regulatory precision with user-friendly interfaces (Mêda et al., 2024; Pfeiffer et al., 2024).

To manage this complexity, municipalities require a clear framework for evaluating their current capabilities and mapping a path towards more advanced digital operations. Maturity models fulfil this need by deconstructing digital transformation into discrete stages, each defined by specific criteria and measurable outcomes (Layne & Lee, 2001; Paulk et al., 1993). At lower stages, authorities may rely on scanned documents and email notifications; at intermediate stages, they deploy integrated portals and basic analytics; at advanced stages, they use predictive modelling and artificial intelligence to optimise resource allocation and compliance enforcement (Hjelseth, 2013; Shahi et al., 2019).

In the context of construction regulation, maturity assessment must account for both technical innovations, for instance, Building Information Modelling

(BIM) and Geographic Information Systems (GIS), other than the legal frameworks governing zoning codes, technical regulations, and environmental standards. BIM provides detailed, three-dimensional models of building designs. Although to support automated compliance checks, these models must first conform to standardised schemas (e.g., Industry Foundation Classes (IFC)), undergo semantic enrichment to capture design intent, and then be mapped to locally specific regulatory rules before a rule-validation engine can interpret and verify compliance (Jakobson, 2023; Succar, 2010). Only once this preparation is complete can a rule-validation engine interpret and verify design compliance. Similarly, GIS offers powerful spatial analysis for site assessments and public consultations, yet its value depends on establishing interoperable data exchange protocols and consistent metadata standards (Lemke et al., 2020; EuroSDR 2020). Integrating these technologies within a coherent regulatory workflow therefore demands robust data governance, clear organisational mandates, and secure IT architectures (Aguiar et al., 2019; Lavikka & Kallinen, 2024).

This chapter introduces the CHEK Digital Building Permit Maturity Model (CDBPMM), developed under the Horizon Europe CHEK project to meet the unique challenges of municipal permit digitalisation. The CDBPMM synthesises insights from software engineering maturity frameworks, e-government studies, and domain-specific models for BIM and GIS, while tailoring its criteria to the procedural and governance aspects of permit approval. It offers municipalities a validated, structured approach for assessing digital readiness across four dimensions: Process, Organisation, Technology, and Information.

The work begins by reviewing the evolution of maturity models from the Capability Maturity Model (CMM) in software engineering to contemporary e-government and BIM/GIS frameworks, to identify lessons and gaps relevant to permit digitalisation. We then detail the CDBPMM's structure, including its key maturity areas (KMAs), assessment methodology, and interactive tools that guide evaluators through structured questionnaires and dynamic visualisations. Subsequent sections demonstrate how the model translates assessment results into clear outputs, such as visual maturity profiles, dependency-aware roadmaps, and peer benchmarking metrics, and compare its efficacy against existing alternatives. Finally, we explore emerging trends, including artificial intelligence for rule validation and automated analytics, and discuss practical considerations for governance, data interoperability, and resource allocation that support successful digital transformation.

By offering a comprehensive framework that integrates procedural precision with technological innovation, the CDBPMM aims to empower municipalities to pursue more transparent, efficient, and sustainable building permit processes.

Background Literature

Origins and Evolution of Maturity Models

The concept of maturity modelling originated in software engineering through the CMM, pioneered by the Software Engineering Institute at Carnegie Mellon

University in the mid-1980s. Commissioned by the U.S. Department of Defence to address chronic delays, cost overruns, and quality deficiencies among software contractors, the initial framework characterised five ascending levels: from initial undocumented and ad hoc practices, through repeatable documented processes, to defined standardised procedures, quantitatively managed operations, and finally efficient continuously optimised systems. This staged representation emphasised the degree of process formality and optimisation, guiding organisations towards disciplined, metrics-driven software development.¹ Subsequent refinements culminated in Capability Maturity Model Integration (CMMI), which integrated systems engineering and process improvement into a unified architecture and further codified best practices across multiple disciplines.²

By the late 1990s and early 2000s, maturity modelling had surpassed its software-centric roots. Public administration scholars adapted the approach to evaluate e-government initiatives, aiming to benchmark how governments deploy information and communication technologies to deliver services and foster citizen engagement. Among the most cited, Layne and Lee (2001) proposed a four-stage e-government model (“catalogue,” “transaction,” “vertical integration,” and “horizontal integration”) mapping increasing organisational and technological complexity across government levels. Their work highlighted that e-government evolution does not depend only on online service provision but on the coordination of back-office systems and data sharing among entities.

Simultaneously, the construction and urban planning sectors began employing maturity concepts to guide digital innovation. The UK BIM maturity model introduced discrete levels (0–3) to describe the adoption of 3D modelling and integrated data environments, emphasising collaborative information exchange and lifecycle management (Dakhil et al., n.d.). GIS maturity frameworks emerged to assess spatial data infrastructures’ capacity to support advanced analytics and decision-making in urban contexts. However, these domain-specific models often omitted the procedural and regulatory dimensions critical to building permits, specifically the technical translation of individual regulatory clauses into machine-readable checking (rule validation), the coordination of multiple stakeholders throughout application and review, and the broader assurance that all statutory and administrative obligations (forms, fees, timelines, appeals) are satisfied (legal compliance).

The growth of specialised maturity models, ranging from e-government extensions to BIM/GIS frameworks, emphasised two consistent findings: first, digital transformation is multi-dimensional, requiring simultaneous advancement in technology, process, and organisational culture; second, generic or single-domain models frequently lack the granularity to address sector-specific challenges. These observations motivated the development of a more comprehensive, contextualised framework, such as the CDBPMM, that blends insights from diverse maturity traditions while targeting the particularities of municipal permitting systems.

Maturity Models in the Built Environment and Permitting Context

Building permit processes have traditionally relied on manual, paper-based workflows, which introduce delays, redundancies, and vagueness for applicants and administrators alike. In recent years, researchers and practitioners have been referring to maturity models as instruments to map gradual progress towards digital workflows that increase regulatory accuracy and transparency. Early applications of maturity concepts in the built environment centred on BIM and GIS, domains where structured data exchange and lifecycle management are critical. For instance, the UK Government's BIM maturity framework defines successive levels of collaboration, from basic 3D modelling (Level 1) to integrated data environments enabling coordination of supply chains (Level 3), emphasising standardised data protocols and shared digital assets throughout project lifecycle (Layne & Lee, 2001; Paulk et al., 1993). Likewise, GIS maturity assessments evaluate spatial data infrastructure capabilities, highlighting how map-based decision support evolves from static repositories to real-time, interoperable platforms that inform urban planning and infrastructure management (Lemke et al., 2020) (CMMI).³ These models clarified technological trajectories but largely excluded regulatory procedures, stakeholder coordination, and legal compliance essential to permitting.

Hybrid approaches emerged to address these gaps. Wendler (2012) highlights maturity models' adaptability across sectors. Ochoa-Urrego and Peña-Reyes (2021) conducted a systematic review underscoring digital maturity models' role in transformation. Kafel et al. (2021) proposed a multi-dimensional public-sector model covering management structures, employee competencies, and stakeholder engagement. Hjelseth's L+I+C framework emphasises the integration of legal requirements, information systems, and construction practices to reflect the complexity of e-permitting (Hjelseth, 2013).

Despite these advances, BIM and GIS maturity models often fall short in addressing the procedural complexities of municipal permitting. While they excel at technological integration and data standardisation, they typically omit organisational and regulatory dimensions such as rule-based compliance checks, multi-stakeholder coordination, and legal accountability. In recognition of these gaps, recent research has proposed more holistic frameworks. Janssen et al. (2017) extended e-government maturity concepts to "smart governance," integrating citizen-centric services with support-office interoperability, yet their model overlooks domain-specific criteria for construction regulation (Layne & Lee, 2001). The European Network for Digital Building Permit (EUnet4DBP) initiative likewise emphasises interoperable tools and methods for permit digitalisation, encouraging shared ontologies and interdisciplinary collaboration. However, the initiative falls short of defining a detailed, diagnostic maturity assessment tool (Noardo et al., 2022; EuroSDR 2020). Specifically, it provides high-level guidelines for data exchange and shared ontologies but does not articulate fine-grained maturity criteria, structured evaluation procedures, or sequenced improvement roadmaps that

municipalities can apply to benchmark their digital permit processes and plan targeted interventions.

Empirical studies of building permit digitalisation have documented that most permit authorities remain in low maturity stages, characterised by electronic document management and basic online portals. A recent perspective article notes that while automated code-checking and data integration show potential for efficiency in procedures, only a handful of pioneering cities have advanced to mid-level maturity, where rule engines and GIS-linked dashboards support semi-automated reviews (Ataide et al., 2023). Similarly, EuroSDR's 2020 report on digital building permits highlights that although several European municipalities piloted online submission platforms, only a few of them achieved integrated workflows that include application, review, and approval, emphasising continuous barriers in data interoperability and organisational readiness (Noardo & Malacarne, 2021).

Empirical Insights and Pilots

Studies reveal that most permit authorities remain at early maturity stages, characterised by electronic document management and basic online portals. Automated code-checking and GIS-linked dashboards are rare outside pioneering cities (Ataide et al., 2023). Pilot programmes such as Finland's RAVA3Pro and Estonia's e-construction portal demonstrate that targeted digital tools can reduce processing times and improve compliance accuracy, even in resource-constrained settings (Jakobson, 2023; Lavikka & Kallinen, 2024) (CHEK Maturity model and roadmap).⁴

Persistent Barriers and Research Gaps

Despite these advances, interoperability challenges, legacy systems, limited digital skills, and regulatory uncertainty continue to hold back progress (Mêda et al., 2024; Noardo et al., 2022). Generic frameworks like CMMI, the Common Assessment Framework,⁵ and the TOE model⁶ provide high-level guidance but lack domain specificity for permitting operations. Taxonomies developed by Fauth et al. (2024) offer conceptual clarity but do not prescribe actionable roadmaps.

In response to these observed shortcomings, toolkits and guidelines have emerged to guide practitioners through staged digital adoption. The European Commission's "Toolkit on Digital Building Permits for Municipalities"⁷ outlines maturity stages from paper-centric processes to advanced BIM-GIS integration, accompanied by templates, training modules, and open-standard recommendations to prevent dependency on authoring software. However, such toolkits typically provide prescriptive roadmaps without embedded diagnostic assessments that measure an authority's current baseline or generate customised improvement strategies. This gap highlights the need for validated maturity models that combine evaluation accuracy with implementation guides.

Open research questions persist regarding the optimal granularity and scope of maturity assessments in the permitting context. Key debates include whether maturity criteria should prioritise technological readiness over organisational capacity, how to weight interoperability versus data quality, and the degree of transparency the digital maturity should meet. Moreover, the rapid evolution of regulatory expectations, driven by sustainability mandates, resilience planning, and automated compliance checks, demands maturity models capable of adapting in parallel with policy changes. Addressing these gaps will require interdisciplinary research that combines insights from software engineering maturity models, e-government cases, and domain-specific research on building regulation.

Overall, while BIM and GIS models provide valuable templates for technological progression, and e-government models offer organisational perspectives, the building permit domain requires a customised maturity model. Such a model must integrate procedural criteria, stakeholder coordination, and legal compliance, with organisational, technological, and informational dimensions. The following section introduces the CDBPMM (Ataide, M. et al., 2023), designed to fill this gap in the maturity of the permitting process framework by delivering a customised assessment tool to fit the needs of the municipal permitting procedures.

Method

The Value and Context of Maturity Assessment

Maturity models offer a structured methodology for evaluating the digital readiness of permitting processes by establishing clear benchmarks across various dimensions. Through a systematic combination of evaluation criteria and progression levels, these frameworks enable municipalities to identify operational deficiencies, such as manual submission bottlenecks, fragmented data repositories, and inconsistent rule enforcement, and to translate insights into pragmatic, sequential improvement plans. This strategic approach aligns digital transformation initiatives with broader municipal objectives, including enhanced regulatory transparency, more reliable decision cycles, and conformity to sustainability directives, hence reinforcing the role of permitting as a foundational element in sustainable urban development.

The context for applying maturity assessment to building permits is characterised by several persistent challenges. First, the reliance on paper-based workflows carries redundant data and compromises process transparency. Second, information barriers within and between municipal departments inhibit collaboration between departments and complicate integrated rule checking, particularly when linking BIM and GIS datasets. Third, the absence of standardised data schemas and interoperability protocols undermines efforts to automate compliance validation and to generate actionable analytics. By synthesising perspectives from academic research, public-sector practice, and industry standards,

maturity models contextualise these issues within an evaluation framework, guiding authorities towards solutions that address technology adoption, organisational change, and information governance.

Reviewing existing maturity approaches reveals a spectrum of focuses and limitations: software engineering models excel in process accuracy but overlook regulatory complexity; e-government frameworks emphasise citizen engagement and service provision but lack technical depth in construction domains; BIM and GIS models address data integration but seldom incorporate procedural or governance criteria. This divergence highlights the necessity for a customised model that combines these features while targeting the specific demands of digital permit systems. The subsequent presentation of the CDBPMM responds directly to that need, offering a comprehensive, validated instrument explicitly designed to measure the digital maturity of municipal permitting processes.

CHEK Digital Building Permit Maturity Model

The CDBPMM⁸ emerges from the collaborative efforts of the Horizon Europe CHEK project, which seeks to fill a critical gap: the absence of a validated framework customised to the building permit processes. Traditional maturity models, embedded in software engineering, BIM adoption, GIS capabilities, or broad e-government strategies, offer valuable insights but fail to capture the procedural complexities, building regulatory requirements, and stakeholder engagement that characterise permit workflows. The CDBPMM was created to assess municipal digital readiness, expose capability shortfalls, prescribe an actionable progression path, and facilitate process evaluation and standardisation across departments.

Its methodological foundation went through four phases. The first phase involved a systematic literature review of existing maturity frameworks from domains including process management, BIM, GIS, and e-government, alongside examination of the CHEK consortium's initial process maps. In the second phase, elements from reference models were filtered into high-level categories, capability sets, and KMAs, which were then aligned with the envisioned end state of a fully digital permit system. During the third phase, level design principles from CMMI and domain-specific schemas (such as Succar's BIM Maturity and URISA's GIS frameworks) guided the calibration of 35 KMAs organised into four categories: Process, Organisation, Technology, and Information (Succar, 2010; URISA, 2013). Semi-structured interviews and questionnaires conducted with municipal practitioners and technology specialists refined terminologies, level nominations, and assessment criteria. Finally, the fourth phase structured dependencies among KMAs to generate a logical roadmap: foundational capabilities must be established before advancing to complex functions, ensuring that each municipality's action plan reflects its contextual constraints and priorities (Figures 3.1 and 3.2).

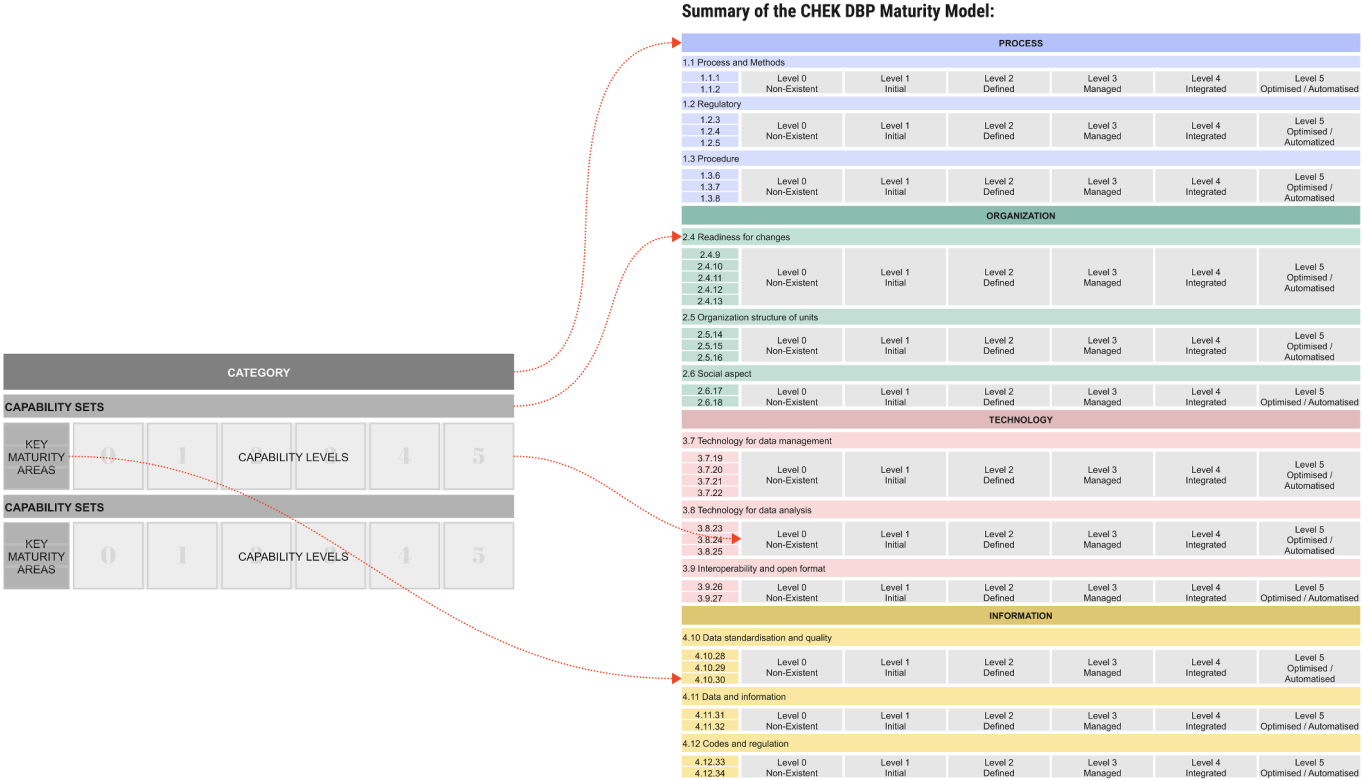


Figure 3.1 CDBPMM structure.

CATEGORY		DESCRIPTION	CAPABILITY SET		DESCRIPTION
1	PROCESS	Encompasses aspects related to the permitting process itself, including the steps, procedures, methods, and overall understanding of how the process flows.	1.1	Process and Methods	This covers the overall workflow, steps, and methodology of the permitting process. It looks at how well the process is defined, mapped, understood and followed by all stakeholders.
			1.2	Regulatory	This focuses on how standardized the process is to regulations and codes. It involves having benchmarks, indicators, quality controls, and standardized procedures to ensure regulatory compliance.
			1.3	Procedure	This looks at the accessibility, transparency, timelines and overall ease of use of the permitting process for stakeholders. It involves clear communication, tracking, and efficient flows of information.
2	ORGANISATION	Covers aspects related to the organisational structure, capabilities, readiness for change, and the people involved.	2.4	Readiness for changes	This focuses on the organizational and human readiness to adopt new digital technologies and processes. It looks at openness to change, infrastructure, and strategic planning for digital transformation.
			2.5	Organisational structure of units	This covers how the organization structures its departments, teams, training, and personnel dedicated to implementing digital technologies like BIM. It involves strategic planning, expertise, and knowledge management.
			2.6	Social aspect	This looks at the overall knowledge and level of expertise of the staff and stakeholders involved in the permitting process. It involves assessing skills, sharing knowledge, and building competencies.
3	TECHNOLOGY	Deals with the various technologies utilised throughout the permitting process for data management, verification, visualisation, analysis, and exchange.	3.7	Technology for data management	This focuses on the systems used to store, submit, communicate, and manage data throughout the permitting process. It ranges from fully paper-based to integrated digital platforms.
			3.8	Technology for data analysis	This covers the technologies available for validating, visualizing, analyzing and checking project data for regulatory compliance and quality control.
			3.9	Interoperability and open format	This looks at how capable the technologies are at integrating and exchanging data across different formats, platforms, and systems involved in the process.
4	INFORMATION	Focuses on the data standards, formats, regulations, and overall information used within the process.	4.10	Data standardisation and quality	This focuses on having guidelines, protocols, and standards in place to ensure high quality, standardized data. It involves monitoring quality control and refinement of standards.
			4.11	Data and information	This focuses on the types of data utilized throughout the permitting process, including both the building/intervention design data and the city context data.
			4.12	Codes and regulation	This looks at how digitized, accessible, and machine-readable the codes and regulations are. It ranges from paper to fully parameterized and integrated rule databases.

Figure 3.2 CDBPMM general description.

Within the Process category, the model assesses submission workflows, rule-validation mechanisms, review and coordination across disciplines and departments, and stakeholder communication and feedback loops. Each KMA features precise indicators, such as the level of digitalisation and automation in document flow, the integration of rule engines for code compliance, and the presence of structured feedback channels that track progression from analogue submission procedures to fully integrated platforms offering real-time status updates and automated compliance checks (Figure 3.3).

The Organisation category evaluates governance frameworks, leadership engagement, and organisational capacities. Maturity advances as municipalities move from reactive, department-specific initiatives to proactive, centralised digital governance, marked by dedicated transformation offices, interdisciplinary coordination groups, and formal data management roles. Assessment criteria examine the existence and effectiveness of participatory forums involving architects, planners, IT specialists, and municipal officers, which serve to align strategic objectives with operational workflows (Figure 3.4).

PROCESS							
CS	KMA	Level 0 Non-Existent	Level 1 Initial	Level 2 Defined	Level 3 Managed	Level 4 Integrated	Level 5 Optimised / Automatised
1.1 Process and Methods	1.1.1 Understanding of the process and mapping of steps	There is no clear understanding and the process is not formally mapped.	The process is mapped at a general level and publicly accessible.	The process steps are identified and documented, providing a clear understanding of the process. The digitalised process is defined and it is a visible step on initial steps.	The process is mapped in detail and integrated into a digital environment for the management of all technical-administrative processes. However, not all steps are fully implemented.	The whole process is mapped and automated in a digital environment. All steps are implemented and technical-administrative processes can be managed with the aid of connectivity.	The whole process is mapped and automated in a digital environment. There is automation throughout the process to ensure that efficiency, constant monitoring by feedback and lessons learned.
	1.1.2 Stakeholders are aware of process steps and required information they must provide	There is no clear understanding and the process is not formally mapped.	Stakeholders have limited understanding of the process steps. Lack of awareness regarding the required information and documentation needed to complete the process. Minimal guidance provided about their roles and responsibilities in the process.	Stakeholders have clear understanding of the process steps. There are guidelines and standards to assist about their roles and responsibilities in the process.	Comprehensive process documentation and checklists enable stakeholders to self-serve. Online resources help stakeholders prepare required information. The digital solution reduces ambiguity.	Stakeholders are fully aware of the steps, the required information and documentation needed to complete the process. Data can be validated and shared digitally. However, they work in their own digital environment.	Stakeholders are fully aware of their roles in the process. There is simultaneous communication and support during all process progression and across the same source of data.
	1.2.3 Benchmarks and key performance indicators	There is informal or no quality control plans, neither for process, data, or documentation. There are no performance benchmarks for processes or services.	Process, data, and documentation standards are initially defined. Quality targets and performance benchmarks are set, however, there is no official measuring.	Process, data, and documentation standards are defined and explained. Key performance indicators (KPIs) and benchmarks are clear defined, but not officially measured.	Proactive quality monitoring is conducted through audit checks and structured reviews. Some KPIs are measured, but not all of implemented metrics provide clarity into performance in targets.	Performance against benchmarks and KPIs are measured and monitored. KPIs and performance benchmarks are incorporated into daily management and performance improvement systems.	Quality improvement and adherence to regulations and codes are continuously aligned and refined. Benchmarks are continuously refined to ensure higher possible quality in processes and services.
1.2 Regulatory	1.2.4 Standardised process	There are no guidelines or standards for the processes.	The process is mapped primarily from an administrative perspective. The technical checks after the process are performed by individual knowledge of technicians based on the normative documents. There are informal internal guidelines to help technicians in the steps of process to follow.	In addition to the process map and the normative documents, technicians receive support from a detailed guideline that defines the specific checks to be performed for each step of the process, with comprehensive instructions and specifying the details that need to be followed during each stage.	The supporting guideline for technicians provides a comprehensive list of all planning and construction aspects that need to be checked for each phase of the building permit process. The guideline serves as a reference tool, ensuring that technicians have clear instructions on the specific aspects they need to assess.	The guideline is continuously refined to reflect lessons learned. Quality improvement and adherence to regulations and codes are continuously aligned and refined. The guideline to support the technicians is updated and monitored based on the KPIs and benchmark measures to simplify the process.	There is a detailed standardised process, defined at municipality level for all stakeholders involved in the process where a constantly monitored and on-time updated.
	1.2.5 Data templates, use of common data formats, and documentation requirements	There are no data templates, use of common data formats, or documentation requirements.	Unlimited identification of data formats, templates, or documentation requirements. Inconsistency in data formats and documentation across different permit processes or projects.	Some steps of the process have standardised data formats, templates and documentation. However, the efforts to create a single standardised data is ongoing.	There are standardised data formats and templates. They are not followed by external stakeholders and there is only an informal quality control verification.	There are standardised data formats and templates. They are easily accessible by all stakeholders and there is a control to maintain the application of the templates. Best practices are identified and shared across all the stakeholders.	There are standardised data formats and templates following open standards. Continuous improvement are implemented to enhance the use of the open formats. Automated control is done during the process.
	1.3.6 Timeliness and response time	There is no clear knowledge of timelines and response time is not pre-defined.	There is an informal understanding of the timelines, but they are not clearly communicated and mostly not followed.	There are defined timelines for each step of the process. They are internally communicated but not clearly communicated to all stakeholders.	The timelines are clear defined and communicated. They are not followed by external stakeholders and measurement or no efforts to optimise the timelines.	Timeliness and response time are clear defined and communicated. They can be monitored by all stakeholders. Measurements are done to allow optimisation of timelines.	Timelines are monitored and measured in all steps of the process. They are continuously open to all stakeholders to enhance the use of the open formats. Automated control is done during the process.
1.3 Procedure	1.3.7 Accessibility of stakeholders	The information may be accessible through physical documents.	Unlimited accessibility to the stakeholders involved in the process. The information has a different source and changes workflow for each stakeholder.	Stakeholders can have access to the same source of information and the defined workflow are standardised. However, changes made in the data have to be provided to other participants in the process.	Automated workflows push permit status alerts and relevant information to some stakeholders (e.g. applicants).	There is a unique source of data where all stakeholders can retrieve their data. All exchanges happen inside the same digital ecosystem. The data is shared and updated to all stakeholders.	A digital ecosystem enables access to information, include real-time data updates, interactive interfaces, decision-making capabilities, and stakeholders to actively engage and release the necessary information efficiently from the same source of data.
	1.3.8 Transparency	There is no transparency on the information workflow. Official stakeholders are not aware of what information is shared and what information is not shared by them, other than the final outcome.	There is limited access to information, and stakeholders have difficulty tracking and understanding the flow of information. The information is shared across and changes workflow for each stakeholder.	Stakeholders have access to the information that influences their workflow. Information on the process is not clearly communicated and documentation is not shared.	Real-time permit tracking with notifications is implemented. Performance metrics regularly monitored. Improved transparency might be through APIs.	The information is visible to all stakeholders, with the defined permissions. There is a clear workflow for data access and updates that can be followed by all stakeholders. External transparency might be through APIs.	Automated workflow tracking and advanced data analytics provide transparent and collaborative decision-making capabilities, and stakeholders to actively engage and release the necessary information efficiently from the same source of data.

Figure 3.3 CDBPMM – process.

ORGANISATION							
CS	KMA	Level 0 Non-Existent	Level 1 Initial	Level 2 Defined	Level 3 Managed	Level 4 Integrated	Level 5 Optimised / Automatised
2.4 Readiness for changes	2.4.9 Internal staff	Staff does not express openness to change or adaptation.	Less than 25% of staff acknowledge the need for digital transformation. There is a clear cooperation between limited individuals on digitalisation.	25-50% of staff participate in cross-functional teams to identify digitalisation needs and benefits. Regular meetings are held to discuss digital technology opportunities.	50-75% of staff embed procedure manuals about adapting digital innovations. Training opportunities adequately and readiness for new technologies.	Over 75% of staff are open to innovations. Defined processes in place for corporations on digital best practices.	Staff members are constantly seeking changes. They implement new group stakeholders to several digital best practices.
	2.4.10 Higher management	Management does not express openness to organisational changes or digital transformation.	The management supports the vision, however, a strategy is needed to direct the situation or digital progress including technologies such as BIM and GIS.	There is a movement to kickstart the implementation of digital processes, including BIM, GIS, or other technology. However, the initiative starts from the bottom-up. Management does not have clear plans supporting the implementation.	The management recognises digital innovation including BIM, GIS, or other technology. It promotes a strategy plan for the organisation. The effort for implementation starts from a top-down approach.	Digital innovations such as BIM, GIS, and/or other technologies are a part of the strategy. An implementation plan of the strategy goals has been promoted at all levels in the organisation.	Digital innovation planning is fully implemented and integrated into strategic planning documents. History of digitalisation and the possibilities of the utilization of digital technology supports the development of services provided.
	2.4.11 Infrastructure	Hardware/software infrastructure is not capable of supporting required tools for the digital permitting process.	Less than 20% of infrastructure can support required software. There are limited pilot permitting software and test servers, used by less than 20% members of the staff.	20-30% of infrastructure capable of supporting required software. 20-50% of staff have access to internet. Licenses or have a trademark. There is an internet network accessible for file sharing.	Up to 50% of infrastructure is capable of supporting required software. All data permitting software purchased or licensed. Redundant permitting servers. Cloud backup, common data ecosystem for management of data and file sharing.	All hardware and software required for the digital permit system are fully implemented. The permit database is database and integrated with other systems, and the network infrastructure enables data sharing both within and outside the organisation.	Continuous thorough capability of hardware/software. Established program for continuous infrastructure upgrades. Regular server refreshes, software updates, new feature additions.
	2.4.12 Legislative system	Not open for changes.	There is no flexibility for creating clear and well-defined laws from the existing legislation. However, there might be current ongoing efforts to simplify the process.	There are a few technical requirements within law texts that are clearly formulated. However, more than 50% of requirements are subject to human interpretation.	There is an effort at municipal level to ensure that the technical requirements in the normative texts are formulated in a clear and direct way, reducing subjective interpretation.	More than 50% of the legislation under the scope of the municipality have clear and easily interpretable normative text. In addition, the interpretation and simplifying the compliance checks.	There is an effort at regional or national level to minimise the subjective interpretation of the laws, facilitating the law interpretation and simplifying the compliance checks.
2.5 Organisational structure of units	2.5.13 Strategic objectives for data ecosystem implementation	There is no implementation strategy.	Implementation is conducted without a guiding strategy. There is a lack of awareness and understanding and limited use of tools. Processes are limited integration into the workflow and there is a lack of standardised processes.	The implementation strategy has some specific actionable details. There is a general plan of implementation, but processes are not fully integrated and there are no formal standardised guidelines for the implementation.	The implementation strategy is accompanied by comprehensive action plans and a monitoring system. The organisation recognises that data ecosystem encompasses technological advancements, process improvements, and policy changes.	The vision is shared by staff across the organisation and external stakeholders. The organisation works clearly and easily interpretable normative text. In addition, the interpretation and simplifying the compliance checks.	There is a culture of innovation and continuous improvement in data ecosystem practices. The organisation seeks for integrating smart knowledge (e.g., AI, data spaces).
	2.5.14 Dedicated personnel	There is no staff fully dedicated to work on BIM, GIS, or other technologies.	Up to 25% staff work part-time on BIM, GIS, or other technologies.	Small team of 3-5 staff dedicated to implementing BIM, GIS, or other technologies within the organisation and internal processes.	Multiple teams working full-time with BIM, GIS, or other technologies. Each team is dedicated to specific part of the process or data technology. There are high individual and collective knowledge on digital processes and tools.	There is a department dedicated to digital data, such as BIM, GIS or other technologies. The department is distinct part of the process or data technology. There is high individual and collective knowledge and sharing is stimulated.	There is a team inside the department working with digital processes dedicated to maintaining the quality of process, data, standards, and guidelines.
	2.5.15 Training, preparation and support	There is no type of training or support.	There is a lack of dedicated training or support for technicians to realise BIM, GIS, or other technologies needed status. There is no external training as needed. However, less than 5 hours of training per employee per year is stipulated.	There are documented training requirements for digital and data. Staff requires formal course. Annual training is provided to staff members that work directly with BIM, GIS, or other technologies. 10-20 hours of training per employee per year is stipulated.	Training requirements are managed to meet competency and performance objectives. Regular training is provided to staff members that work directly with BIM, GIS, or other technologies. 10-20 hours of training per employee per year is stipulated.	Training plans based on roles and competencies. Training program uses real work scenarios and outcome learned. There is support inside the organisation and external partners. 20-40 hours of training per employee per year.	Training is integrated into organisational strategies. On-demand training program are established to cater to the organization's needs and requirements. Training programme to access training resources when necessary. More than 40 hours average training per employee per year.
2.6 Social aspect	2.6.16 Overall knowledge of technicians	No technicians have knowledge or practical experience in data technology (BIM, GIS, or other).	Less than 25% have basic conceptual knowledge, minimal skills. They may have basic understanding of concepts but lack practical skills and experience in using it.	25-50% have basic knowledge, while less than 25% have practical skills on the tools.	50-75% of staff members require use data tools and spatial analysis to work on permit workflow. There is a tendency to pursue formal certification to expand capabilities.	Over 75% have good working knowledge and skills on required data technologies and spatial analysis. 20% of individuals are experts in BIM, GIS, or other technology.	50% of the technicians are experts in BIM, GIS, or other technology. They experience and serve as mentors for other staff members. They are constantly sharing their knowledge and experience to build a strong digital ecosystem competency for the organisation.
	2.6.17 Stakeholders' knowledge	None of the stakeholders work with data technologies (BIM, GIS, or other).	Up to 10% of key stakeholders use basic digital data. However, there is no data reuse throughout the process between stakeholders.	50-80% of key stakeholders use digital data such as BIM or GIS. Primarily isolated use, minimal interoperability, collaboration, and BIM coordination or data re-use.	More than 80% of key stakeholders use shared data in a digital ecosystem. Most data is accessible in multiple stakeholders.	100% of key stakeholders use integrated digital ecosystem. All data is shared and accessible by the various stakeholders across the entire value chain. Data is available through the information system digital data log. BIM-GIS in their specific domain.	Data fully integrated across all stakeholders and steps in process with key data sharing and collaboration. Data is consistent throughout the information system digital data log. BIM-GIS in their specific domain. Data is shared on data use and value creation.

Figure 3.4 CDBPMM – organisation.

In the Technology category, the model reviews IT infrastructure maturity, system interoperability, and platform scalability. Initial levels reflect reliance on standalone or legacy systems; higher maturity allows for modular, cloud-enabled architectures with standardised APIs that facilitate consistent BIM and GIS integration. Detailed evaluation assesses technical documentation quality, proprietary platform risks, and microservice adoption, ensuring that digital systems remain robust and adaptable (Figure 3.5).

The Information category explores data governance, quality assurance, metadata standards, version control, and analytic capabilities. Municipalities progress from isolated data systems, often comprised of scanned PDFs and manually tagged records, to centralised repositories featuring consistent ontologies. Advanced maturity expects the deployment of analytics dashboards, predictive models, and AI-driven insights to forecast application backlogs, detect anomalies, and optimise resource allocation (Figure 3.6).

TECHNOLOGY							
CS	KMA	Level 0 Non-Existent	Level 1 Initial	Level 2 Defined	Level 3 Managed	Level 4 Integrated	Level 5 Optimised / Automatised
3.7 Technology for data management	3.7.18 Data management environment and network platform	No platform support.	Digital platform only for submission, communication and data exchange between applicant and building authority. There is no digital process for data management.	Closed or proprietary tools supporting the different steps. There is a digital tool for managing data, however, not 100% of the information is digitally accessible through it. There are different sources of data depending on the step of the process.	Modular platform: The digital tool stores and manages the data through the different steps of the process. The organisation has access to the same data, but external stakeholders' data is not integrated.	Open APIs based microservices ecosystem. The tool for data management, works for sharing, storing and managing the data. All internal staff of the organisation can contribute, while external stakeholders can interact with the data according to defined permissions.	Dedicated data space based ecosystem. There is structured working collaboration with all stakeholders of the organisation and automated workflow.
	3.7.19 Data storage repository and documents	The process is analog. Information is stored in paper files and documents.	There is a repository for files of archival purposes. There are digital document storage but no centralised repository. Multiple electronic drives and folders.	There is a centralised repository for the data. There are digital document storage and digital processes that serve as a database and can be accessed by internal staff.	Formal data governance for repository. Lifecycle management with archiving and retention policies.	Centralised digital repository. Integrates all data throughout the process with building, archiving, and governance. Integrated with data management and accessible by all stakeholders according to assigned permissions. Automated backups, archiving and governance.	There is possibility of automating tasks and providing the platform with the data management. The effectiveness of the process is measured across and structures within data between various data tabs.
	3.7.20 Submission system and identification (eg. electronic signature)	There is not a submission platform. Signature is done manually.	Documents are submitted digitally using not machine-readable formats. The signature is not machine recognizable.	Required information is submitted in a digital ecosystem, using machine-readable data. Models are electronic signed, however, other required information is not automatically verified.	Signature application is available covering all the required information for the automatic validation is performed. Internal systems are integrated with the applicant's portal, directly or via API.	Integrated validation of submission packages required files and data. An application within the process ecosystem enables the digital signing of the corresponding submitted content.	Documents and models are digitally signed, integrated within submission process and with the ID authorities. There is automated checking of the identification validation emitted in the process.
	3.7.21 Communication system	The communication is done in an analog only.	The communication is done digitally. However, there is a lack of one-channel and procedures for timely and effective communication between stakeholders.	There is a tool that allows communication internally on the organisation. However, external communication is done in a separate digital environment.	An online portal is introduced for external stakeholders to track permit status, submit documents, and receive notifications. Internal systems are integrated with the applicant's portal, directly or via API.	There is an official tool that allows communication between different stakeholders, both internally and with the ID authorities. Standard APIs enables communication with other external stakeholders.	There is an official integrated tool that allows communication between different stakeholders, both internally and with the ID authorities. Automation and digital tools are integrated to streamline communication and enhance responsiveness.
3.8 Technology for data analysis	3.8.22 Verification of procedural data	Manual inspection of physical formats and documents. Analog process.	Data can be obtained in a digital format to be verified. Electronic information analysis is done using software is unstructured and irregular.	Digitalization of data with semi-digital verification process. Software usage is critical verified organisation.	Procedural data is provided in machine-readable formats. Basic analytical functionalities for data verification.	Advanced analytical functionalities for data verification. Flexibility, operational and decision-making are introduced. Open interfaces allow for automatic connection with databases representing different system information (e.g. CA, professional regulations and notifications, etc.).	Fully digitised and automated data verification. Operational and decision-making can be automatically verified and validated in the connected databases. Procedural data is integrated in the cloud and supported by high-performance computing for decision making.
	3.8.23 Data inspection and visualisation	Manual inspection of physical models or drawings of planned objects. No use of software applications.	3D map data can be obtained to produce 2D deliverables. Proprietary Software is used to produce and deliver a 2D to produce 2D renderings of planned objects. Usage of software is unstructured and irregular.	3D only models can be obtained to produce 2D deliverables. Proprietary Software is used to produce and deliver 3D models of planned objects in specified proprietary formats. Software usage is limited within an organisation or team.	Deliverables are provided in open file formats. This based system visualisation in 2D and 3D space by all stakeholders as well as basic analytics functionalities.	Advanced analytical functionalities for operational decision-making are introduced. Open interfaces allow for exchange of data between specialised software applications and real-time data integration in a system of systems infrastructure (see highlines).	Powerful/complex visualisation through model the external impacts of potential change in real-time and providing integrated visualisation with interactive measures/verifications, such as AR/VR, to support decision-making for non-quantifiable phenomena in a potential model non-linear developments.
3.9 Technology for data analysis	3.8.24 Data validation for building data	There is only manual validation of the data, based on human input.	Manual validation, based on official data requirements, supported by tools that allow visualisation and manual inspection of the data.	(Semi)automatic validation, based on standardised formal data requirements.	Advanced validation rules implemented with complex logic and integration. Automated notifications of issues needing manual review.	Automatic validation against machine-readable standardised data requirements.	Automatic validation against comprehensive machine-readable standardised data requirements. Support for automatic forcing the data.
	3.8.25 Data validation for geospatial data	There is only manual validation of the data, based on human input.	Manual validation, based on official data requirements, supported by tools that allow visualisation and manual inspection of the data (including consistency and cross-checking).	(Semi)automatic validation, based on standardised formal data requirements.	Advanced validation rules implemented with complex logic and integration. Automated notifications of issues needing manual review.	Automatic validation against machine-readable standardised data requirements.	Automatic validation against comprehensive machine-readable standardised data requirements. Support for automatic forcing the data.
	3.8.26 Content analysis and Regulations' Checking box	Manual inspection of rules and regulations.	Manual checking: content analysis and rule checking are done in a digital environment, supported by data experts or reporters.	Semi-automatic checking of rules and regulations, based on digital building data.	Automatic checking based on digital data. Automated checking is done based on project for a limited number of rules.	Automatic checking based on multiple digital data, eg. BIM/GIS, depending on the rule, including mostly simple analysis.	Automatic checking based on multiple digital data, eg. BIM/GIS, depending on the rule, including all possible regulations and complex analysis.
	3.9.27 Data format interoperability	No use of digital formats.	Use of mainly proprietary formats, isolated capacity to manage and create open source file. Limited support for exchanging data with external systems using standard formats.	Possible use of open formats, however, proprietary formats are still the main practice.	Use of open formats in internal data exchange. However, there are all interoperability related issues when exchanging with external stakeholders.	Support of only open format files, following the standards and tool practices for data exchange. Full capability of data exchange within the process and among the different stakeholders.	There are APIs to facilitate interoperability between different systems in common language and protocol for different systems to communicate and exchange data internally and externally.
3.9 Interoperability and open format	3.9.28 Building data to geospatial data (eg. BIM to GIS)	No use of building or geospatial data.	Joint visualisation in a geospatial environment, with manual location of building data in geospatial data.	Joint visualisation in a geospatial environment, with correct building data georeferencing.	Conversion of building to geospatial data through semantic mapping and building data georeferencing.	Thorough automatic mapping, georeferencing and conversion of building to geospatial data (georeferencing, geometry semantics, structure).	Automatic communication and real time on the right through mapping, georeferencing and conversion of the two resources in the respective environments.
	3.9.29 Geospatial data to building data (eg. GIS to BIM)	No use of building or geospatial data.	Joint visualisation in a building data environment, with manual location of geospatial data in building data.	Joint visualisation of geospatial data in a building data environment, with automatic reciprocal registration.	Conversion of geospatial to building data through semantic mapping and automatic reciprocal registration.	Thorough conversion of geospatial to building data (georeferencing, geometry semantics, structure). Manual interventions, possibly supported by partially automated routines.	Automatic through mapping, georeferencing and conversion. Artificial intelligence and Machine Learning methods, enabling precise connection to further data sources to achieve reliable resulting building data.

Figure 3.5 CDBPMM – technology.

Each KMA assesses the maturity across six levels: from Level 0 (Non-Existent) to Level 5 (Optimised/Automatised). Level 0 indicates the absence of formal digital capability; Level 1 (Initial) corresponds to rudimentary digital outputs supporting primarily manual workflows; Level 2 (Defined) corresponds to documented procedures with basic system support; Level 3 (Managed) signifies cross-departmental integration of processes and data

INFORMATION							
CS	KMA	Level 0 Non-Existent	Level 1 Initial	Level 2 Defined	Level 3 Managed	Level 4 Integrated	Level 5 Optimised / Automatised
4.10 Data standardisation and quality	4.10.30 Data standards and guidelines	There are no guidelines or data requirements specification.	Human readable data requirements specification as basic guidelines, documentation protocols or data standards.	Standard-based data requirements. There are basic guidelines for data standardisation, such as training manual and delivery standards.	Standard-based and Machine-readable data requirements. The organisational standards are aligned with industry standards.	Detailed and comprehensive standard-based and formal data requirements covering geometrical, semantical, structural, syntactical, organisational, and legal aspects enabling easy interoperability and usability.	Organisational modification to Model View Definitions and Information Delivery Manuals are balloted for inclusion in industry standards. Data standards and guidelines are fully integrated into the organisation's policies.
	4.10.31 Data quality control	There are no quality control of data.	There are informal quality control plans.	Quality targets and performance benchmarks have been set to maintain high standards.	Proactive processes for monitoring guidelines through audits and spot checks. Metrics track quality trends.	There are comprehensive quality plans to ensure accuracy and consistency. Guidelines are tightly integrated with data validation workflows. Automated reporting on adherence and anomalies.	Quality improvement and adherence to data standards are consistently prioritised and refined. Automated feedback loop from lessons learned.
4.11 Data and information	4.11.32 Building/intervention design data	The data is analog. Use only of 2D drawings.	2D drawings, with basic semantic data information.	Building model with geometric data and semantic data. (eg. BIM)	Building model with standardised data.	Building data is compliant to open standard formats (eg. IFC) and to specific standard-based data requirements (e.g. MVD, IDS etc.) including metadata.	Integrated dynamic building model. Virtually all authoritative information loaded with metadata and linked to fully integration of data ecosystems.
	4.11.33 City context data	The data are analog. Use of only 2D maps	There is a city model; however not all model is populated with the correspondent semantic data. Use of geospatial data, eg. GIS.	3D city model is more than 80% loaded with semantic data; however the data is not standardised.	3D semantic city model with standardised data.	Open-standard based 3D city model. Specific data requirement compliant. City model with relevant information loaded with metadata however, not linked to other data systems (eg. BIM).	Integrated dynamic 3D city model, digital twin. Virtually all authoritative information loaded with metadata and linked to fully integration of data ecosystems.
4.12 Codes and regulation	4.12.34 Regulations formats	Natural language, needing interpretation and referring to several external laws and definitions.	Unambiguous natural language, containing the needed definitions and related rules, including exceptions. No reference to customs, priorities of different governance levels (municipal, regional, national) are clear.	Regulations are also defined as (semi)formalised language or pseudocode	Regulations are machine-readable	Regulations are machine-readable and refer to standardised information. Fully parameterised rules integrated across platforms	There is a database used as repository of rules, allowing the creation of new rules according to the updates in the regulation.
	4.12.35 Regulations accessibility	Normative texts can be consulted only in paper and/or pdf format, in the same way by both internal and external stakeholders.	The normative texts can be consulted online according to queries and through a webGIS system associating the regulations to zoning areas	The normative texts can be consulted online according to specific queries in a geographic system. Limited integration and dependencies are managed manually.	Validation rule sets formalised with version control. Central repository established with some real-time updating. Web-based portals for external access, data can be imported into checking software, directly or via APIs.	There is a tool allowing the automatised analysis of data contents and check compliances according to the defined rules. Automatised synchronisation and versioning from centralised repository.	The codes are available in a machine-readable format and there are available tools to support the translation of non-translated rules, or to modify parameters in the existing available rules.

Figure 3.6 CDBPMM – information.

exchange; Level 4 (Integrated) represents quantitative management through performance metrics and feedback loops; and Level 5 reflects an adaptive, self-improving ecosystem that leverages predictive analytics, automated rule engines, and stakeholder co-creation.

Three testing rounds, within CHEK, validated the model's utility. Municipal staff tested the granularity of the category-specific assessments and the clarity of the dependency-aware roadmap. Technical teams highlighted the value of detailed interoperability and data governance diagnostics, which exposed unseen integration hurdles. Governance bodies noted that the visual maturity profiles facilitated stakeholder alignment by translating abstract digital goals into tangible, measurable objectives. These experiences confirm that the CDBPMM provides a robust, adaptable framework for supporting comprehensive digital transformation in building permit processes.

Results

Results from Model Application

The results generated by the CDBPMM combine maturity assessment with strategic planning guidance, facilitating a clear understanding of municipal digital maturity alongside actionable next steps. Upon completion of the self-assessment, which examines 35 KMAs across the Process, Organisation, Technology, and Information categories, the model produces four integrated outputs.

The first result is visual charts that show how each category and capability ranks on a scale. Using radial charts, it compares current performance with target goals, making it easy to spot strengths and areas that need work. This helps stakeholders quickly understand complex data and agree on digital priorities.

Second, the dependency links between different competencies show which basic elements, such as metadata governance or simple rule-checking scripts, must be in place before advancing to more complex features like automated decision-making and support. By mapping these dependencies, the model ensures that maturity progresses in a logical order and helps prevent poorly timed or misdirected implementation.

Third, the strategic roadmap connects existing and desired maturity levels with a clear action plan, considering also dependencies through KMAs. For each maturity area, it outlines phased steps, suggests how to allocate resources, and provides reference materials from the broader CHEK toolkit. For example, a municipality might first be guided to create a collaborative environment across departments and set data protocols before moving towards more advanced stages like deploying integrated BIM-GIS platforms. The roadmap balances ambition with practicality, aligning recommendations with typical municipal limitations and staffing capacities.

Finally, benchmarking analytics use anonymised data from pilot projects to show how a municipality's maturity profile compares to others. With these

insights, local authorities can see how their digital progress stands against similar cities, encouraging shared learning and ongoing improvement. The assessment reports include rankings and benchmark scores defined by CHEK.

Collectively, these outputs highlight the two main roles of the CDBPMM: first, providing a clear, evidence-based assessment of complex technical and procedural aspects; and second, giving municipalities a structured, step-by-step plan to guide their digital progress in building permit processes. The model not only shows current strengths and gaps but also helps predict what investments and steps are needed to reach more advanced levels of maturity.

Summary and Analysis of Municipalities' Assessment Results

The preliminary application of the CDBPMM across four diverse municipalities confirmed its effectiveness in showing digital maturity variations and guiding strategic interventions. One municipality consistently achieved the highest maturity levels, particularly in the Process and Organisation categories, supported by ISO-9001 workflows and strong governance structures. In contrast, the other three municipalities clustered at lower maturity stages, sharing common weaknesses in Technology and Information, especially in areas like data standardisation and system interoperability. Across all cases, maturity in Process and Organisation generally outpaces Technology and Information, suggesting that cultural and procedural development often comes before digital and data capabilities. This pattern highlights the importance of strengthening IT infrastructure and data governance only after building solid organisational structures and efficient workflows.

Practitioners affirmed that the CDBPMM's maturity assessment and its accompanying roadmap were both useful and actionable. Users reported that the visual representation through maturity charts provided useful evaluation data in an intuitive format: by displaying current and target levels side by side, the visual profiles immediately revealed priority gaps, allowing teams to focus their efforts efficiently. This clarity was matched by the strategic roadmap, which transformed those insights into a phased plan tailored to municipal realities. Respondents emphasised that the roadmap's alignment with budgeting and staffing cycles made each recommended step feel attainable, and they valued the direct links to CHEK toolkit resources, templates, training modules, and technical specifications, which smoothed the transition from assessment to implementation. While some suggested grouping tasks into administrative work packages to better fit existing project structures, the overall feedback confirms that the CDBPMM effectively bridges maturity assessment with pragmatic, sequenced guidance.

The feedback derives from officers' use of the CHEK virtual assistant^{9,10} for assessing the maturity of their process and building a roadmap that guides them to reach CHEK benchmark maturity levels, demonstrating how the CDBPMM framework seamlessly bridges maturity assessment and strategic planning.¹¹

Discussions

Comparative Assessment

A comparative lens across existing frameworks reveals that the CDBPMM combines strengths while addressing common shortcomings. Software engineering maturity models such as CMMI excel in articulating process discipline and quantitative management but lack considerations for regulatory compliance, stakeholder heterogeneity, and public-sector governance. E-government models, notably Layne and Lee's (2001) staged approach and the United Nations e-Government Survey (Department of Economic and Social Affairs, 2022), the latter introducing the E-Government Development Index as a global benchmark,¹² foreground citizen engagement and digital service delivery. However, these models presume standardised backend architectures and omit domain-specific criteria essential to construction regulation, such as code validation routines and spatial data interoperability.

BIM maturity frameworks (e.g., the UK BIM Levels)¹³ and GIS maturity assessments contribute detailed guidance on data architecture, 3D visualisation, and geospatial analysis.

These models define progressive technical capabilities, from basic entity creation to fully federated data environments, but seldom address procedural dimensions like application workflow orchestration or performance measurement for permitting timelines. Moreover, their emphasis on project-level information exchange does not translate directly to administrative permit approval processes, where legal accountability and formal approvals introduce additional complexity.

Some hybrid models have attempted to bridge these domains by combining e-government principles with BIM/GIS data paradigms. Yet such efforts often remain conceptual, lacking empirically validated assessment instruments or prescriptive roadmaps. For example, the maturity model developed under the EUnet4DBP working group (Noardo & Malacarne, 2021) and the EUnet4DBP initiative outlined interoperability standards and maturity stages for permit digitisation, but did not deliver fine-grained criteria or automated evaluation mechanisms. Consequently, jurisdictions seeking to advance beyond pilot implementations lacked practical guidance on sequencing improvements or evaluating incremental changes.

By contrast, the CDBPMM integrates procedural accuracy, organisational aspects, technological infrastructure, and information management into an integrated framework. Its modular design allows municipalities to prioritise dimensions according to local objectives, whether reinforcing decision-making parties, codifying metadata frameworks, or piloting automated rule engines, while maintaining visibility on interdependencies. The explicit mapping of capability requisites ensures that early stage investments in process standardisation yield returns when more complex analytics or integrations are pursued. Moreover, the model's validation across diverse European contexts confirms

that its criteria are adaptable to different administrative structures and legal frameworks, distinguishing it from more rigid or narrowly scoped alternatives.

Challenges and Implementation Insights

Implementing maturity assessments in building permit settings unfolds several interrelated challenges. First, coordination across organisational units demands conscious governance structures and communication channels. Without ways to bring together stakeholders from different departments, digital projects risk becoming isolated, which weakens system compatibility and data consistency. Second, outdated IT systems and existing contracts with current vendors can limit the ability to adopt new platforms. This makes it necessary to use transitional setups, API-based integration, and step-by-step migration plans. Third, information governance must align various data sources, from scanned documents to GIS files, using standardised formats, version control, and quality checks. Without this, it becomes difficult to ensure reliable data analysis and automated rule checking.

Moreover, organisational resistance remains a critical barrier. Personnel may perceive digital maturity initiatives as threats to established roles or as adding to workloads without clear benefits. Addressing this requires robust change management: articulating the value proposition of maturity progression, linking assessments to professional development pathways, and demonstrating quick wins through pilot projects. Resource limitations further challenge implementation efforts, particularly in smaller municipalities with constrained technical personnel. Capacity gaps can be addressed through peer-learning networks, shared service delivery models, and regional support centres, which also promote scalability and operational efficiency.

Finally, changing regulations highlight the need for flexibility. As sustainability goals, energy rules, and resilience standards evolve, maturity models must include feedback loops to track these changes and update their assessment criteria. This could involve creating modular components that can be added or adjusted separately, helping the model stay in line with current policies and new technologies.

These challenges show that successful maturity assessment needs more than just diagnostic tools. It also requires supportive governance structures, adaptable technical systems, training and capacity-building efforts, and flexible policy frameworks. The CHEK project's wider toolkit, including action guides, training materials, and stakeholder engagement templates, demonstrates how maturity models can be part of broader change programmes, turning abstract assessments into real, lasting improvements.

Achieving multi-dimensional change requires coordination across processes, organisations, technology, and information management. Organisational structures should support cross-department decision-making and effective change management. At the same time, technology strategies must address outdated systems, proprietary dependencies, and maintenance liability. Information

governance needs to standardise metadata, manage document lifecycles, and ensure version control. Resistance often stems from perceived risks, lack of incentives, or limited digital skills. Framing digital maturity as a continuous improvement journey can help ease these concerns.

Limited resources make adoption more difficult, particularly for smaller municipalities, highlighting the need for scalable, step-by-step approaches and support through peer learning networks. Fragmented data and inconsistent formats reduce system compatibility, making open standards and shared data models critical. Projects like CHEK can show that roadmaps that account for system dependencies, combined with focused actions, can successfully address these challenges and support real progress in digitalising building permit processes.

Conclusions

The review of maturity models for digital permits shows that structured assessment tools are essential for helping municipalities navigate complex regulatory changes. The CDBPMM stands out for its ability to combine procedural, organisational, technological, and informational aspects into a single framework offering both analytical depth and strategic value. However, to remain effective, maturity models must be flexible and adapt to new technologies, changing policies, and the needs of different stakeholders.

For researchers, future studies should focus on validating maturity models over time, examining how gradual adoption affects permitting efficiency, compliance results, and sustainability outcomes. Comparing results across different legal systems, city sizes, and planning priorities can help determine how widely the model applies and what adjustments are needed for specific contexts. Researchers also look into automated assessment methods, using tools like natural language processing and machine learning to simplify data collection and improve objectivity.

Practitioners leading digital transformation should use maturity assessments as part of broader change programmes, not just as one-time diagnostics. Integrating CDBPMM evaluations into regular performance reviews, connecting maturity levels to key performance indicators, and coordinating cross-department governance groups can help turn strategic plans into long-term practice. Investing in capacity building, through focused training, peer learning, and pilot projects, can reduce resistance and support the cultural changes needed for successful digital adoption.

Policy makers play a key role in building the system needed for digital permitting. Regulations should require interoperability and open data standards, with clear rules for metadata, rule validation, and cybersecurity. Funding programmes can support progress by providing grants or technical help to municipalities that align with CDBPMM and CHEK benchmarks. Importantly, policy goals should go beyond basic compliance; by linking digital maturity to broader sustainability and resilience strategies, authorities can strengthen the

connection between efficient permitting and wider environmental, social, and economic outcomes.

In conclusion, maturity models like CDBPMM act as both mirrors and maps; they reflect current capabilities and guide the way towards fully digital, transparent, and sustainable permitting systems. When supported by a solid methodology and paired with clear, actionable recommendations, these models enable researchers, practitioners, and policy makers to work together in advancing the digitalisation of building permits, helping create more resilient and sustainable built environments.

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Data Availability

The datasets and tools underpinning this chapter are publicly accessible. Assessment questionnaires, pilot study results (including the CHEK maturity model testing phase data), and benchmarking datasets are available on the CHEK project's official website: <https://www.chekproject.eu/resources/data>.

The full CDBPMM, including its structure, KMAs, and scoring guidelines, is published on Zenodo: <https://zenodo.org/records/10276314>.

Notes

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4 Complexity in Building Permit Decisions

Beyond Pass and Fail

Judith Fauth, Nicholas Nisbet, Peter Nørkjær Gade, and Eilif Hjelseth

Introduction

In an era of accelerating urbanization and increasingly complex regulatory environments, the building permitting process remains a cornerstone of public safety, environmental stewardship, and urban development (Noardo et al., 2022). Traditionally conceptualized as a linear, rule-based system with binary outcomes, either ‘pass’ or ‘fail’, the building permitting process is often treated as a technical check against established codes and regulations. However, this oversimplification masks the intricate reality of how building permitting decisions are actually made in practice (Gade, 2020).

This complexity is perhaps best captured by a pair of lyrical observations from popular music. The Rolling Stones remind us that ‘you can’t always get what you want, but if you try sometimes, you just might find, you get what you need’ (The Rolling Stones, 1969). Coldplay, in contrast, poses the inverse: ‘when you get what you want but not what you need’ (Coldplay, 2005). In the world of building permitting, these phrases resonate deeply. Applicants may secure formal approvals without achieving functional or sustainable outcomes, while authorities may withhold approval not out of rigidity, but in pursuit of broader planning objectives. These tensions reflect the often-misaligned relationship between codified compliance and contextual appropriateness. Moreover, a study by Fauth, Bloch, et al. (2024) indicates that many stakeholders consider decision robustness more important than time savings.

Based on the expected impact of improving the building and available technologies for decades, one should expect a high degree in processing of building permit applications and likewise services. However, this is not the case for multiple reasons. A literature review study by Amor and Dimyadi (2021) concludes that numerous challenges remain to be addressed, which will likely keep researchers engaged for at least the next half century. However, practical implementations are still limited. One of the major challenges is presented this way: ‘The evolving solvers need to become more sophisticated, with support for the many important concepts found in buildings, as well as the needs of performance-based codes which are not sufficiently supported currently’ (Amor & Dimyadi, 2021).

This study intends to explore that our expectation can be misleading to expect either ‘Pass’ or ‘Fail’. This study therefore introduces the ‘Unknown’ as an embedded alternative in the system. It is important to have a holistic understanding of the system, including the legislation side, its interpretation in a given context, the logic for processing, and the relevant information in Building Information Modelling (BIM). This implies the need for further development of the system or manual processing. ‘Unknown’ must not be understood as a missing property in the BIM.

Building permitting involves more than the mechanical verification of compliance. It requires decision makers, ranging from permit administrators and inspectors to architects and engineers, to interpret regulations, assess non-compliances, and make judgements under conditions of uncertainty, limited information, and time pressure. These decisions are influenced by a mix of legal constraints, performance-based standards, contextual factors, and institutional practices (Fuchs et al., 2025). In this light, the notion of a purely objective, automated building permitting decision becomes increasingly untenable.

Despite the growing interest in digital building permitting, including automated compliance checking (ACC) (as described in Amor and Dimyadi (2021)) and BIM-enabled checking (such as in Solihin et al. (2020)), there is limited understanding of the nature of the decisions themselves. Most digital systems are designed to replicate or support rule-checking rather than the full scope of discretionary, interpretive, and strategic thinking that practitioners bring to the table (Fauth, 2021). This presents a critical gap in both practice and research: how can we model, support, or even automate building permit decisions if we do not yet fully understand what contributes to these decisions, what they comprise of, and how these are communicated?

This chapter addresses that gap by proposing a hypothesis about the structure and dynamics of decisions in building permitting. We start with understanding the decision as a basis for the main outcome from building permitting and as an indicator of the decision-making process. Drawing on literature, professional experience, and cross-jurisdictional reflections, we suggest that building permitting decisions are best understood as layered and conditional rather than binary. Specifically, we introduce a conceptual framework that distinguishes between different types of non-compliances; explores the role of tolerances, exceptions, and conditional approvals; and accounts for the influence of information gaps and procedural requirements.

The central research questions guiding this chapter are:

- What is understood as the binary outcomes of ‘pass’ and ‘fail’ and what goes beyond that?
- How can building permit decisions be classified?
- What kinds of non-compliances and tolerances are considered acceptable, and under what conditions?

To explore these questions, we adopt a hypothesis that the pass/fail model for permitting decisions is inadequate to describe actual outcomes. Given the

challenges of gaining access to formal decision data, due to confidentiality, legal constraints, and institutional opacity, this chapter offers a framework as a foundation for future empirical research and tool development.

Background

At the centre of the building permitting process lies the phenomenon of interpreting intent. While lawmakers provide a regulatory framework through building codes, these are not applied in a vacuum. Both applicants and administrators must interpret provisions within specific organizational, procedural, and local contexts (Baldwin et al., 2011). For instance, although a national code may require ‘adequate daylight’ in living areas, one municipality might define this using a minimum window-to-floor ratio, while another might assess it based on room orientation and function. Similarly, an applicant may consider a carport a ‘light structure’, but interpretations vary across jurisdictions, resulting in divergent outcomes. As Black (2005, p. 512) argues, regulation does not merely respond to obvious risks; it actively shapes what is understood as risk and how it is managed. In this light, compliance with building codes unfolds along a spectrum shaped by situated interpretation. People involved in permitting processes are not passive executors of rules but actors whose decisions reflect bounded rationality, constrained by tasks, institutional settings, and expertise (Simon, 1990). At one end of the spectrum lies strict code adherence; at the other, more flexible interpretations that prioritize regulatory intent. Administrative context, organizational culture, and resource availability all influence where a decision may fall on this spectrum.

This interpretive flexibility is not a flaw but a functional necessity. Built environments differ markedly; what is reasonable in a dense urban zone may not apply in coastal or rural areas. Codes are often written broadly to remain applicable across such diversity (Fauth, Gade, et al., 2024). Interpretation helps tailor general rules to specific conditions, ensuring regulations stay practical. It also enables administrators to evaluate whether a design fulfils a regulation’s purpose, even if it deviates from prescriptive language. This promotes meaningful compliance, focused on outcomes rather than formalities. Interpretation likewise fosters innovation (Lawson, 2006). New design methods, materials, and construction approaches may not align with outdated regulatory templates. A rigid system could stifle creativity, whereas interpretive space allows novel solutions, as long as regulatory aims are fulfilled. Additionally, flexibility addresses uneven administrative capacity. Not all offices have equal resources; strict enforcement may be unfeasible. Allowing discretion lets under-resourced authorities meet standards pragmatically. Moreover, situated interpretation reflects local political and planning priorities, whether preservation, densification, or climate adaptation, making the permitting process more responsive to community needs and values.

However, interpretive flexibility introduces challenges. Inconsistent interpretations across municipalities, or even between officers, can frustrate applicants, leading to costly design changes or risk of abandoned projects. Legal predictability suffers, and the principle of equal treatment may be undermined.

When decisions rely heavily on personal judgement without clear justification, perceptions of arbitrariness or bias may emerge, especially in smaller communities. Over time, lenient precedents may degrade regulatory standards if codes are not revised accordingly. These issues complicate efforts to digitalize permitting. Systems like automated rule-checking or AI-based tools depend on formalized, machine-readable criteria. Yet decisions shaped by local judgement, context, or institutional memory defy simple codification. This limits the reach of automation, as it struggles with nuance, trade-offs, and exceptions. As compliance checking processes become increasingly digitized, the balance between discretion and formalization in the decision-making must be reconsidered. Discretion remains essential for navigating complexity, but it must be structured, justified, and transparent. Digital tools should not eliminate human judgement but support it, by flagging ambiguous cases, documenting interpretations, and enabling consistent reasoning across jurisdictions. Hybrid systems that combine rule-based automation with contextual human oversight may offer a more effective and realistic path forward.

Methodology

This study proposes a hypothesis about the nature of permitting decisions based on the previous research and literature. The purpose of proposing a hypothesis is two-fold. Firstly, it is unlikely that a large-scale investigation into decision-making in building permitting would ever be possible, given the sensitivities and legal constraints around public access, so a quantitative study is unlikely to be feasible. Secondly, by offering a hypothesis, researchers can be alerted that the nature of the permitting decision in specific jurisdictions can be investigated, with some of the aspects of a decision already proposed.

Hypothesis: The binary pass/fail model is inadequate to represent the full range of outcomes in building permitting decisions. Building permit decisions are inherently compound, involving conditional approvals, tolerances, exceptions, and cases of incomplete or uncertain information (see Table 4.3 for examples). Therefore, any kind of (digital/automated) decision (support) systems should be designed to accommodate multiple result types, including intermediate states such as ‘unknown’. Such expanded models enable more accurate, explainable, and resilient decision-making in digital permitting systems.

The purpose of this chapter is to contribute to applicable knowledge for both researchers and practitioners. We have therefore chosen to use pragmatism as a guiding scientific philosophy. The methodology of analysis in this study is based on an abductive approach (Peirce, 1994; Popper, 1959). Compared to the deductive approach, where you go from theory to hypotheses to empirical evidence, or induction, where you go from empirical observation to hypothesis and theory, abduction is characterized by including questioning in the loop and allowing iterative loops to increase understanding. The hypothesis in this study is therefore based on scientific approaches.

The abductive approach implies both questioning our findings and proposing new questions. In the context of digital implementation in the construction industry, this means questioning what needs to be achieved and discovering what needs to be put in place to achieve this (Rekve et al., 2026), promoting an abductive approach over the more popular approaches of deductive and inductive approaches in our domain. Interpretative approaches are widely in more societal and legal sciences (Jacobsen, 2015, p. 20). This can be further explored by going into legal reasoning by Boe (2020). Having limited the scope of this section, we do not go into the legal domain for interpretations of legislation but apply established scientific methods.

Exploration

When questioning what a building permit decision is, the two central elements of the building permit process are the submission and the decision. This section explores the nature of building permit decision. While the submission is well understood, being defined by the information required to answer well-published questions (e.g., in the building application document or submission interface), the decision has not been explored. The language in previous research around decisions has focused on a binary outcome. Figure 4.1 shows a schema for more nuanced decisions based on categorization of the state of individual provisions once checks have been completed. In the following text, the key elements of a building permit decision are identified as Case identification, Overall decision, Non-compliances, Categorization of non-compliances, Tolerances, and Conditions. They are described as follows and presented in Table 4.1.

Case identification: A building permit decision relates to a specific ‘application’, ‘case’, or ‘file’ as a foundation. The case may be created by the receipt of an application, or it may be raised by a complaint or issue raised by the authority or the public. A case is defined by the identification of the applicant or the authority, and its date or unique version. It may relate to an assessment of a virtual proposal or to an inspection of the actual situation. It will usually relate to a specific land parcel. The case identification signifies the start of a decision process.

Overall decision: To count as a decision, there must be an overall outcome. For example, if the decision-making body postpones a decision, then that is still part of the building permit process. Similarly, if the evaluation has currently resolved overall to ‘unknown’, then the decision-making process must continue. A decision will indicate if there is a ‘pass’, broadly indicating that the evaluation has been resolved to ‘true’, or to fail (‘false’). This decision may depend on the number and state of the non-compliances, summarized in Table 4.1. The overall decisions conclude the decision process and are usually communicated in a notification letter from the authority to the applicant.

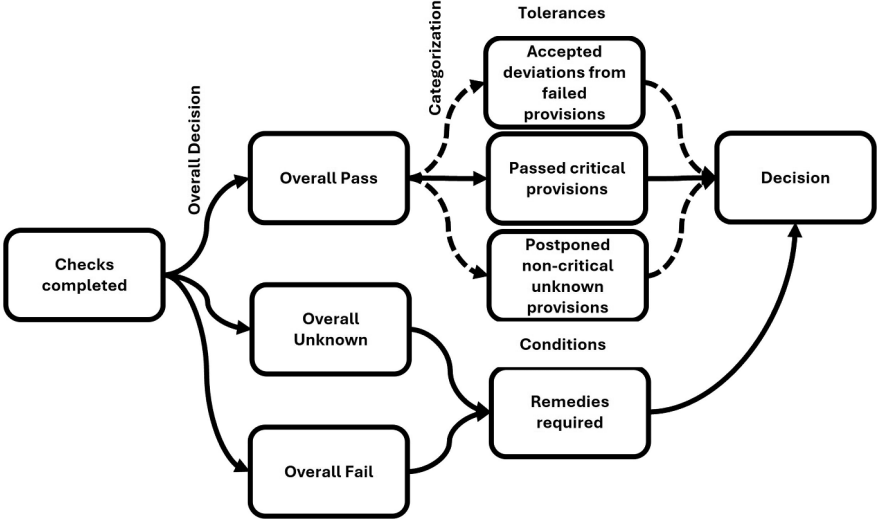


Figure 4.1 Schema of decision options at the point of making a decision.

Table 4.1 Effects of Individual Provisions on the Overall Decision

Provision Classification	Evaluated as 'True'	Evaluated as 'Unknown'	Evaluated as 'False'
Mandatory provision	No effect on overall decision	Decision delayed	Overall decision is 'fail'
Non-critical provision		Non-compliance is noted for later resolution. Overall decision is unaffected.	
Other provision		Non-compliance is tolerated	

Non-compliances: Non-compliances are instances where a specific element of the facility is found to conflict with a specific provision such as a requirement, clause, section, or document. A provision is a normative statement within a regulation, including its applicability and exceptions in and above it. The element is the set of components, spaces, or tasks with a distinct set of values for the properties relevant to the provision. Non-compliances may include omissions from the administrative process, such as signatures or fee payments. Non-compliances may need to be evidenced with explanations and can be supported with suggestions for resolution.

Categorization of non-compliances: If there are no non-compliances and no external interventions, then the overall decision will be 'pass'. If there are non-compliances, then each non-compliance may be classified

according to whether it is considered to be mandatory, for example relating to prescriptive or formal requirements, or considered to be essential or prioritized, for example relating to ‘life and safety’. The presence of non-compliances within these categories will establish a ‘fail’ outcome as the overall decision. The categorization of non-compliances may be indicated by the relevant law or regulation, or it may be explicit in the policies of a specific authority. In some cases, the categorization may be tacit to the regulatory system and the administrative procedures adopted. Informal heuristics may be justified pragmatically by work pressure or prioritization, if at all.

Tolerances: Other non-compliances classed as ‘fail’ can be tolerated. These may variously be described as ‘tolerances’, ‘derogations’, ‘departures’ or ‘exceptions’. A provision may be decided to have been met by other means, achieving the same degree of protection using methods not anticipated in the regulation, such as evidence from complex simulations or experts. The provision may be deemed ‘unreasonable’ in the specific circumstances. An example might be a refurbished staircase in a historic building, where it may be impossible to fit a compliant staircase. In some scenarios, the non-compliance in one aspect may be deemed to be compensated for in other areas. This is common in zoning decisions, where conflicting pressures need to be balanced. Compensations may be achieved by other benefits within the proposal, or by financial compensation, among others, as illustrated in Figure 4.2.

Conditions: Some non-compliances may be classified as ‘unknown’, having been triggered by gaps in the information available either in the submission or in the context. If the topic is considered critical, then a decision may be postponed. Alternatively, the non-compliance affecting an isolated aspect or element may be listed as pending, imposing a condition on the decision. An example would be that structural calculations for balcony fixing may be demanded before that aspect of the work is commenced, without delaying the ability to start the work in general. In some regulatory systems, some provisions are held over to a later inspection stage. An example might be the checking of colour contrast between walls and floors to aid visually impaired users of the building. Conditions may also come from other by-law departments.

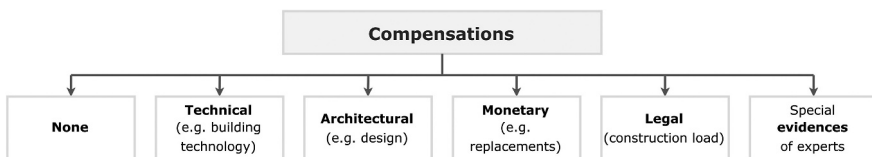


Figure 4.2 Options for compensation (Fauth, 2021).

Standard conditions: Alongside the specific content arising from the evaluation of the ‘application’, there may be fixed text summarizing the normal procedures following on from the decision, or the options for challenges, objections, or appeals. These clauses relate to the ‘deontics’, the permissions and obligations, created by the laws that control the building permit process and its impact on applicants’ rights.

Discussion

Reflecting the Challenges

This chapter challenges the common presumption of two-value (Boolean) logic in building permitting. In this logic, both the assessment of individual clauses against elements and the overall decision are assumed to be either ‘true’ (indicating compliance) or ‘false’ (indicating non-compliance). In practice, many of the metrics that drive the individual assessments of clauses against elements can be ‘unknown’, signifying that the question is well-defined, but the relevant value or assessment is not available. This is not necessarily terminal to the compliance checking process, as the processing of three-value logic can absorb unknowns. An unknown applicability may be overridden by a known exception. Making a selection of ‘openings and doors’ can, in the case of a ‘door’, be easily answered, even if the determination of an ‘opening’ may be dependent on some unknown factors. Some unknown values can still leave an assessment ‘unknown’. For example, even a generic provision such as ‘All doors should be soundproof’ requires careful evaluation to obtain the correct assessment as shown in Table 4.2. Note that not all unknown cases lead to unknown outcomes.

In addition, the second challenge is that the overall decision is not limited to being pass or fail. The presence of some but not all failures or unknowns can be managed. This implies that the overall decision can be conditional, with exceptions or further requirements attached. In this situation, a decision can more accurately be described as a ‘rule’, based on the filtering down of all the assessments and the regulations, and the decision-making process into a summary, as presented in Table 4.3.

Table 4.2 Evaluation of a Simple Provision

<i>Is It a Door?</i>	<i>Is It Soundproof?</i>	<i>Is It Compliant?</i>
True	True	True
True	Unknown	Unknown
True	False	False
Unknown	True	True
Unknown	Unknown	Unknown
Unknown	False	Unknown
False	True	True
False	Unknown	True
False	False	True

Table 4.3 Example UK Permitting Decisions (Author, Private Correspondence, Redacted)

Document	Commentary
 BUCKINGHAMSHIRE COUNCIL DECISION NOTICE Application no. [REDACTED] TOWN AND COUNTRY PLANNING ACT 1990 Town and Country Planning (Development Management Procedure)(England) Order 2015 In pursuance of their powers under the above mentioned Acts and Order, Buckinghamshire Council as Local Planning Authority, HEREBY PERMITS the following: Applicant: [REDACTED] Location: [REDACTED] Proposal: First storey extension over existing building footprint and sun-pipe over stairs through existing roof In accordance with your application received on 19 December 2023 and the plans and particulars accompanying it subject to the following conditions and reasons set out on the following page(s): [REDACTED] Service Director of Planning and Environment On behalf of the Council Date: [REDACTED] SCHEDULE OF CONDITIONS AND REASONS RELATING TO THIS PERMISSION 1. The development to which this permission relates must be begun before the expiration of three years from the date of this permission. Reason: To prevent the accumulation of unimplemented planning permissions, to enable the Local Planning Authority to review the suitability of the development in the light of altered circumstances and to comply with the provisions of Section 91 (1) of the Town & Country Planning Act 1990, as amended. 2. The materials to be used in the external construction of the development hereby permitted shall match the like, colour and texture of those of the existing building. Reason: To ensure that the external appearance of the enlarged building is not detrimental to the character of the locality. 3. Notwithstanding the provisions of the Town and Country Planning (General Permitted Development) (England) Order 2015 for any Order revoking or re-enacting that Order, with or without modification, no window/blower/ventilator other than those expressly authorised by this permission, or as subsequently agreed in writing by the local planning authority, shall be inserted or constructed at any time at first floor level or above in the east flank elevation of the extension hereby permitted. Reason: To protect the amenities and privacy of the adjoining property. [REDACTED] BUCKINGHAMSHIRE COUNCIL Planning, Growth & Sustainability NOTICE OF APPROVAL WITH REQUIREMENTS OF BUILDING PLANS BUILDING ACT 1984 AND BUILDING REGULATIONS 2010 BUILDING REGULATION APPLICATION REF NO. [REDACTED] Date of Decision: 30th April 2024 Proposal: First floor storey side and rear extension Address: [REDACTED] The plan(s) have been passed under Section 16 of the Building Act 1984. The passing of the plans operates only for the requirements of the Building Regulations 2010 and any section of the Building Act 1984 authorising rejection of the plans in certain cases. BUT DOES NOT operate as an approval under the provisions of the Town and Country Planning Acts, or any other purpose whatsoever. If this work is not commenced within three years from the date the application was submitted, the Council may declare that the deposit of the plans is of no effect and a new application must be made. Your attention is drawn to Regulation 16 of the Building Regulations 2010, which requires persons intending to carry out work to give notice at certain stages of the work. Yours faithfully [REDACTED] Service Director of Planning & Environment On behalf of the Council Service Director for Planning, Growth & Sustainability For and on behalf of the Council The plan(s) have been passed under Section 16 of the Building Act 1984 subject to the following requirements: Further plans, details and/or calculations of the following, showing compliance with the requirements of schedule 1 shall be deposited with the council (s)to commencement of the relevant work: 1. Please provide manufacture's details and facing details to the Juliet balcony to be installed. Requirement 4.1.	Zoning permit decision Case identification Basis in law Base decision Case description Authority Date of decision Standard condition on duration Postponed non-critical unknown provision and justification Extraordinary condition and justification Technical permit decision Base decision Basis in law Case identification Date of decision Case description Standard condition on duration Standard conditions on further duties Authority Justification for postponed non-critical unknown provision

Reflecting on the Hypothesis

The analysis presented in this chapter confirms the hypothesis that a binary pass/fail model is insufficient to represent the full range of outcomes in building permitting decisions. As the investigation shows, real-world decisions are rarely reducible to simple compliance or non-compliance. Instead, they often involve layered assessments, partial information, compensatory measures, and conditions for future resolution. By introducing categories such as ‘unknown’, ‘tolerated’, and ‘conditional’, the chapter demonstrates that permitting decisions function as compound judgements shaped by regulatory interpretation, local context, and institutional capacity. These findings suggest that (digital) decision-support systems must move beyond rigid automation and incorporate flexible, explainable decision pathways that reflect the complexity of regulatory practice. Rather than disproving the hypothesis, the analysis presented reinforces the need for hybrid models that combine automated rule-checking with structured human oversight to ensure fair and resilient building permitting processes.

In addition, the building permit decision is not necessarily a direct output of the compliance checking process, and involves the participation of public, other agencies, and validators. Instead, in many cases it is a finely nuanced instrument to control the next steps. There could be simple cases where the determination of the overall decision is directly determined by the compliance checking, or, at the other extreme, there could be cases where the determination of the overall decision is independent of any written criteria. An expectation would be that some of the complexities identified in Table 4.1 would apply in most cases.

Reflecting with Existing Literature and State of the Art

When our study proposes ‘unknown’ in compliance checking and ‘undecided’ in decision-making, this should be regarded as a benefit of being more systematic, not as a weakness. The literature review by Amor and Dimyadi (2021) identifies performance-based regulations as the main challenge. By introducing ‘unknown’, we can make these types of requirement an embedded part of the digital solution. If one needs to be 100% sure that the data contains all relevant information before submitting, this process will be very demanding in itself. We do therefore need to have a resilient process. As the ‘Methodology’ section introduced, we do not use questioning research approaches (Peirce, 1994; Popper, 1959). Our proposal aligns with the principles outlined by Law Professor Dag Wiese Schartum (2018, p. 20), who distinguishes between legislation as a frame (defining boundaries) and legislation as content (defining what happens within those boundaries). In the context of compliance checking and ACC, we suggest that the use of ‘unknown’ represents the context (as the situational and interpretive layer within the defined content), as illustrated in Figure 4.3. This implies that interpretation must be understood as more dynamic than a rule that can be processed in the same way in all decision-making scopes. Interpretation can be done at the ‘Content’ and/or ‘Constraint’ level, while how it is applied is at the ‘Context’ level.

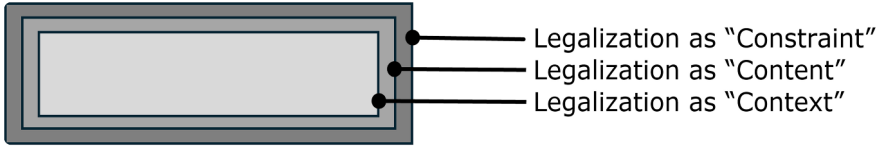


Figure 4.3 Legalization as ‘Content, Constraint, and Context’. Based on Schartum (2018).

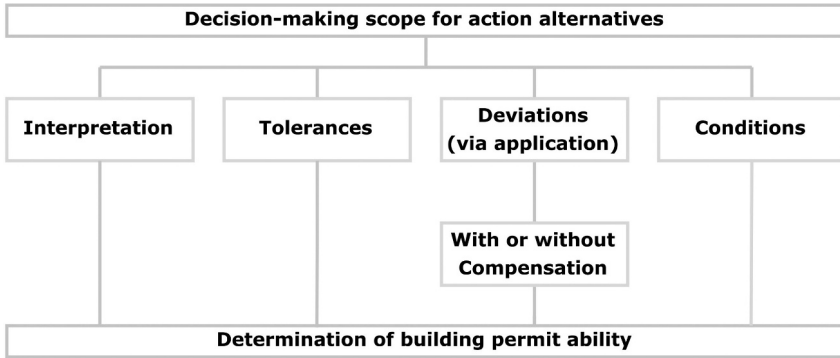


Figure 4.4 Classification of decision-making scopes (Fauth, 2021).

As presented in Figure 4.4, this type of interpretation process can be supported by exploring relevant actions. Examples of action alternatives are Interpretations, Tolerances, Deviations (with or without compensations), and Conditions, which must be identified and can thereby be solved as separate interpretation processes, as presented in Figure 4.3. As examples, Deviations can be split into: Technical, Architectural, Monetary, Legal, Expert evidence, or None (as shown in Figure 4.2 for compensation options). This will create a ‘learning solution’ that does not have to be perfect at the start, but is good enough to improve the processes compared to individual manual processing.

Findings from Rekve et al. (2026) identify that abductive reasoning is very limited in use, accounting for only 4% in research in the construction domain (the linear inductive and deductive ways of reasoning dominate). Abduction is characterized by the ‘question’ loop. This supports creating new thoughts and proposals as part of scientific research. By rethinking the building permit decision as a complex, context-sensitive process, we aim to provide new directions for the integration of robust and careful decision-making into (digital/automated) decision (support) tools. This includes not only technical considerations such as traceability and explainability of automated decisions but also the recognition of the enduring need for human judgement in regulatory interpretation. Ultimately, the goal is to move beyond the illusion of purely rule-based automation and towards more transparent, fair, and efficient building permit systems that respect both regulatory intent and project realities. The concepts presented in Figures 4.3 and 4.4 indicate that it is applicable to develop a permit system

that covers ‘most used’ cases. By identifying ‘Constraint’ (Figure 4.3) clearly, for example, the type of building with defined characteristics (area, height, type of roof, and more) and the ‘Deviation’ with compensation (Figure 4.4), for example, 4 metres from a garage is the default, but if you include fire-preventing solutions, it is allowed to build 3 metres from the garage. This type of approach can both make the application process more transparent and predictive.

A more detailed understanding of building permit decisions, beyond the simple categories of pass or fail, is essential, especially since many of the inputs to the decision process are not strictly binary. For example, comments arising from participation by the public, other authorities, and expert validators. Furthermore, applicants and authorities can benefit from the decision being explainable in terms of the factors determining the decisions. Greater clarity and appreciation of the subtlety of a decision should also affect the development of systems supporting and automating the inputs into the decision-making process. It may help developing thinking beyond demands for a ‘human-in-the-loop’ (Beach et al., 2020) towards an understanding of what the role of that human should be: rather than endorsing the huge bulk of individual provisions, the human could focus on whether the provisions and their individual results have been categorized appropriately.

Some requirements are expressed as a minimum level within a published grading scheme. The outcome of a BREEAM (BRE Group, 2022) environmental assessment can be ‘unclassified’, indicating the schema has failed to achieve the minimum standard, and there are then several levels of pass up to ‘platinum’. Kasim et al. (2013) reported that the BREEAM scheme can be assessed using an automated compliance rule engine, though there are several institutional obstacles to adoption. A higher level of achievement may be considered tradable against lower levels in other assessments.

The proposed framework reflects and extends existing literature on the interpretive nature of building permitting. As Baldwin et al. (2011) and Black (2005) argue, compliance unfolds through situated interpretation shaped by institutional and local contexts. This aligns with the framework’s inclusion of tolerances, conditional approvals, and information gaps. Simon’s notion of bounded rationality supports the role of discretion, emphasizing that decisions are shaped by constraints rather than pure logic (Simon, 1990). By drawing on these foundations, the framework formalizes the view that permitting decisions are not binary outcomes but complex, context-dependent judgements.

Implications

The implications for ACC or any other compliance checks (including manual) would include ensuring that there is a full trace of the checking process, giving full explainability of the ‘pass’, the ‘unknown’, and the ‘fail’ compliances. In the UK, for example, some applications now require a full schedule of building elements and the provisions they have satisfied (Legislation.gov.uk, 2023). Similarly, tools proposed to support compliance checking processes need to ensure a detailed record is created, so that the final decision can correctly

describe the non-compliances and compliances. Decision-support tools could be configured with the classification of non-compliances if they are explicit and available.

The approach developed in the ‘Exploration’ section can be applied in practice when considering a specific jurisdiction, comparing different jurisdictions, or examining different aspects within a jurisdiction, such as differences in generating zoning and technical decisions moving from implicit to explicit decision-making. Thinking of planning rather than the technical aspects of a building, zoning requirements generally cover the set of factors to be taken into account without necessarily setting a minimum level for each criterion, whereas technical requirements will usually set a minimum level. Any flexibility in the technical assessment is often not explicit, but manifests only in decisions. Zoning regulation may anticipate that, beyond minimum levels of performance, there can be trade-offs between distinct objectives.

Limitations and Future Directions

This chapter presents a conceptual framework and hypothesis on the nature of building permit decisions, grounded in the literature, expert insights, and cross-jurisdictional observations. However, the analysis is limited by the lack of access to empirical decision data, which is often restricted due to legal confidentiality, institutional opacity, and variations in administrative transparency. As a result, the proposed model has not been validated through large-scale quantitative analysis or systematic case studies. Furthermore, while the framework aims to be broadly applicable, permitting practices and legal interpretations vary significantly across jurisdictions, which may limit the generalizability of some findings. The abductive methodology employed supports theoretical exploration and hypothesis generation, but further empirical research is necessary to test, refine, and contextualize the proposed categories and decision pathways within operational building permitting environments.

A proposal for future work is to explore the degree of digitalization in legalization as a first step in the development of ACC solutions. This would help to discover challenges in advance and help prioritize which parts of the legislation can be processed automatically, semi-automatically, or manual. Including multiple ‘status level’ between Pass and Fail as part of our understanding of building permitting and of ACC can contribute to a more resilient and emergent system. This recommendation can appear counterintuitive compared to a system that can give clear ‘Pass’ or ‘Fail’ feedback. However, due to the embedded complexity in legislation or user attitudes, the assumption that a simple approach is sufficient may not be relevant or useful.

Conclusion

This study has argued that building permitting decisions cannot be adequately captured by a simple binary of ‘pass’ or ‘fail’. Instead, these decisions emerge as layered, conditional, and often provisional assessments that reflect the

intricate interplay of codified regulation, contextual interpretation, stakeholder input, and information availability. By introducing the notion of ‘unknown’ as a legitimate and necessary outcome within the decision-making process, we challenge prevailing assumptions about (automated) compliance checking and (digital) building permitting systems.

The framework proposed here distinguishes between different types of non-compliance, tolerances, compensations, and conditions and offers a conceptual foundation for both empirical research and the development of more nuanced, explainable (digital) tools. It acknowledges that permitting is not the end of a decision chain but rather a bundle of interdependent judgements shaped by legal structures, organizational practices, and human discretion. Recognizing this complexity is essential for designing resilient permitting systems that balance efficiency with accountability, and automation with professional judgement.

Ultimately, this chapter invites a shift in how we understand, design, and support building permitting decisions. It calls for a move beyond the illusion of definitive outcomes, towards a more reflective, transparent, and adaptive permitting ecosystem, one that not only accommodates the uncertainties of practice but uses them as a basis for improvement, learning, and trust, building in the regulatory process.

Reflecting back on the lyrics cited in the introduction, the tension between ‘getting what you want’ and ‘getting what you need’ remains a fitting metaphor for the realities of building permitting. Permit decisions often require balancing applicant expectations with broader regulatory and societal goals. Just as the Rolling Stones and Coldplay suggest, outcomes in permitting are rarely absolute – approval does not always guarantee functional or desirable results, and rejection may serve longer-term needs. Recognizing this complexity reinforces the chapter’s central argument: building permitting decisions are not binary endpoints but negotiated judgements that require both structure and flexibility.

Acknowledgements

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5 Sustainability in Building Permitting

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Introduction

The transition towards sustainable built environments has become a critical global priority in both policy and practice, as societies face increasing pressure to reduce carbon emissions, promote resource efficiency, and improve quality of life in urban environments (Crisan et al., 2024). As the built environment significantly influences global resource consumption, emissions, and human well-being, the Architecture, Engineering, Construction, and Operation sector plays an important role in achieving sustainability goals. Within this sector, building permitting (BP) is a key intersection of policy, planning, and execution, traditionally rooted in administrative control and legal compliance, but is increasingly recognized as a strategic lever for embedding sustainability in the construction sector. Through digitalization, BP systems are being redefined not only as regulatory gateways but also as enablers of environmental efficiency, social equity, and economic innovation (Lavikka et al., 2025).

Research Background

Sustainability in construction encompasses a wide range of environmentally responsible practices aimed at reducing the ecological footprint of the built environment. These include the use of resource-efficient and low-impact materials, integration of renewable energy systems, and strategies for reducing water and energy consumption throughout the building lifecycle (Crisan et al., 2024). Sustainability in BP ensures that new developments align with long-term environmental, social, and economic objectives. By setting performance requirements, reviewing design choices, and integrating digital tools, BP processes can influence how buildings minimize environmental impact from the earliest planning stages (Wilkinson, 2014).

Buildings represent around 40% of the EU's energy use and 50% of its gas consumption, about 80% of which goes to heating, cooling, and hot water. In response, the revised EU Energy Performance of Building Directive aims for a fully decarbonized building stock by 2050, supporting energy independence and healthier living conditions (European Commission, 2021). The 10 Year

Framework of Programmes on Sustainable Consumption and Production is a global framework promoting sustainable practices through digital standards and technologies that improve transparency and traceability (United Nations, 2024). Consequently, building renovation and digital product passports act as policy tools supporting circular economy (CE) (Adisorn et al., 2021; Walden et al., 2021).

These long-term objectives are also reflected in the United Nations Sustainable Development Goals (SDGs), which offer a globally recognized framework for advancing sustainability (United Nations, 2024). Several goals, including SDG 11 (Sustainable Cities and Communities), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption Production), and SDG 13 (Climate Action) are particularly relevant to the building sector and, specifically, to BP processes (United Nations, 2024).

A fundamental concept in sustainability research is the three-pillar model, which is distinguished between environmental, social, and economic dimensions. Each pillar contributes to a balanced approach to sustainability, and together they form the foundation for achieving lasting, resilient outcomes in the built environment (Pourmatin, 2017). The environmental pillar focuses on the reduction of negative ecological impacts throughout the lifecycle of a building. This includes minimizing energy consumption, lowering greenhouse gas emissions, reducing construction and demolition waste, and avoiding the use of harmful materials. Sustainable building practices support this goal by promoting the use of renewable resources, eco-efficient technologies, and environmentally responsible design strategies (World Green Building Council, 2025). The economic pillar focuses on ensuring long-term financial viability and productivity of the built environment. In the context of BP processes, this includes effective governance, risk management, and regulatory compliance, all of which can contribute to stable investment conditions (Kararctech, 2024; Pourmatin, 2017). Sustainable construction practices can involve higher upfront costs, but they often result in significant long-term savings through reduced operational and maintenance costs (Sánchez-Garrido et al., 2024). Aligning BP processes with economically sustainable strategies could support developers to participate more actively in achieving sustainability goals, as profitability remains a key role in decision-making (Alaloul et al., 2022; Hussain & Hussain, 2023; Lavikka et al., 2024). At a broader level, sustainable building projects can foster local economic development by supporting employment, enhancing local productivity, and generating value through the building lifecycle. The social pillar focuses on human well-being, inclusion, and fair access to services, principles that are directly relevant to the BP processes. This encompasses the working conditions of employees within building permit administration, as well as the experience and accessibility of the process for applicants, professionals, and citizens (Pourmatin, 2017). A socially sustainable BP system supports inclusion by ensuring that access to BP processes is equitable and transparent for all stakeholders.

The digitalization of the building permit process can play an important role by providing transparency, accountability, and timely access to information, thereby strengthening public trust in regulatory institutions (Fauth et al., 2024). Participatory tools, such as Switzerland's e-participation platforms or Estonia's x-road system, further support citizen involvement in planning decisions, making governance inclusive and responsive (Eirinaki et al., 2018). By supporting fair participation in planning and approval processes, BP systems contribute to broader goals of social equity, education, and inclusive urban development.

Across Europe, an ongoing housing shortage means BP processes directly affect the speed, accessibility, and affordability of new homes (Sasse & Berz, 2025). Social sustainability in BP thus includes reducing bureaucratic barriers and delays that can disproportionately affect low- and middle-income populations in need for housing. Moreover, rising housing costs continue to put pressure on urban populations across Europe. In 2023, nearly 20% of disposable income in the EU was spent on housing, with the burden disproportionately affecting lower income households. Among those at risk of poverty, housing costs consumed an average of 38.2% of disposable income. Additionally, over 10% of urban residents lived in households spending more than 40% of their income on housing, which indicates severe affordability stress, particularly in countries like Greece, Denmark, and Germany (Eurostat, 2024).

Importantly, the three sustainability pillars (i.e., environmental, economic, and social) are interrelated. Many sustainable outcomes emerge at their intersection, and their impact is often more significant when viewed together. For instance, speeding up approvals for energy-efficient housing not only improves affordability through lower utility costs (economic), but also contributes to climate goals by lowering emissions (environmental) and supports access to healthier, more comfortable living conditions (social). These overlaps highlight the need for an integrated perspective when embedding sustainability into BP systems. Moreover, it requires a coordinated, systematic approach that acknowledges and leverages the overlaps between the pillars.

Research Objective

Although BP systems are increasingly recognized for improving administrative efficiency and transparency, their contribution to sustainability remains underexplored and often vaguely defined. In most cases, digitalisation of building permits is framed in terms of administrative speed and error reduction, while the broader environmental, social, and economic impacts remain secondary considerations. Yet, many scientific studies as well as practical initiatives suggest that digital building permits (DBP) could support sustainability goals, though it is rarely explained how this might happen in a structured or measurable way. One reason for this gap may lie in the complexity of the BP processes, which includes multiple actors, legislative frameworks, organizational structures, processes, and technological parts. The study aims to

address this complexity and explore how sustainability should be meaningfully integrated into DBP systems.

In current practice, BP processes remain primarily focused on functional standards, such as room dimensions, as well as urban regulations, including building distances, heights, and accessibility. They also address compliance with safety and technical standards, such as structural integrity, fire protection, accessibility, and seismic resistance. While these requirements are essential, sustainability-related aspects are often treated as procedural checkboxes, rather than used as a tool to enhance the overall performance of the building. Yet, design choices that extend the lifespan of a building by even a few years can lead to considerable reductions in environmental impact by lowering the frequency of demolition, reducing construction and demolition waste, and deferring the demand for new building materials.

These effects are especially relevant considering lifecycle assessment (LCA) studies, which consistently highlight the long-term environmental benefits of retaining and reusing building materials over constructing new ones (Kabirifar et al., 2020). Despite this, BP rarely includes criteria that evaluate the durability, adaptability, or long-term usability of a structure.

This underscores a critical, and often overlooked, point. BP systems have untapped potential to actively contribute to a more sustainable outcome not only by regulatory compliance but also by guiding design towards greater resilience and lifecycle efficiency. Aligning BP with CE principles, like reuse of structural elements or requiring provisions for adaptability, could enhance the contribution of the construction sector to SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) (Brandão & Verissimo, 2024).

Another key limitation of current regulatory frameworks is that many existing building codes and BP regulations do not include effective incentives or mechanisms for promoting sustainability in practice (Crisan et al., 2024; Olugboyega, 2022). Despite their widespread adoption, existing sustainability certifications such as Building Research Establishment Environmental Assessment Methodology (BREEAM), German Sustainable Building Council (DGNB), or Leadership in Energy and Environmental Design (LEED) operate independently of the BP systems.

Moreover, these certifications are more commonly adopted in large-scale developments led by established firms. For example, LEED adoption has been more prevalent in major cities with political engagement, and BREEAM Communities have been used in selected large-scale municipal projects (Cidell & Cope, 2014; Grodzka, 2023; Sullivan et al., 2014). However, smaller-scale developments and companies often face barriers to certification due to limited complexity in terms of project complexity and cost (Goode & Xiao, 2012; Grodzka, 2023).

Integrating certification frameworks, or their underlying sustainability criteria, into the BP process could significantly enhance their reach and practical impact. Rather than remaining voluntary and accessible primarily to

large-scale or well-resourced developments, such integration would embed sustainability requirements directly into regulatory pathways. This integration would promote a more inclusive and scalable approach to sustainable construction practices, allowing a broader range of projects to contribute meaningfully to climate objective and long-term development goals.

In summary, the motivation for this chapter lies in the recognition that improvements in BP processes, from legislation frameworks and organizational structures to procedural workflows and technological tools, can collectively contribute to sustainability goals. Although often perceived as a bureaucratic formality, BP plays a defining role in shaping the way cities are planned, built, and renewed. Given the significant environmental costs of demolition and new construction, and the increasing demand for adaptable, resource-efficient development, it is essential to recognize BP as a strategic instrument for sustainability.

While previous research has largely emphasized technical interoperability and process efficiency in DBP systems (Fauth et al., 2023; Noardo et al., 2022), a new sustainability dimension is added by systematically mapping sustainability considerations, grounded in relevant SDG targets and three-pillar sustainability, into the structure of DBP systems.

The research questions tackled in this chapter are:

- 1 What is the role of DBP in supporting sustainability in the built environment?
- 2 Which sustainability aspects are currently addressed through BP processes?
- 3 How can a structured, system-based approach help to identify opportunities for embedding sustainability more effectively into BP systems?

Method

This study adopts a qualitative, system-oriented methodology to explore how sustainability considerations can be integrated into DBP systems. The objective is to explore how sustainability dimensions intersect with DBP systems and to provide a structured tool for identifying these relationships across multiple subsystems. It is structured around three core stages. Each methodological step, outlined below, contributes to one or more of the research questions outlined in the introduction section:

- i **Framework Structuring and Taxonomy Adaptation:** Building on a previously developed taxonomy of DBP systems, the analysis was structured around four core subsystems: legislative, organizational, procedural, and technological. Each subsystem was further divided into categories and subcategories, such as building law, public participation, financial aspects, or data and information tools. These elements were retained and organized into a structured spreadsheet matrix, forming the analytical foundation of this study. This stage primarily supports research question 1 by

framing the DBP system as a structured and analysable context for sustainability integration.

- ii **Sustainability Mapping:** Each category and subcategory within the taxonomy was then analysed to identify its potential contributions to the three pillars of sustainability: environmental, social, and economic. This mapping was guided by a review of selected SDG targets, selected policy frameworks, and scientific literature. Rather than measuring impact or performance, the aim was to capture the diversity of ways in which sustainability concerns are reflected, or could be reflected, within BP processes. This stage addresses research question 2, highlighting which sustainability aspects are already present or potential in DBP practices.
- iii **Matrix Development and Categorization:** A comprehensive matrix was developed to visualize the intersections between DBP subsystem components and sustainability dimensions. For each entry, the following were identified: (1) the relevant sustainability pillar; (2) sustainability linkage description; (3) concrete example cases or practices from the BP; (4) references to applicable policies, standards, or scientific sources.

The matrix was developed collaboratively, with contributors reviewing and refining entries through feedback rounds used to improve clarity, consistency, and coverage. Eventually, the final step addresses research question 3, offering a structured tool to systematically examine the integration of sustainability across DBP systems.

This structured approach provides a broad but detailed exploration of the complexity and diversity of sustainability integration across DBP systems. It explores how sustainability can be embedded into DBP systems, not as an outcome measure, but as a framework for identifying where and how sustainability linkages can be strengthened. It also provides a further dialogue on how BP reforms can better align with environmental, social, and economic goals (Figure 5.1).

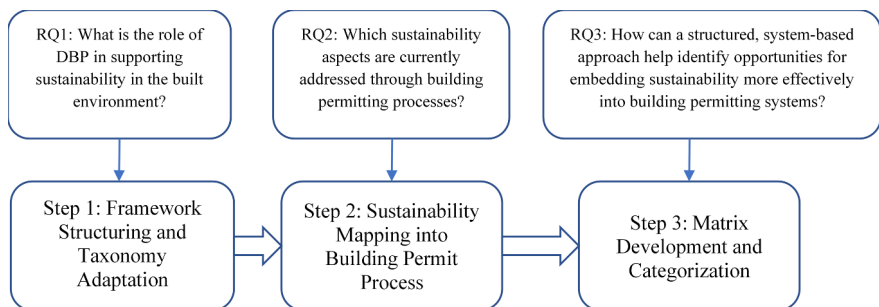


Figure 5.1 Methodology diagram.

Results

To better understand the ways in which sustainability is or could be integrated within DBP systems, a structured classification matrix that expands upon a taxonomy from a previous study has been developed. The framework distinguishes the building permit system through four subsystems: legislative, organizational, procedural, and technological. The subsystems are further divided into categories and subcategories.

In the current study, these permit system elements were linked with sustainability aspects. The resulting Tables 5.1–5.4 map these elements against the three sustainability pillars (i.e., environmental, social, and economic) and link them to relevant sustainability linkages, describing how each element can contribute to sustainability aspects; afterwards, they have been linked to relevant SDGs. Each entry includes a description of the sustainability contribution, practical examples or policies, and references to BP or sustainability frameworks.

The visual representations in Tables 5.1–5.4 highlight the complexity and multidisciplinary of integrating sustainability into BP, emphasizing the overlaps between pillars and the importance of context-specific implementation.

Legislative Subsystem

The Legislative Subsystem (Table 5.1) explores the role of legal and regulatory frameworks in supporting sustainability objectives. It focuses on how national laws, municipal regulations, and EU directives can enable or mandate practices that align with sustainable development, such as requirements for energy performance certificates or CE principles. The entries illustrate how legislative tools can set minimum standards or enable incentives for environmentally responsible development, and how these instruments are reflected in broader EU climate and energy directives.

Organizational Subsystem

The Organizational Subsystem stands for the management of behaviours, including political, social, and business aspects. Table 5.2 identifies how institutional arrangements, management practices, and stakeholder engagement influence the sustainability of BP systems. It examines both business management aspects, such as fee structures and data integrations, and political and social aspects, such as participatory engagement, equitable access, and public trust. In this case sustainability emerges through mechanisms such as financial incentives, staff efficiency improvements, and digital governance platforms.

Procedural Subsystem

The Procedural Subsystem focuses on workflows, methods, and content validation processes integrated within BP systems. In this case, two different aspects

Table 5.1 Legislative Subsystem: Sustainability Mapping into the Building Permit System

<i>Category</i>	<i>Subcategory</i>	<i>Sustainability Pillar</i>	<i>SDG</i>	<i>Sustainability Link</i>	<i>References</i>
Government level		Environmental	SDG 7.3., 13	DBP frameworks mandated at the national level can include requirements for EPC documentation and LCA, thereby supporting environmentally responsible construction practices	EU Directive 2018/844 on EPC of buildings and its national transposition laws (e.g., Romania's Law no. 101/2020), which mandate energy documentation and encourage digitalisation in BP
Rule and regulation	Building law	Environmental		Guides energy efficiency requirements	EPBD, ISO 52000
Rule and regulation	Building law	Environmental	SDG 9.2.	DBP supports compliance with building laws and sustainability standards by automated verification of construction plans against current safety, energy efficiency, and environmental regulations. This strengthens regulatory enforcement and contributes to the development of safe, resilient, and energy-efficient infrastructure	Automated compliance checking for seismic codes and green building certifications (Amor & Dimyadi, 2021; Patlakas et al., 2024)
Rule and regulation	Building law	Environmental, economic	SDG 12.5	Mandating reuse of materials directly supports CE principles	CE, Action Plan (EU); reuse percentage of materials (Hradil et al., 2024)
Rule and regulation	Building law/ planning/ zoning law	Environmental	SDG 11.6	DBP helps reduce city environmental impact through standards enforcement, minimizing carbon footprint, and supports construction waste circularity via the digital building logbook (DBL)	Buildings as material banks (BAMB, 2020)

(Continued)

Table 5.1 (Continued)

<i>Category</i>	<i>Subcategory</i>	<i>Sustainability Pillar</i>	<i>SDG</i>	<i>Sustainability Link</i>	<i>References</i>
Rule and regulation	EU Directive	Environmental, economic	SDG 7 7.1, 7.3, 7.A, 7.B	Supports energy-efficient building design, materials, and technology integration, helping to reduce overall building energy consumption; mandates renewable energy sources like geo-energy in permits	Energy performance criteria in building codes; building permits for solar and geo-energy installations (Majuri et al., 2020); Building Renovation Passports support energy transparency and sustainable renovation strategies across the EU
Rule and regulation	Municipal law	Environmental	SDG 11.3, 11.7, 13.2	Enables municipalities to systematically enforce sustainable construction codes (e.g., green roofs, local material use) which support urban climate resilience and sustainable development	(Basel, Switzerland: Building regulations for green roofs, 2010) Local Policy: City of Basel (2002); (Kazmierczak & Carter, 2010), Basel Green Roof Ordinance; (Oberndorfer et al., 2007)

Table 5.2 Organizational Subsystem: Sustainability Mapping

<i>Category</i>	<i>Subcategory</i>	<i>Sustainability Pillar</i>	<i>SDG</i>	<i>Sustainability Link</i>	<i>References</i>
Business management aspect	Financial aspect	Economic	SDG 7	Incentives like subsidies and fee reductions encourage low-energy building design. These mechanisms support the adoption of passive housing standards and reduce the economic barriers to sustainable construction	Brussels' passive house programme offers fee reductions and incentives for projects meeting passive house standards
Business management aspect	Financial aspect	Economic	SDG 7.3, 8.2	DBP promotes efficiency and innovation by enforcing sustainable building regulations	EU initiatives promoting digitalization (e.g., DigiPLACE, DBL standardization efforts)
Business management aspect	Financial aspect	Economic	SDG 17.6	DBL enhances productivity through improved data integration and technological adoption	World Bank: Infrastructure Prioritization Framework, Assessment Framework
Business management aspect	Staff management: efficiency and innovation	Social, economic	SDG 8.1–8.5	DBP improves financial management by increasing transparency; reducing delays, cost overruns, and corruption risks; and supporting sustainable infrastructure investment	Streamlines DBP in Singapore and Dubai; DBP processes (World Bank) (Fauth et al., 2024)
Political aspect	Stakeholder	Social	SDG 16.6	Boosts productivity, streamlines building permit processes, reduces bureaucratic barriers, fosters innovation and SME growth	(World Bank, 2025)
Political aspect	Strategic objective	Social, environmental, economic	SDG 11.a	Strengthens trust and accountability by increasing transparency in BP through digital governance tool	Urban Development Plan (City of Vienna, 2014): integrates DBP into long-term housing and regional equity strategies
				Strengthens regional and national planning transparency and accountability, while streamlining approvals to support faster development, particularly in remote or underdeveloped areas	

(Continued)

Table 5.2 (Continued)

<i>Category</i>	<i>Subcategory</i>	<i>Sustainability Pillar</i>	<i>SDG</i>	<i>Sustainability Link</i>	<i>References</i>
Political aspect	Strategic objective: data-sharing frameworks	Social, economic	SDG 17	Digitalization supports partnerships between governments, industries, and academia for sustainable development goals in the building sector	Horizon Europe projects: ACCORD, DigiPLACE
Social aspect	Stakeholder	Social	SDG 10.2	Supports social, economic, and political inclusion by ensuring equitable access to BP systems	EAP (electronic application processing) Estonia
Social aspect	Participation of the public: transparency and accountability	Social	SDG 16.6, 16.7, 16.10	DBP increases transparency in public processes, fosters inclusive governance, and encourages active citizen participation in local decision-making	Estonia x-Road Platform; Aarhus Convention; OECD Principles of Open Government
Social aspect	Personal aspect: citizen engagement in permitting	Social	SDG 11	DBP platforms promote inclusive planning by supporting citizen participation and sustainable urban development	Participatory planning portals (e.g., Switzerland's e-Platforms, Aarhus Convention) enhance transparency and participation while simplifying regulatory compliance (Eirinaki et al., 2018)

Table 5.3 Procedural Subsystem: Sustainability Mapping

<i>Category</i>	<i>Subcategory</i>	<i>Sustainability Pillar</i>	<i>SDG</i>	<i>Sustainability Link</i>	<i>References</i>
Process and method	Content check	Environmental, social	SDG 9	Automated checks ensure compliance with energy efficiency and seismic standards, supporting resilient infrastructure	ACCORD project and automated code-checking tools (Amor & Dimyadi, 2021; Patlakas et al., 2024); EN ISO 16739 IFC Standard
Process and method	Content check: climate mitigation criteria	Environmental	SDG 13	Digital tools enhance enforcement of climate-resilient and low-carbon building standards during building permit approval	Denmark's national climate mitigation standards for new buildings (Nordic Sustainable Construction, 2024); EU/ UN tools supporting Paris Agreement implementation
Process and method	Content check	Social	SDG 11.4	Ensures transparent BP and data use for safeguarding cultural and natural heritage	DBP processes for heritage buildings; UNESCO Historic Urban Landscape (HUL) approach
Process and method	Participation of other agencies: compliance with health standards	Social	SDG 3.4, 3.6, 3.8, 3.9	DBPs help ensure new buildings, particularly health facilities, meet safety standards and protect vulnerable populations	WHO Hospital Design Guidelines: Standards addressing infection prevention and safe BP of health facilities
Process and method	Submission	Social, economic, environmental	SDG 11.1, 11.7, 11.a	Facilitates affordable housing development, speeds up project delivery, and ensures compliance with environmental and resilience goals	Vienna smart housing; EU urban agenda on affordable and sustainable housing initiative

Table 5.4 Technological Subsystem: Sustainability Mapping

<i>Category</i>	<i>Subcategory</i>	<i>SDG</i>	<i>Sustainability Pillar</i>	<i>Sustainability Link</i>	<i>References</i>
Data and information	Building design data	SDG 13.1–13.3	Environmental	Supports national and local climate adaptation by improving resilience monitoring and enabling better resource management	Digital Twin for resilience monitoring (e.g., BAMB vision), Local flood resilience projects; EU Green Deal Level(s) Framework
Data and information	Geospatial data	SDG 10.2, 10.3	Social	Improves transparency in the built environment, supports fair decision-making processes, and reduces the risk of discrimination in BP and housing access	Open Access Urban Digital Twins (e.g., Helsinki 3D+); EU Open Data Directive; European Data Governance Act
Data and information	Building design data/geospatial and context data	SDG 17.6	Economic	Facilitates international cooperation and knowledge sharing in sustainable construction	Interoperability projects (e.g., EU INSPIRE Directive); World Bank Reports, UN Initiatives
Data and information	Building design data/third-party data	SDG 3	Environmental, social	DBLs and Digital Twins can help monitor material toxicity and indoor air quality, supporting healthier and safer built environments	Material Passports (e.g., Madaster); Indoor Air Quality sensors integrated with DBLs; EU Level(s) Framework (air quality indicators); WELL Building Standard
Data and information	Geospatial and context data	SDG 9.4	Environmental, economic	DBPs promote resource-use efficiency, adoption of clean technologies, and digitalisation of processes	Adoption of DBL for sustainable infrastructure (Ataide et al., 2023); Crisan et al., 2024)
Data and information	Procedural data	SDG 17.1, 17.6	Economic	DBPs and DBLs enable data standardization, enhance cross-border interoperability, and facilitate international cooperation in the building sector	BuildingSMART standards (ISO 16739, ISO 27039), European BIM Task Group initiatives

Data and information	Procedural data and third-party data	SDG 12.2.	Environmental, economic	Reduces waste and promotes efficient resource use across construction lifecycle; enhances analytics and data management for sustainable practices	Buildings as Material Banks (BAMB) initiative; Pilot projects from Horizon 2020 Programs
Data and information	Procedural data and third-party data	SDG 12.6, 12.7, 12.8	Social	Supports sustainability reporting, facilitates sustainable public procurement, and raises citizen awareness through improved access to building lifecycle data and planning information	BAMB project; ISO 14040 (LCA); Open Digital Twins (e.g., Helsinki 3D+); sustainable certification systems
Data and information	Third-party data	SDG 8.4	Environmental, economic	Supports resource efficiency, waste reduction, sustainable consumption, and production	EU Digital Product Passport Initiatives; 10-Year Framework of Programmes on Sustainable Consumption and Production (10YFP)
Tools, software and hardware	Content analyser and regulations checking tool	SDG 9.1–9.5	Environmental, economic	Boosts efficiency and resilience by sustainability and safety standards; fosters innovation through digital solutions.	Automated seismic code compliance checks (e.g., New Zealand, Finland); ISO19650
Tools, software and hardware	Workflow/process management platforms	SDG 8; SDG 11	Environmental	DBP tools enhance transparency, reduce paper consumption, support data-driven planning, and strengthen compliance with sustainability regulations	Examples of national e-permitting portals (e.g., Estonia's x-Road system, Finland's Lupapiste platform)

are considered, the process and method, which exemplify the activities that happen during building permit processes, interpreting any laws or guidelines to reach reasonable decisions about BP, and the procedure itself, which represents the workflow that administrative operations must follow. Table 5.3 explores how streamlining approval procedures; integrating pre-consultation practices; and enforcing compliance with health, safety, and environmental standards can enhance sustainability. The table links procedural innovations with SDG targets on health (SDG 3), climate action (SDG 13), and sustainable cities (SDG 11). Several entries demonstrate how automation, model checking, and cross-agency cooperation can improve both project quality and regulatory effectiveness.

Technological Subsystem

The Technological Subsystem (Table 5.4) represents the digital infrastructure supporting DBP, with a focus on data, software applications, and interoperability solutions that can be used as part of the building permit compliance-checking procedure. Categories include Data and Information, Tools, Software and Hardware. Subcategories include public access to building data, environmental monitoring, digital product passports, or geospatial and context data. These technological tools are mapped to sustainability functions like improving transparency, reducing environmental impact, and promoting informed decision-making. The table also illustrates how better data sharing and integration can enhance regulatory outcomes and support climate-resilient design.

Discussion of Results

Sustainability in the built environment is essential for ensuring it is planned, approved, and operated in a manner that supports long-term environmental, social, and economic goals. This chapter contributes to the growing body of knowledge on DBP by examining how sustainability is embedded across four subsystems: legislative, organizational, procedural, and technological. In contrast to previous research that has often concentrated on specific aspects, such as energy efficiency in BP procedures (Gokarakonda et al., 2022) or automation within BP procedures (Noardo et al., 2022), this study adopts a more holistic approach. Using a structured taxonomy, it offers an analysis of how sustainability is embedded within the legislative, organizational, procedural, and technological dimness of DBP. The developed mapping matrix clarifies the often-overlooked connections between BP processes and sustainability.

In addressing the research questions, the findings show that sustainability is indeed embedded within DBP, although its integration varies widely across subsystems. Environmental considerations are the most consistently represented, particularly through legislative mandates and procedural innovations, such as digital compliance tools, as illustrated in Tables 5.1 and 5.3. In contrast, social and economic dimensions appear more fragmented and often

depend on specific organizational practices or localized policies (Table 5.2). Technological tools supporting data interoperability, open access, and circularity further contribute to sustainability outcomes, though their adoption remains uneven and sometimes lacks integration with broader regulatory goals (Table 5.4). Overall, the matrix shows that while diverse instruments and initiatives exist to support sustainability within the BP workflows, their implementation is inconsistent and coordination between levels of governance is limited.

Among the findings is the strong presence of social sustainability aspects in the organizational subsystem (Table 5.2), particularly through transparency measures, participatory platforms, and inclusive governance frameworks. Although less frequently addressed in DBP literature, these measures demonstrate considerable potential to enhance equity and accessibility within the BP process. Another important result is the multidimensional potential of procedural innovations (Table 5.3). Tools initially developed for efficiency, such as submission optimization and automated rule-checking, can also support environmental and social objectives, particularly when applied to buildings serving vulnerable or underserved populations, such as hospitals, schools, or affordable housing.

Looking ahead, the findings underscore the need for more interdisciplinary understanding to explore the interplay between data interoperability, governance structures, and behavioural incentives in BP systems. The integration of DBP with green certification schemes, such as BREEAM, LEED, or DGNB, and with lifecycle-based design approaches could help elevate sustainability from an optional add-on to a core element of regulatory compliance. These certifications already incorporate metrics on energy performance, material reuse, and occupant well-being; aligning them more with BP processes could provide a more standardized and impactful framework for sustainable development.

Conclusions

This chapter provides a structured and comparative overview of how sustainability dimensions intersect with BP systems. By applying a taxonomy-based framework, it highlights the multifaceted potential of BP processes, not only to enforce code compliance, but also to advance broader goals in climate resilience, economic adaptability, and social inclusion. The study enhances existing understanding by identifying where sustainability is currently embedded across systems and where further integration is possible. In doing so, it provides actionable support for practitioners (e.g., use of LCAs, adoption of digital tools), guidance for policymakers, through promoting interoperability and aligning BP with certification schemes, and a foundation for researchers to explore governance models and behavioural incentives in future studies.

While the study provides a structured overview of sustainability integration in BP systems, certain limitations remain. The analysis is based on secondary sources and expert-informed examples rather than primary empirical data,

which limits its ability to capture practical implementation challenges or stakeholder experiences. Furthermore, the mapping relies on available references that reflect prominent initiatives and frameworks but may overlook emerging or less formalized practices that influence sustainability outcomes. As such, the findings offer an indicative, rather than exhaustive, mapping of current sustainability linkages. Future research should expand on this foundation through case studies, interviews, or regional analyses to validate and deepen the understanding of the role of sustainability in BP environments.

Ultimately, the chapter demonstrates that BP is not just a technical or bureaucratic process. When strategically structured, it can play an important role to create more sustainable built environments, supporting climate goals, economic resilience, and social inclusion from the earliest stages of a project development.

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6 Interconnection of Digital Building Logbooks and Building Permits

Realisation, Common Data, and Added Value

Pedro Mêda, Judith Fauth, and Silvia Mastrolembro Ventura

Introduction

The digital transformation of the construction industry has been identified as a strategic priority for the European Union (EU), with the goal of modernising and enhancing the competitiveness of the industrial ecosystem on an international level. For a comprehensive understanding, it is also necessary to contextualise it within the European Green Deal objectives. These objectives aim to achieve a zero-impact and resilient built environment by 2050 (European Commission, 2019). The so-called twinning of the green and digital transitions is at the core of the new EU industrial strategy (European Commission, 2021a), which has placed particular emphasis on the ongoing acceleration towards data-driven processes for the promotion of greater transparency, regulatory compliance, and effective collaboration along the entire value chain (European Commission, 2024).

In contrast, studies and research indicate that construction remains relatively underdeveloped concerning digitalisation when compared to other industries (European Commission, 2023a). The lag stems from a fragmented value chain, shifting ownership, and the life cycle of built assets. The key issue is the difficulty of having digital solutions supporting a significant set of requirements, encompassing various construction process phases, and managing built entities (European Commission, 2023a). The reliance on repetitive data inputs across various digital technologies suggests a persistent underutilisation of digitalisation, impacting efficiency and misleading perceptions of the real digitalisation level. The most relevant aspect is that the implemented tools serve a narrow scope and lack interoperability, limiting the gains and impacts.

Data plays a crucial role in various dimensions of the built environment. It encompasses the interactions and needs of individuals and organisations, as well as construction-related information, including the recording and analysis of the performance of a building. However, these data remain scarce and are often characterised by unreliable quality and/or restricted interoperability. Inconsistencies and a lack of data mark the daily routine of construction-related stakeholders in almost all processes (European Commission, 2023a). The absence of standardised data repositories, for example, leads to additional costs and inefficiencies, hampering innovation, elevating risks, and ultimately

detering confidence in data reliability. Consistent and dependable data can significantly enhance the design, construction, and management of buildings, enabling a wide range of possibilities that are increasingly being adopted as requirements.

The practice of data-driven processes that are effectively life cycle-oriented is a strategic pillar for digital transformation (European Commission, 2023a). Within a life cycle-oriented perspective, these include the widespread adoption of Digital Building Permits (DBP), Digital Product Passports (DPP), and Digital Building Logbooks (DBL) (European Commission, 2023b). There is a growing awareness that a wide-scope, linked data repository is needed to facilitate streamlined interactions throughout the construction value chain, interacting with multiple tools to minimise reworks and engage multiple stakeholders with various types of data (European Commission, 2023b). The EU framework initiative for the DBL shares many similarities with the United Nations Building Passport initiative (GABC and UNEP, 2021), highlighting the significant contributions that such an instrument can make to the construction industry and the built environment. Furthermore, DBL functions keep expanding, driven by stringent requirements in terms of energy efficiency and sustainability. The objectives in supporting the monitoring of the use phase align the DBL closely with the requirements set for Digital Twins (DTw) at the building level (Calvetti et al., 2025). As will be further detailed, the DBL embodies different dimensions, namely the building life cycle and the construction process life cycle. Several researchers have been focusing on the requirements and functions of the DBL to deliver energy and sustainability-related outputs (Gonçalves et al., 2024). Other data have explored the DBL scope across these cycles and their interactions during the construction phase, specifically by identifying touchpoints with other EU actions, such as building permitting processes, which represent a critical interface between the design and construction phases (Malinovec Puček et al., 2023) (Figure 6.1).

Building permits verify compliance with building codes and regulations (Ataide et al., 2023). The DBP refers to the use of electronic systems to manage existing processes between construction process-related agents and authorities for compliance assessment and licencing at different stages (Fauth, Bloch, et al., 2024). This innovation, which cannot be reduced solely to the conversion of paper documents into static digital formats such as PDF files (European Commission, 2023a), aims to streamline these processes significantly. The reduction of paperwork, expediting approvals, and enhanced communication between stakeholders, including contractors, architects, and regulatory authorities, are among the practical benefits of implementing machine-readable rules and interoperable process management platforms (Al-Turki et al., 2024). By facilitating the real-time tracking and management of building permit applications, digital permitting aims to minimise delays and foster greater compliance with regulatory standards by reducing ambiguities and subjective interpretations (Zhang et al., 2024). A standardised approach to data collection, management, and interoperability is recommended for the effective implementation of

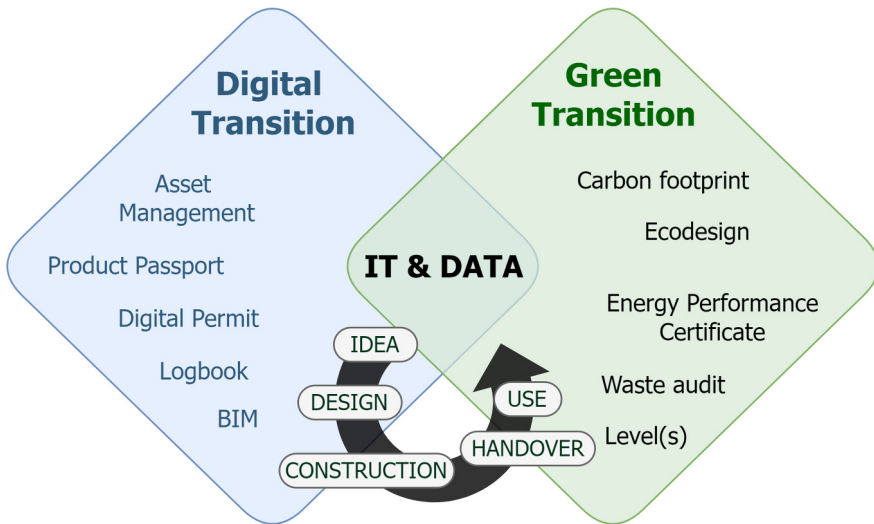


Figure 6.1 Twin transition through the construction process life cycle and key instruments and goals from each transition, sharing data and information technologies.

data-driven processes, supported by guidelines that integrate and link existing databases (European Commission, 2021a).

Despite the worldwide differences in building permitting processes regarding timelines, purposes, and data requirements, it is clear that building-related data need to be presented, assessed, and validated, leading to the issuance of a licence or a non-compliance report (Fauth et al., 2024). From these processes, new information is generated. These relevant datapoints for the project life cycle need to be stored and remain accessible. Examining the scopes of DBP and of DBL suggests that several relationships exist (Mêda, Calvetti, et al., 2024).

In line with the findings of previous studies, this chapter aims to consolidate their conclusions and explore, from a data perspective, the common ground between the DBL and DBP concepts as pillars of the EU digital transformation.

Understanding Digital Building Logbooks

The definition of the DBL was first established in 2021 (European Commission, 2020). That report concluded the phase aimed at defining the DBL concept and assessing national and sectoral initiatives, conducting a gap analysis based on the findings and requirements, and setting future actions. To detail the importance of the EU DBL, it is necessary to understand the specificities presented in its definition:

The DBL serves as a comprehensive repository for essential building data, promoting transparency, trust, and informed decision-making within the construction sector. This instrument enables the recording, access, and

organisation of various data and documents related to the building life cycle, including ownership changes, maintenance, and renovations. It encompasses administrative documents, technical systems, performance data, and links to building certifications, thereby supporting circularity in the built environment. The DBL contains both static data and dynamic information from smart devices, requiring continuous updates. It ensures user control over data and third-party access while safeguarding personal data rights. These data can be stored within the DBL or linked to external locations, with the DBL acting as a gateway (European Commission, 2020).

Therefore, it is important to stress that the DBL focuses on the built entity/building level (Mêda et al., 2022). However, due to the information requirements and user interfaces, it needs to integrate, work with, and articulate information related to cadastral parcels and building unit/property levels (Figure 6.2) (European Commission, 2023b). Its range of action results from integrating different life cycles, such as the design and construction processes, as well as the operation and management. Some datapoints are static, while others are dynamic, and their type changes as the building progresses through its life cycle. While serving as a common repository, it should also act as a common ground for linking to other repositories. All the presented aspects demonstrate the importance of the DBL. It aims to represent a significant advancement in building information management from multiple perspectives and throughout the respective life cycles, enhancing efficiency, transparency, and accessibility, thereby facilitating multiple assessments, improving knowledge of the built environment, and promoting more informed decision-making. Moreover, the development of a framework and implementation metrics is being boosted by the growing emphasis on sustainability, as discussed in the Twin Transition strategy. This data-driven approach not only supports compliance with

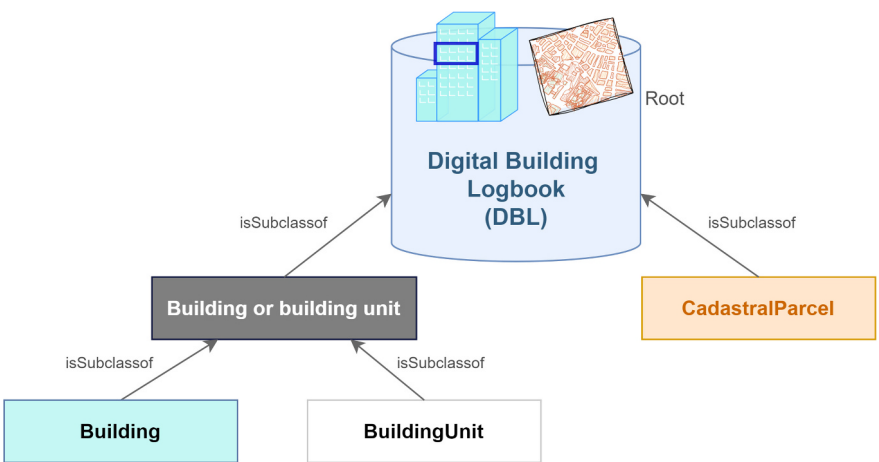


Figure 6.2 The different levels of the Digital Building Logbook. Based on European Commission, 2023b).

regulatory requirements but also facilitates achieving sustainability certifications, which are increasingly important in an environmentally conscious market. Given the DBL characteristics and the requirements for DTw at the building level, several studies advocate for the DBL as a critical enabler for Building Digital Twins (Gómez-Gil et al., 2022; Mêda and Calvetti, 2023). In this respect, the DBL would function as an information container, providing background data for the DTw systems and recording the data collected from those systems, whether raw or processed.

Before the DBL studies, sectoral actions had worked with the same digital assumptions, proposing specific concepts that used the word “passport” as part of their naming, but targeting precise goals. Originating from the new version of the Energy Performance of Buildings Directive (European Commission, 2021b), the Building Renovation Passport (BRP) aims to provide a step-by-step renovation roadmap that supports homeowners and building managers in improving energy performance over time. The definition of a sequence of financially and logistically manageable renovation stages incrementally improving the energy performance of buildings, meeting Green Deal and Renovation Wave goals, is the key objective. Similarly, in the context of the Waste Framework Directive (European Commission, 2018), the Material Passport (MP) (Heinrich & Lang, 2019) utilises building and product-level datapoints to construct a material inventory. The vision of buildings as material banks (Mulhall et al., 2017) or cities as urban mines underpins the concept, aligning with the goals of the circular economy.

Without delving into details, it is clear that the DBL has a broader scope and can link to or overlap with these concepts. However, the articulation of these concepts is, at this point, a gap in the body of knowledge.

The Interconnection between Digital Building Logbooks and Digital Building Permits

Considering the research on the building permitting domain, it is clear that this is a process that occurs within the context of the design and construction phases, taking place within specific timeframes depending on the realities (Fauth et al., 2023). Regarding the logbook, the evolution of related studies led to the recognition that it needs to encompass several life cycles, one of which is the construction process. The intuition of potential overlaps and commonalities in data and processes between the two concepts led to the realisation that these overlaps could also encompass stakeholders, technologies, and legal frameworks (Mêda, Calvetti, et al., 2024). From this understanding, the following reflections regarding DBP and DBL articulation were drawn:

- The DBP processes are fundamentally driven by regulatory requirements, serving as crucial milestones in the design and construction phases. These processes involve compliance checks based on structured data submitted to authorities (Fauth & Soibelman, 2022). Additionally, the outcomes must be

- documented and integrated into project decision-making records for future phases of the project.
- The DBL is designed to gather building-related information, including data on characteristics and relevant event records. It aims to connect with existing databases that hold metadata or documents for specific purposes, such as linking to building permitting tools for initiating and concluding processes.
 - The deployment of the DBL must occur prior to the design phase. To effectively record events during the use phase, engaging with asset management systems and the DTw at the building level is crucial, aligning with the building life cycle.
 - The DBL should be incorporated into the legal framework to enhance and update concepts related to record-keeping throughout the building life cycle.
 - DBLs serve as a comprehensive and dynamic “passport” for buildings, streamlining access to essential building data for various processes, including building permits. They facilitate an iterative closure of the building life cycle for new construction projects on buildings with a DBL, ensuring accuracy and efficiency.

Noardo et al. (2022) note that digital building permitting is one strand of the broader digitalisation agenda of the sector. However, research and practice evidence show that several gaps exist in the understanding and alignment of these relationships. Considering all the mentioned aspects and focusing on the perception that the DBP can or should use data from the DBL to streamline compliance checks, and that DBP outcomes should become part of the DBL, Figure 6.3 was created, presenting the conceptual vision of the intuition.

The diagram comprises four main phases: (1) Promotion/Feasibility, (2) Design/Procurement, (3) Construction, and (4) Operation. Each is depicted as a separate section for the building permit and the building logbook processes, highlighting their interconnection and the associated information flows.

The exploration of these perceptions led to the definition of a series of characteristics that express the scope of each concept, as well as their relationships,

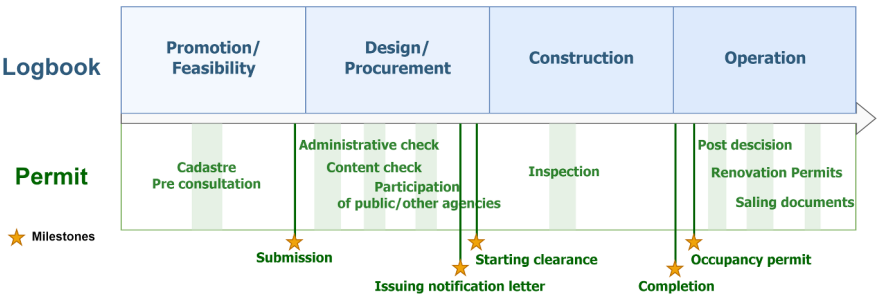


Figure 6.3 Process-level connections regarding DBL and DBP. Based on (Mêda, Fauth, Schranz, Urban, et al., 2024).

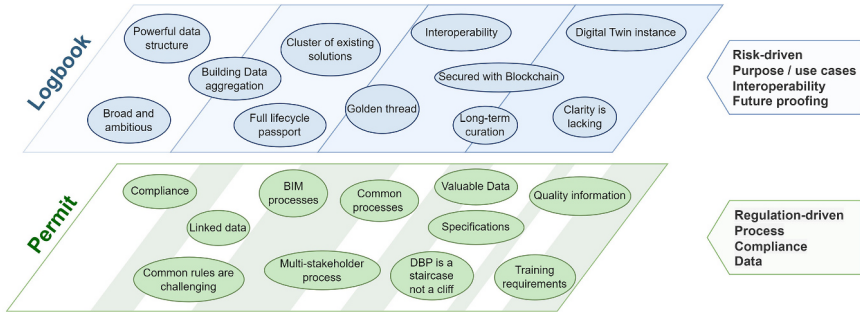


Figure 6.4 Summary of DBP and DBL characteristics. Based on (Mêda, Fauth, Schranz, Urban, et al., 2024).

positioning, and challenges. Moreover, Figure 6.4 provides an overview of the results, clustering the main perceptions.

Stakeholder connections also warrant attention. As previously stated, given the DBL range, a wider variety of stakeholders will interact with it. However, design teams and authorities must deal with DBP and DBL from different perspectives. Regarding building permits, the design team needs to prepare all necessary data for submission to the authority for compliance verification. Regarding the DBL, the design team will include all the key design deliverables and other “relevant” information to be recorded. With respect to authorities, they can assume the role of owner, meaning that they will deploy and ensure the proper DBL evolution for their buildings. The other situation involves the authority acting as a stakeholder, accessing specific data for all buildings under its jurisdiction. These perceptions enable an understanding that homogenising the interaction processes between the DBL and the DBP can expedite the work of design teams. However, it also implies changes in usual practices, as well as in the legal framework. Still, concerning authorities, it is essential to emphasise the need for awareness, training, and improved competencies to utilise the data made available in DBLs more effectively, particularly for the strategic planning of urban areas. This is part of the upskilling and reskilling strategy aimed at facilitating the digital transition of the construction industry, which is also highlighted as an EU priority, particularly when the public sector is involved (European Commission, 2023a).

As evidenced, several overlaps exist between DBP and DBL, impacting stakeholders, processes, and the legal framework. However, all rely on data that constitute the ground requirement for each concept individually. These data are common to both, either because they are structured in one and need to be exchanged with the other or vice versa. The next session will explore examples of these datapoints and the data exchange processes.

Common Datasets and Datapoints

The studies to define a taxonomy for the building permit system (Fauth, Bloch, et al., 2024) identified a set of high-level datapoints that are paramount. These data and information include “Building design data”, “Geospatial and context data”, “Procedural data”, and “Third-party data”. Greater granularity lets users pinpoint detailed datapoints, considering that some of the mentioned groups have background regulations, legal frameworks, or guidelines. One case is represented by geospatial data, which are harmonised under the EU Directive INSPIRE (JRC, 2017). Regarding building design data, the regulations governing construction activities and reporting tools, such as the construction statistics and real estate, can be used as a reference. In fact, these were used as a source in studies aimed at collecting relevant existing data to streamline DBL implementation (Mêda, Fauth, Schranz, Sousa, et al., 2024). In this respect, recent EU studies regarding the common framework for the DBL propose seven main components/groups of data, by type. These are labelled as “Identification”, “General”, “Legal Finance”, “Dimensions”, “Performance”, “Structure and Material”, and “Building services” (European Commission, 2023b). Despite the different criteria for the naming, it can be recognised that these groups are somehow affiliated, meaning that there are strong possibilities of identifying common datapoints. Figure 6.5 aims to exemplify the situation where one data point or a set of common datapoints are used to integrate processes between the two concepts.

Findings from Mêda, Fauth, Sousa, et al. (2024) indicate that the data required by national statistics offices are well-structured, standardised, and database-ready. The reviews also identified that efforts are being made to convert existing datapoints to those defined by the INSPIRE Directive, a work in progress with varying adoption levels across member states. Similarly, the Energy Performance Certificate (EPC) is recognised as one of the most trustworthy

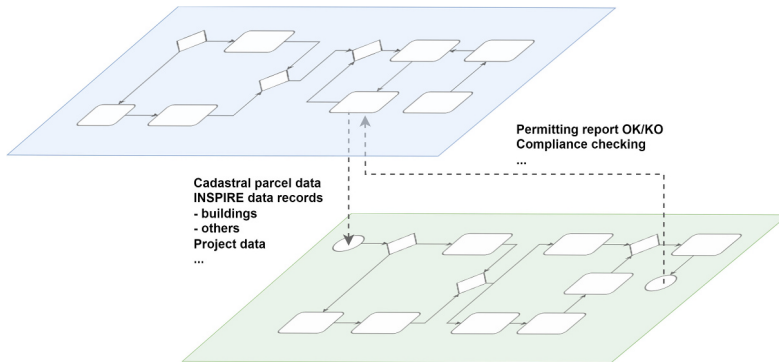


Figure 6.5 Example of the DBL/DBP process integration and data exchange. Based on (Mêda, Fauth, Sousa, et al., 2024).

Table 6.1 Example of Common Datapoints between DBP and DBL

<i>Datapoint</i>	<i>Source</i>	<i>DBP Group</i>	<i>DBL Component</i>	<i>Phase</i>
Geographic coordinates	Cadastral parcel	Geospatial	Identification	Idea
Street designation	Cadastral parcel	Geospatial	General	Idea
Building type	DBL	Building design	General	Idea
Building height	DBL	Building design	Dimensions	Design
Number of floors	DBL	Building design	Structure and material	Idea
Number of dwellings per type	DBL	Building design	Structure and material	Design
Building volume	DBL	Building design	Dimensions	Design
Preliminary energy class	DBL	Building design	Performance	Design
Soil classification	DBP	Procedural	General	Idea
Type of work	DBL	Building design	Legal and finance	Idea
Gross construction area	DBL	Building design	Dimensions	Design

documents, meaning that the source data for its issuance are subject to higher scrutiny compared to others. It is critical to highlight that data accuracy is a major issue, as, except for the EPC, it should be recognised that actions and procedures should be taken to strengthen the reliability and correctness of datapoint definition and value introduction. Table 6.1 provides examples of DBP and DBL common datapoints, identifying the data, their sources, groups or components, and the moment when they should be defined. This list is not exhaustive, but it aims to showcase examples of common datapoints and their positioning in the two concepts, as well as forecasting the moment of definition during the construction process life cycle.

Added Value of the Interconnection for the Industry Value Chain

Key aspects have to be consolidated and widely understood by the construction industry and its value chain relating to the adoption of DBP and DBL in terms of (1) enhancement of project deliverables, (2) efficiency gains, (3) potential cost reduction, and (4) potential savings:

- Enhancement of Project Deliverables – What DBP and DBL can bring:
 - Better decision-making – Integration enables access to legacy and project development data (via DBLs) alongside current legal framework data (from DBPs), supporting more informed design, planning, and construction decisions. It helps identify suitable materials, energy performance

benchmarks, and design strategies based on previous projects and compliance requirements.

- Improved compliance and quality control – Real-time verification of building permit conditions against as-designed/built data stored in DBLs ensures that construction meets all regulatory and safety standards better. Early identification of non-compliance or deviations from permitted design reduces rework and legal risks.
- Life cycle value optimisation – By maintaining a complete, accessible digital history of building materials, equipment, and maintenance (in the DBL), decisions during renovation or demolition phases can be highly improved, supporting circular economy goals (and enabling MPs and BRP implementation). The possibility of deploying a DBL in the context of a renovation project by collecting legacy data and incorporating possible elements from surveys and diagnoses prior to the renovation design can support and streamline the building permitting processes required for the intervention. In this context, a DBL can be built based on initial work aimed at delivering MPs.
- Efficiency Gains – What DBP and DBL can enable:
 - Streamlined building permitting and approval processes – Integrating DBPs with DBLs enables automated cross-checks and pre-validation of designs against building permit requirements, significantly reducing the building permitting process time. This connection can reduce the administrative workload for design teams and public authorities.
 - Improved workflow coordination – A single, integrated data environment potentiates cross-stakeholder collaboration, aligning architects, engineers, contractors, and regulators on a shared source of truth. Enabling machine-readable permit data facilitates the automatic update of workflows and triggers the subsequent steps without manual input. The DigiChecks project (DigiChecks consortium, 2023), for example, has revealed the need to orchestrate the DBP process within a distributed and open platform for interoperable data sharing, in line with the broader European data strategy.
 - Reduced redundancy and duplication – Eliminating the need to repeatedly enter and verify data at different project phases and in distinct systems. The guarantee of consistent data use throughout the project life cycle significantly contributes to reducing inefficiencies and errors, ensuring data continuity and valorisation in the building life cycle.
 - Improved time efficiency – In addition to minimising the need to repeatedly enter data, a time-consuming and error-prone task, the organisation and alignment of processes and technologies will make time more effective in performing assessments rather than low-performing or inefficient tasks. Although it can be recognised that digitalisation and Artificial Intelligence tend to replace humans, in this specific scenario and in the following decades, more than replacing, these supporting technologies

will allow the existing staff to be more productive and increase competencies in other meaningful fields that were not possible to follow just because they were physically attainable.

- **Potential Cost Reductions – What DBP and DBL can lead to:**
 - **Reduction of transaction costs** – This topic presents a nuanced challenge, with limited existing research. The possibility of omitting it from this chapter was considered; however, it is deemed essential to highlight certain key issues that warrant attention. On the one hand, the implementation of these systems is likely to result in a reduction of costs. Conversely, substantial investments will be required in areas such as hardware, software, training, and the acquisition of new skills necessary for the effective deployment of these systems. It is imperative to weigh this balance carefully, taking into account the array of new services that can be developed within the data landscape, as well as the escalating energy consumption associated with the utilisation of these technologies.
- **Potential savings – What DBP and DBL can lead to:**
 - **Placing the focus on the people** – A fair trade-off/balance between the human staff and its efficiency and investment in machines. Savings in effort and in the engagement of people in searching for things that already exist, things that were lost, or things that are inaccessible throughout a building life cycle for a specific purpose can be used for more analytics or new assessments.
 - **Reducing rework and delays** – Integration facilitates real-time assessments and the early detection of permit-related issues or design mismatches (via DBP-DBL integration), preventing costly on-site changes or fines.
 - **Optimising resource use** – The perspective that DBLs can provide and collect performance and maintenance data (or interact with specific types of systems) will enable facility managers to plan operations and upgrades more effectively, thereby reducing long-term operational costs.
 - **Facilitating financing and insurance** – Reliable and structured data from DBLs and DBPs improves transparency. Assessing risk and value becomes easier, which can reduce premiums and increase access to green financing.

Future Research Direction

The DBL and the DBP constitute key parts of the construction transition pathway to a more digital and sustainable built environment. Throughout this chapter, several cornerstone understandings were presented to demonstrate that, despite the challenges, there are already some elements that can serve as a starting point. In fact, this constitutes a first research direction, as there is a need to identify what and where datapoints already exist, as these can be

relevant for the respective concepts. A link, exchange process, or technical integration requirements might arise from their identification. This will inevitably lead to questions about the level of detail in the data sources or what they could be. EU initiatives such as “Once Only” (Tepandi et al., 2021) constitute an affiliate field of work.

Consolidating the relationship between the DBL and the DBP does not imply terminating individual research on the concepts. In contrast, the DBL and DBP-specific research should be strengthened, and the associated links and relationships should be forecasted, including MPs, BRP, DPP, and DTw at the building scale. Regarding this, the data integration between the DBL and DTw at the building and city levels constitutes a relevant research domain, specifically in its contributions to analysing, predicting, and calculating district characteristics, such as energy performance and fire safety.

From a legal framework perspective, it is clear that the permitting process has a long history in regulations. Nevertheless, these need to be updated to become machine-interpretable. Likewise, the DBL concept is not clearly presented in the EU legal framework nor in the regulations of member states. However, some related concepts aim to translate the idea of an information repository that should be maintained and made available to support multiple purposes throughout the building life cycle. Cross-domain research, which brings together construction-related stakeholders and lawyers, constitutes another key direction.

Without being exhaustive, there are other domains related to the development of technical solutions and support systems to assist the value chain efficiently. Organising tools, developing exchange protocols, and ensuring data traceability and reusability are paramount to ending repetitive data entry across applications. Role access control systems will also play a role in future scenarios of such ecosystems (Fauth, Deac-kaiser, et al., 2024). At some point, it will be interesting to measure the actual performance and impact of DBL-DBP integration quantitatively.

Conclusion

This chapter examined the intersection between DBPs and DBLs as pivotal instruments in the digital transformation of the construction industry. The objective was to summarise their respective roles, identify overlapping datapoints, and assess how their integration can enhance regulatory compliance, efficiency, and sustainability across the construction value chain, employing a data-driven approach to support transparency and reliability.

The study demonstrated that DBPs and DBLs, while distinct in scope and function, share a significant number of common datasets and operational synergies. The mapping of these shared datapoints confirmed the potential for improved coordination between permitting authorities and life cycle data repositories. In particular, the study validated that DBP outputs could serve as essential inputs for DBLs. In contrast, DBLs could pre-structure and streamline the data needed for various permitting processes.

In addressing the research aim, this chapter provides a conceptual overview of the connection between the procedural logic of building permits and the data-driven logic of logbooks. This work sheds light on the opportunities for reducing redundancy, increasing data accuracy, and enhancing stakeholder collaboration through more interoperable systems. It also highlighted the need for legal and procedural adaptations, particularly in the role and competencies of public authorities to realise these benefits fully.

Looking forward, further research is required in several areas: legal harmonisation for DBL inclusion in regulatory frameworks, development of common data exchange protocols, and empirical studies assessing the real-world impacts of DBP-DBL integration on project timelines, costs, and decision-making quality, as well as the maturity of stakeholders in addressing these challenging innovations. Advancing this agenda will require cross-disciplinary collaboration among policymakers, technologists, and built environment professionals.

As the construction sector navigates the green and digital transitions, embracing integrated digital systems, such as DBP and DBL, will be essential. Their alignment holds the potential to streamline compliance and documentation and build the foundation for a more transparent, resilient, and sustainable built environment in Europe and beyond.

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7 Legal Reasoning for Interpreting Requirements

Eilif Hjelseth

Introduction

There is a paradox that we don't see more use of automated compliance checking (ACC) solutions supported by Building Information Modeling (BIM). The development of compliance checks had its early roots in BIM development, being regarded as one of the most significant impacts for the utilization of BIM. Studies by Amor and Dimyadi (2021) illustrate that multiple technologies for processing and compliance checking have been developed.

Based on available technology and the high volume of small cases, we can expect widespread implementation of all compliance checking solutions, particularly within building permit processes. All countries have some building permit system, so joint solutions should be expected. The increased capability of artificial intelligence should also be an enabler for processing building permits.

However, this is not the case based on general observations. There is a considerable gap between selecting simple requirements, such as the turning circle of a wheelchair should be a minimum of 1500 millimeters, and performance-based requirements like this: "The threshold should not be too high". A study by Hjelseth (2012b) on the "ISO 21542:2011 Building construction – Accessibility and usability of the built environment" standard demonstrated that use of the Tx3 and TIO framework increased the number of requirements applicable for implementation in ACC from 57% to 83% of the requirements in the standard.

Performance-based regulations define required outcomes without prescribing specific methodologies, resulting in interpretive ambiguity. Addressing this gap, this research systematically incorporates legal reasoning and Fairness, Accountability, and Transparency (FAT) principles through legal informatics, ensuring practical interpretation of ambiguous regulations. The FAT principles are explained in a separate section. Another impact of performance-based regulations is the increased innovation and creation of more sustainable solutions through exploring new approaches.

Awareness that their interpretation process should, in principle, be highly developed and supported by applicable methods. Perhaps practitioners would

benefit from a more stepwise approach to interpreting requirements. Developing digital solutions often involves building on clear, stepwise processes. Eastman et al. (2009) proposed a four-step process for developing all compliance checking systems. The first step was to be careful in interpreting the requirements. The following steps were related to the use of technology. Since then, multiple studies have been conducted, and numerous papers have reported and demonstrated the advanced use of technology in response to relatively simple prescriptive requirements. The focus on limitations in the IFC schema (ISO 16739-1 2024) and the content of information in the BIM has dominated the development of ACC. Once the technology issues were resolved, the case was considered solved, and it was simply a matter of scaling up. However, this scale-up is still tricky to observe.

This study focuses on the first step of this process from a legal science perspective. Here is the interpretation process embedded in the way of thinking, along with guidance on how to support it.

For architects and engineers, legal reasoning involves creating a series of arguments for an interpretation that is “unfamiliar”. This study aims to explore the principles and methods applicable for the trustworthy interpretation of requirements in law codes, standards, and contracts, in a manner that can be implemented in computable solutions.

The impact of this support/awareness is expected to lead to an increased number of requirements being implemented in compliance checking solutions, as demonstrated long ago in the “Accessibility” study by Hjelseth (2012b). Use of legal reasoning for interpreting Brazilian standards on accessibility was also been demonstrated in a study by Mendonça et al. (2020). Legal reasoning is a professional topic within legal science. The overview of methods does not aim to provide a comprehensive legal education but rather to demonstrate that the interpretation of requirements can be conducted systematically and reliably based on established principles, rather than relying solely on the personal interpretation of the software developer.

This chapter starts with a short introduction to methodology. Then we introduce legal systems, Common law, and Civil law, before going into an overview of applicable principles and methods. This includes Legalization as “Constraint”–“Content”–“Context”, the introduction of the Tx3 framework: Transcribe–Transform–Transfer, and the European Interoperability Framework (EIF). The awareness and applicability of proposed methods or principles are expected to increase the number of requirements implemented in ACC solutions.

Research Methods

This chapter intends to give an overview of relevant principles and methods. This is achieved through a literature review and the author’s experience in compliance checking products over the last 20 years. Social science principles

regarding the interpretive researcher’s influence must be considered. When methods are presented and recommended, these are based on the intention to fulfill the requirements by proposing good (or good enough) solutions, not on how cheaply the minimum requirement can be solved in each case.

Previous research has successfully automated prescriptive regulations, including those defined by measurable criteria, such as minimum door width (e.g., Eastman et al., 2009). Solihin and Eastman (2015) emphasized standardized BIM data for rule-based compliance, while studies by Hjelseth (2012a,b) highlighted the complexities inherent in performance-based regulations.

Rule engines need unambiguous predicates, whereas legislators routinely employ defeasible concepts, like suitable means of “escape route”, “reasonable daylight”. Legal science offers interpretative canons (literal, systemic, teleological) and hierarchy rules that can guide disambiguation before formalization. Embedding those canons in the transformation pipeline is still rare and constitutes the research gap addressed here. Proposed methods aim to bridge the technical–legal gap.

Influence of the Legal System: Common Law versus Civil Law

We begin this section by introducing the two most commonly used legal systems, then present the methods for producing judicial rules based on performance-based requirements.

The two most widely used systems of law are: Common law and Civil law. Awareness of these constraints is essential when working with or understanding how law can be applied as computable rules. The list (incomplete) classifying countries based on their predominant legal system – Common law, Civil law, or a combination (mixed system) – is based on Glenn (2014) and Koch and Øyrehagen (2020). An overview is presented in Table 7.1. Examples of Common law are based on UK examples from the Town and Country Planning Act, UK (1990), and examples of Civil law are based on Norwegian examples from the

Table 7.1 Overview of Legal Systems

<i>Common Law</i>	<i>Civil Law</i>	<i>Mixed Legal Systems</i>
Emphasize judicial precedent and court rulings	Rely predominantly on codified statutes and written laws	Countries rely predominantly on codified statutes and written laws
United Kingdom (England, Wales, Northern Ireland), United States (except Louisiana, which is mixed), Canada (except Quebec, which is mixed), Australia, New Zealand, India, Ireland, and Singapore.	Norway, Germany, France, Italy, Spain, Brazil, Mexico, China, Japan, Russia, Argentina, Netherlands, Turkey, South Korea, and Sweden	Scotland (UK), Quebec (Canada), Louisiana (USA), the Philippines, South Africa, and Israel

Based on Glenn (2014) and Koch and Øyrehagen (2020).

Plan- og bygningsloven, Norway (2008), the Norwegian equivalent of the UK Town and Country Planning Act.

Similarities and Differences between Common Law and Civil Law

This section presents a concise comparison highlighting the similarities and differences between Common law and examples from the UK, and Civil law and examples from Norway.

Similarities:

- Rule of law: Both systems uphold principles of justice, fairness, and equality before the law.
- Written legislation: Both rely on codified statutes or legislative acts to govern various domains such as criminal, commercial, and civil law.

Differences:

- *Sources of law:*
 - Common law: Relies significantly on case law, precedent set by courts, and judicial interpretation.
 - Civil law: Primarily governed by comprehensive, codified laws and statutes; judicial decisions play a secondary role.
- *Role of Judges:*
 - Common law: Judges actively interpret and shape laws through rulings; case precedents strongly influence future cases.
 - Civil law: Judges apply the written law with less discretion, using precedents primarily for interpretation, not as binding law.
- *Legal Procedure:*
 - Common law: Adversarial system, emphasizing opposing parties' arguments and court interpretation.
 - Civil law: Inquisitorial elements; the judge plays a more active investigative role, especially in criminal cases.

Examples Related to the Building Act and the Building Permit

Here are examples illustrating similarities and differences specifically regarding building permits under Common law legislation, with examples from the UK, and Civil law legislation, with examples from Norway.

Similarities:

- Mandatory Approval: Both countries require explicit permission before construction starts, ensuring projects comply with planning laws and local regulations.

- **Compliance with Planning Regulations:** Both jurisdictions emphasize adherence to zoning, environmental protection, and local development plans.
- **Public Participation:** Both systems incorporate mechanisms for public consultation and objections to ensure transparency and accountability.

Differences in Legislative and Administrative Structure

- **Common Law:** Building permits are governed primarily by the Town and Country Planning Act (1990) and related regulations. Local planning authorities have discretion in interpreting these rules, making decisions heavily influenced by precedents from previous cases and appeals. Example: If a building permit decision is disputed, the matter often moves to Planning Inspectors, who consider past decisions and judgments (precedents).
- **Civil Law:** The permitting process is defined by comprehensive codified legislation, primarily the Planning and Building Act (Plan- og bygningsloven, 2008). Decisions are predominantly based on clearly defined rules within this codified statute, leaving less discretionary space. Example: Applications typically follow explicit criteria in the Act, with less reliance on interpretation through precedent.

Role of Case Law and Precedent

- **Common Law:** Decisions rely heavily on case law. Judicial reviews and appeals significantly shape how the law is applied, creating a nuanced landscape. Example: A court decision on the interpretation of the phrase “material consideration” can substantially affect subsequent planning decisions.
- **Civil Law:** Case law influences interpretation but is secondary to statutory text. Precedents clarify but generally do not dictate how statutes are applied in future cases. Example: Court decisions clarify ambiguous points but rarely result in substantial shifts in standard permitting procedures.

Flexibility and Discretion

- **Common Law:** Higher discretion allows authorities flexibility in unique situations, but this can lead to uncertainty or inconsistency. Example: Special considerations for heritage or conservation areas often rely heavily on past rulings.
- **Civil Law:** Less discretion, providing clearer predictability but potentially limiting flexibility in unique or complex projects. Example: Deviations from detailed plan regulations require stringent conditions explicitly defined in statutory law.

Results of Identifying Relevant Methods and Principles

It is essential to be aware of the difference between what can be accepted as a professional interpretation in a single case and what can be processed more or

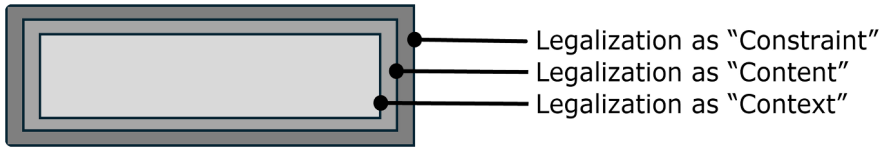


Figure 7.1 Legalization as “Content, constraint and context”. (Based on Schartum, 2018).

less automatically in the ACC solution. Content is the text in requirement (law, codes, standards) representing the maximum limitation in any case. Constraint represents the applied side or requirements in normal use cases. Content represents the actual use case and includes “buffers”, as presented in Figure 7.1. This implies that requirements in a BMC solution should be implemented as “trustworthy” computable rules.

Awareness of this central principle helps us recognize the limitations in the development of digital solutions in advance of programming. Legalization is by principles or general rules to be applied in all (relevant) situations. The Norwegian Building Act (2008) states in §1 about the purpose of the law: “For boliger skal prinsippet om universell utforming ivaretas gjennom krav til tilgjengelighet”. Author’s translation: “For housing, the principle of universal design must be safeguarded through accessibility requirements”. This can be regarded as a constraint by identifying the use of a building, excluding other types of facilities. Regarding the content requirements to access the building and its necessary facilities, it is essential for all users. Examples include the entrance door and toilet, which are the minimum requirements for the building’s fixtures and fittings. The context is access for a person in an ordinary wheelchair, where manually operated wheelchairs have a width of 61 cm, and electric wheelchairs for outdoor use are wider. However, the Norwegian Building Code (2017) specifies 86 cm as the minimum width of door openings. In this case, the interpretation from act to code was done and clearly specified in metrical values. This is not always the case, as the “Accessibility” studies by Hjelseth (2012a,b) demonstrates. This study applied these principles, enabling the specification of set-based values for a large number of performance-based requirements. An ACC can connect to (product data) sources for the width of wheelchairs (or other types of functionality), thereby validating compliance in a more interpretative way, while still documenting compliance with the requirements’ purpose.

This implies that implementation into ACC must not only be based on simple, straightforward, prescriptive requirements. The following overview of methods/principles indicates that even open-formulated performance-based requirements can be implemented, at least in some defined situations or contexts. This will, in practice, increase the scope and usability of ACC.

Introduction to Fairness, Accountability, and Transparency: The FAT Principles

Evaluation against FAT ensures that computational implementations align with these principles. The integration of FAT principles in digital regulatory processes is becoming increasingly significant. Schartum (2018) underlines aligning computational processes with legal reasoning and accountability frameworks to address these complexities.

In legal science, the principles of FAT serve as a foundational guideline to ensure that legal processes, particularly those involving automated or algorithmic decision-making, uphold core values of the rule of law.

- **Fairness:** This principle requires that every individual or group affected by an automated legal process be treated without bias or discrimination. Fairness in legal contexts involves consistency (i.e., applying the same rules to similar scenarios) and equity (i.e., recognizing and addressing disparities to prevent unjust outcomes). In automated systems, this means mitigating the risk of biased or discriminatory algorithms by scrutinizing training data, decision thresholds, and systemic impacts.
- **Accountability:** Accountability ensures that the creators, deployers, and overseers of automated legal systems can be held responsible for their decisions and outcomes. In practice, it involves:
- **Identifiable Oversight:** A straightforward assignment of responsibility, allowing one to trace decisions back to those who designed or implemented the system.
- **Redress Mechanisms:** Legal avenues exist for individuals to challenge or appeal decisions rendered by automated processes.
- **Compliance and Enforcement:** Standards or regulations are in place to sanction non-compliance and correct errors or injustices that automated systems may generate.
- **Transparency:** In legal contexts, transparency demands that the rationale behind decisions is made understandable to the individuals affected and to relevant bodies. This includes:
- **Explanations:** The ability to articulate how and why a decision was reached, often referred to as “explainability”.
- **Access to Information:** Providing stakeholders, including citizens, legal professionals, and regulators, with sufficient insight into the system’s structure and operation.
- **Documentation:** Maintaining clear records of system processes, data usage, and decision-making protocols is crucial for auditing and ensuring the integrity of legal processes.

Introduction to Interoperability

Interoperability is addressed in many studies related to the development of ACC, but it is primarily linked to the connection between semantic and technical interoperability.

Practical cases are often based on identifying relevant properties in IFC. IFC is the abbreviation for files based on the data schema in the ISO 16739-1:2024 standard schema. This data schema describes properties at the semantical level. The most addressed challenge is to map this to relevant attributes in the ACC software. Errors in this mapping are easy to discover but can be a challenge to solve. It is therefore understandable that this gets attraction and must be solved to demonstrate practical use. Even if this is a real problem to be solved to enable ACC, it seldom reduces the scope or the digital solution.

These types of technical interoperability problems have “kind solutions” with a defined answer. The real challenges are often on the other side of the EIF (2017), as illustrated in Figure 7.2.

EIF consists of four interconnected layers integrated by the Public Service Governance. This vertical bar is often forgotten or neglected because it addresses public services. The critical perspective is the need for governance. This implies that each layer must be seen in relation to the others.

The EIF provides a set of recommendations on enhancing the governance of interoperability activities, establishing cross-organizational relationships, streamlining processes that support end-to-end digital services, and ensuring that existing and new legislation does not compromise interoperability efforts. The purpose of the EIF is to support organizations in interacting toward mutually beneficial goals. This involves sharing information and knowledge between these organizations through the business processes they support, via data exchange between their ICT systems.

Legal interoperability is about ensuring that organizations operating under different legal frameworks, policies, and strategies can work together effectively.

The first step toward addressing legal interoperability is to perform “interoperability checks” by screening existing legislation to identify interoperability barriers: Sectoral or geographical restrictions in the use and storage of data, different and vague data license models, over-restrictive obligations to use specific digital technologies or delivery modes to provide public services, contradictory requirements for the same or similar business processes, outdated



Figure 7.2 European Interoperability Framework (EIF, 2017).

security and data protection needs, etc. Bearing in mind that European – and Norwegian – public services are clearly meant to be provided from digital channels, ICT must be considered as early as possible in the law-making process. Proposed legislation should therefore undergo a “digital check”:

- To ensure that it suits not only the physical but also the digital world (e.g., the internet);
- To identify any barriers to digital exchange; and
- To identify and assess its ICT impact on stakeholders.

This will facilitate interoperability between public services at lower levels (semantic and technical) and increase the potential for reusing existing ICT solutions, thereby reducing cost and implementation time (EIF, 2017).

Introduction to the Tx3 Framework: Transcribe–Transform–Transfer

The Tx3 framework was developed as part of the PhD study by the author (Hjelseth, 2015). The intention was to identify the challenges or problems in determining the applicability of the requirements (law, code, standard, and contracts) before programming. The Tx3 framework is presented in Figure 7.3.

An example of “Transcribe” can be a prescriptive specification that is expressed with discrete metrics (more than 900 mm, 2100 mm, 4 m, 12 m², 32 kN, and so on).

It is very easy to test using BIM-based model-checking software, but it provides little motivation for new and innovative solutions, and it is easy to validate.

An example of “Transform” can be a performance-based specification expressed as a purpose (function or goal) without discrete metrics. It is possible to test directly using BIM-based model-checking software based on defined metrics, motivating new and innovative solutions and the flexible use of existing solutions.

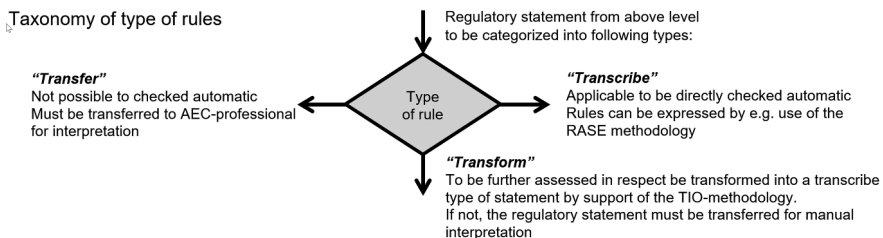


Figure 7.3 Tx3 framework: Transcribe–transform–transfer (Hjelseth, 2012a).

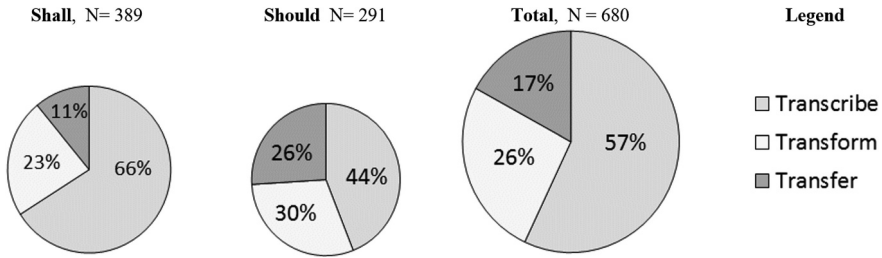


Figure 7.4 Classification of requirements in the ISO 21543:2011 standard (Hjelseth, 2012b).

A study by Hjelseth (2012b) on all 680 requirements, in the 152-page, 42-clause, and 5-annexe “ISO 21542:2011 Building construction – Accessibility and usability of the built environment” standard, demonstrates that it is applicable to identify which requirements can be classified as Transcribe–Transform–Transfer (see Figure 7.4).

The challenges in converting performance-based regulations into computable rules in BIM-based model-checking software are related to establishing a methodology to “transform” a connection from “unambiguous” qualitative statements to discrete quantitative metrics/values. Statements classified as “Transform” will be regarded as “solved”. If they are “unsolved”, the requirement is regarded as “unsolved” and classified as “Transfer” to manual and professional assessment.

Test Indicator Objective

Test Indicator Objective (TIO) presented in Figure 7.5 is an approach to increase the relationship between qualitative and quantitative requirements. It can be helpful “Transforming” the requirement into computable values. The metric value can be identified, specified, or associated with an iterative top-down or bottom-up approach, resulting in a set-based criterion. Examples of outcomes of transformation are presented in Table 7.2.

In a digital solution, can compliance validation be updated simply by changing the Parking distance criteria to 20 m, or should it include a weather criterion, such as “If snow”, with a maximum distance of 15 m?

This indicates that the digital solution must be adaptable to meet defined values. This is particularly relevant in Common law countries, where different types of cases serve as references.

The use of the TIO approach on the ISO 21542 standard is presented in Figure 7.6. The Tx3 and TIO framework reduced the percentage of requirements not applicable for implementation in ACC from 43% to just 17%. This implies that 83% of the requirements can be processed in ACC, impacting the compliance assessment.

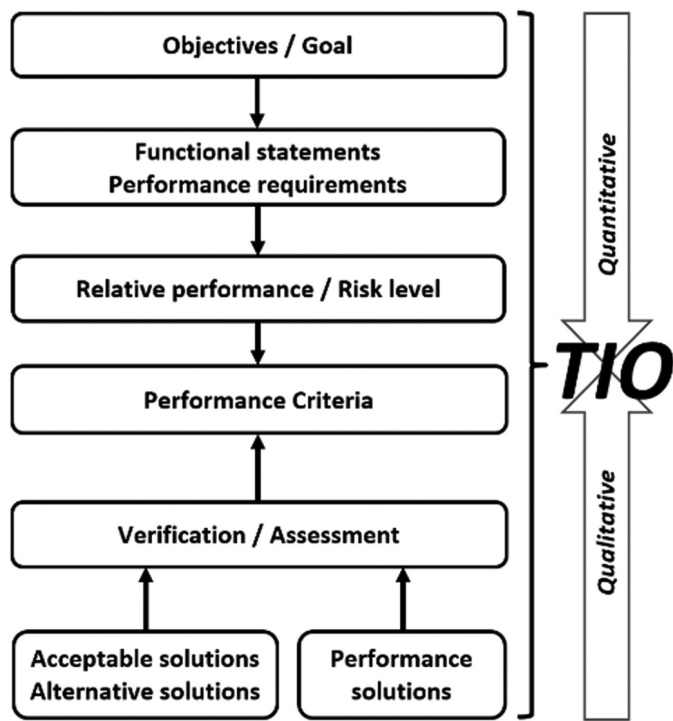


Figure 7.5 Test Indicator Objective (TIO) (Hjelseth, 2012a).

Table 7.2 Examples of Interpretation by TIO

Requirement	Mark for “Transformed To”
• Well illuminated	=> more than 350 lux
• Close to parking	=> less than 30 m
• Close to toilet	=> less than 10 m
• Door sill must not be too high	=> less than 10 mm
• Large enough sleeping rooms	=> more than 12 m ²
• Well-arranged	=> visible from the starting point (e.g., parking slot or entrance)

Information Delivery Specification

The Information Delivery Specification (IDS) is a standard developed by buildingSMART for defining information requirements in a manner that is easily readable by humans and interpretable by computers (van Berlo et al., 2023). IDS is a buildingSMART standard for defining information requirements in a computer-interpretable form. It enables automatic compliance checking of IFC models, enhancing quality control and data fidelity. IDS also

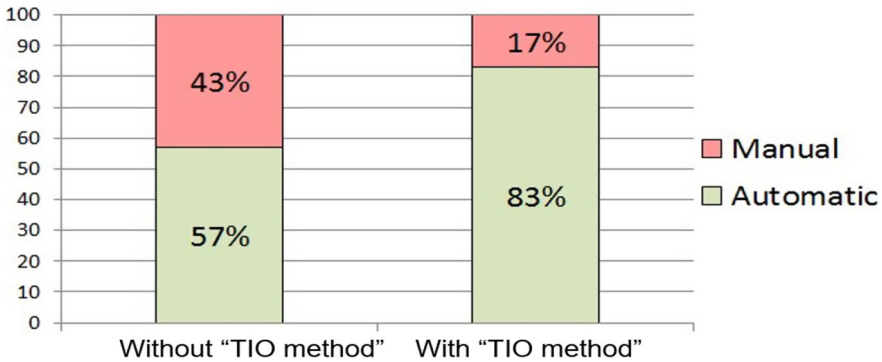


Figure 7.6 Impact of the TIO methodology on model checking (Hjelseth, 2012b).

facilitates the efficient delivery of data by setting expectations and providing clear guidelines on what needs to be exchanged. A user of IDS can specify how objects, classifications, materials, properties, and even values should be delivered in an IFC model (IDS, 2024).

This implies that one can validate BIM as an IFC model prior to running compliance checking. This also illustrates that the compliance check must be regarded as a part of the entire design process, and not only at the final step.

Discussion and Summary

This study introduces legal reasoning for architects and engineers in the AEC/FM industry. This is achieved by providing a concise overview. This study aims to bridge the gap between the legislative intent of interpreting requirements and the computational execution of rules, which is essential for credible ACC.

This overview of applicable frameworks suggests that legal reasoning can be applied in practice by professionals in the AEC industry, not just by those with a legal education. The impact of legal reasoning will increase the number of requirements used in BIM-based compliance checking, enhance trustworthy outcomes, and reduce the time and cost of analysing requirements.

The proposed methods and principles demonstrate that interpretation can be done systematically and transparently. Even if different professionals can disagree about the outcome of the interpretation, they can trace back and identify where their interpretations diverge.

This study analyzes the use, or more precisely, the lack of use of the FAT principles and EIF layer in both studies, as well as the methodology for developing ACC solutions. Providing numbered evidence for limited use is challenging because only a very limited number of studies within ACC projects, including FAT or EIT, are identified. One reason, of course, can be a limitation in the scoping review. Another explanation is that the principles are still used, albeit under different terms and abbreviations.

A general finding in ACC studies is that almost all examples are based on prescriptive requirements, and the case relies on the technology's proof of concept. Interoperability is most relevant for semantic and technical specifications of properties in the BIM file.

One interesting paper is the "Interoperability in construction—Mission impossible?" study by Ziga Turk (2020). This paper discusses EIF explicitly (e.g., its principles) to argue that construction interoperability must address legal/organizational as well as semantic/technical aspects. EIF is profiled as an enabler, not a quick fix.

The EU develops the EIF framework to support the digitalization processes. These are often projects with access to professional resources. The use of FAT and similar principles is embedded as the default in interpretive sciences, such as legal sciences in general and legal informatics (Dolin, 2021) in particular.

The situation in ACC projects in the AEC industry is mostly very different, with limited resources and a lack of multidisciplinary teams. Interpretation is often avoided by selecting prescriptive requirements when demonstrating the ACC solution.

This study does not recommend any legal interpretation method above others. They all have their pros and cons, and user preference and experience play an essential role in determining which methods different users prefer. There may also be other applicable methods and principles, as well as combinations. The primary principle is to establish a shared understanding and use principles or frameworks to solve these challenges systematically, rather than using workarounds or avoiding interpretations.

Another impact of using legal reasoning methods is increased innovation and more sustainable solutions, resulting from exploring new solutions rather than relying on pre-accepted or traditional solutions that were approved in a previous project. BIM-based compliance checking will be your digital companion to enhance the quality of the built environment, not just to get the application approved. The influence of ACC solutions on early awareness will therefore have a significant impact on the design process, particularly in phases where solutions are easier to implement and comply with regulations. ACC can act as a companion to enable a more creative design process.

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8 Putting Automated Compliance Checking in Context

Tanya Bloch and Nicholas Nisbet

Introduction

Automated Compliance Checking emerged as a pivotal area of research in 1960 with the introduction of decision tables by Fenves (1966). Later, in 1975, Eastman envisioned a future Building Description System that would be used for design review by municipalities or designers (Eastman, 1975). Subsequent developments, such as Fenves and Rasdorf's mechanism for representing design constraints (Fenves & Rasdorf, 1985) and Han et al.'s CAD-based tools (Han et al., 1997), laid the foundations for today's rule-based Automated Compliance Checking (ACC) systems. However, a true game changer has been the introduction of Building Information Modeling (BIM), which significantly impacted ACC by providing a digital representation of building design. This includes rich geometric and non-geometric information, represented in a machine-readable form, which allows to verify design elements against regulatory specifications, for example, checking spatial arrangements, accessibility, fire safety, and energy performance. The adoption of BIM technology and the introduction of the Industry Foundation Classes (IFC) schema have further advanced the possibilities for automated compliance checking (Dimyadi & Amor, 2013). However, BIM-based ACC requires high data quality and standardization, and challenges remain in reliance on consistency between geometry and attributes, and between object typing and classification.

Traditionally, ACC is described as a four-stage workflow, as stated in Eastman et al. (2009):

- 1 Interpretation of rules – Regulations and guidance in the AEC domain are written by human experts for the understanding and use of other human experts. They can hardly be considered as formal logical statements or statements that can be encoded into a computer application. However, experts in the field are easily able to comprehend the written text and reason about it. Experts can process the documents to translate them into formal representations suitable for software applications. To do this, we assume that the regulations are prescriptive, providing specific, measurable requirements, rather than performance-based requirements. Additionally, this process relies on

the quality of the regulatory documents themselves. The translation to logical statements is possible for high-quality documents that are internally consistent, clearly structured, and free of ambiguities and contradictions. Unfortunately, contradictions and ambiguities are not uncommon in this domain (Zhang et al., 2023).

- 2 Preparation of the BIM model – With the introduction of BIM, the use of computers in the AEC domain shifted from simply assisting engineers in drafting and generating sets of 2D drawings, to producing semantically rich and unified source of information in the form of a digital building model. However, the way that the models are constructed does not always align with the concepts represented in the building regulations. Regulatory requirements are often described in ways that require comprehension and interpretation of professionals in the domain. Much of the regulatory information can be implicitly represented in the BIM. Such information is understood intuitively by human experts due to their knowledge and experience, but not explicitly modelled or tagged within the digital model. For a computer to reason over a model in the context of compliance, the relevant information must be both present and structured in a machine-interpretable way. This suggests that to enable an automated compliance check, a mapping of the information in the BIM model is needed. Currently, this pre-processing stage is mostly performed manually.
- 3 Execution of the rules – Once the regulations are translated to logical statements and the BIM model has been pre-processed, the next stage involves the execution of the compliance rules. At this point, the system processes the formalized set of rules against the digital model, evaluating whether the design satisfies each specified requirement. Of course, the reliability of this process depends heavily on the quality of both the rule formalization and the model data.
- 4 Report the results – Following the rule execution, the system must report the outcome in a way that is accessible and actionable for stakeholders. This can be in the form of reports of failures and/or passes or as structured messages such as buildingSMART BIM Collaboration Format.

Looking at these stages, two main components lie at the heart of an ACC system: the regulations and the design. In fact, the workflow revolves around the ability to align these two representations: the formalized rules derived from building regulations and the digital models representing design intent. While much progress has been made for both, representing domain knowledge and design in a digital way, achieving the alignment between them remains a difficult task that is currently reliant on significant manual work. While a portion of current research efforts in ACC has been directed toward the automated transformation of regulatory documents into machine-readable rules, less attention has been given to automating the pre-processing stage of the BIM models for compliance checking. In practice, despite years of research and development, existing platforms for ACC, such as those implemented in

Finland, Estonia, and Dubai, are limited to a very narrow class of building requirements and do not allow full automation. Usually, only well-defined, prescriptive regulations focusing on simple geometric or spatial requirements (specifying dimensions, areas, volumes, or distances) are handled.

It is important to note that compliance checking is merely one component in the overall building permitting process. While there have been many efforts aiming to automate the compliance checking stage, the broader context of building permitting remains mostly manual. As highlighted in the McKinsey report (Barbosa et al., 2017), there are three main opportunities for improving productivity in the construction domain: (1) the use of robotic support for manual tasks on-site; (2) the implementation of modular construction and off-site production, including 3D printing; (3) the digitization of design, permitting, and management processes. Unfortunately, the building permitting process has not yet undergone full digitization, and automation remains largely absent.

In recent years, the tide seems to be shifting with much more practical solutions for digitalizing the permitting process and incorporating automation into it (to some extent). Several initiatives have introduced digital permitting platforms, often built on top of BIM, to streamline application review coordination. In research, however, most of the initiatives are either focused on ACC or on BIM-based digital permitting workflows where the integration of ACC is usually not explicitly addressed (Bloch & Fauth, 2023). A prevailing assumption in research appears to be that once BIM is adopted in permitting, ACC will naturally follow. This assumption overlooks the distinct challenges involved in embedding ACC as a core component of the permitting workflow.

This chapter therefore aims to examine ACC within the wider context of digital building permitting. Beyond presenting the latest developments in ACC technologies, we explore how ACC gradually makes its way into building permitting processes around the world. We observed a growing number of initiatives aimed at transforming the building permitting process itself. This includes a shift from traditional manual design review toward increasing levels of automation in the process. The integration of ACC into digital permitting processes holds great promise for enhancing efficiency, consistency, and transparency in building permitting. However, it is not without its challenges, which are usually not only technological.

Compliance Checking – What? Why? How?

What?

Design review is a formal, multi-disciplinary evaluation of a proposed building design. The scope of design review is often defined by the reviewing party. In big organizations, the design review process is often broad and targets multiple goals, including ensuring the design aligns with the client's requirements and complies with relevant legislation and regulations, as well as assessing value for

money, and sometimes maintenance considerations and environmental impact. In the context of building permitting, an important part is the conformance to local planning and zoning requirements and architectural design guidelines. A significant portion of the review is dedicated to ensuring that the design meets all relevant regulations, guidance, and standards. Regulatory compliance checking is not just a ‘task on the list’; it is a significant part of design review that requires the input of experts from multiple disciplines. The regulations checked are mainly those designed to assure public safety such as structural integrity, protection against fire, and means of egress. Ultimately, the process aims to ensure public health and wellbeing. Planning and zoning regulations consider the urban aspects such as infrastructure capacity and sustainability.

Why?

Currently, domain experts review drawings (usually 2D) and produce a document detailing the issues detected. The document is transferred back to the designers to make the needed changes, and the process repeats until no rejections are found. In the most common case, the information that flows in the process is unstructured and not machine readable. This is a labor-intensive process subject to inconsistencies due to its non-systematic nature and the underlying interpretations of the regulations by designers and reviewers.

Over the years, stakeholders have been seeking ways to make the process more systematic and efficient. This has led to the development and adoption of structured checklists and forms to guide reviewers through more standardized procedures. This kind of supported workflow also intends to increase consistency by ensuring all aspects of a project are reviewed uniformly and improve transparency and communications. This form of regulatory checking is implemented as part of the building permitting process in many countries (e.g. Fauth et al., 2023).

The most advanced form of regulatory checking is automated, namely, directly evaluating informative knowledge (description) against normative knowledge (regulation). While some early implementations of automated compliance checking exist, it seems the sector is only now starting to adopt.

How?

The technical challenge around automating compliance checking comes from the variety and complexity of the source regulations and complexity of the target information model. Both need to be examined and understood before they can then be interpreted into a machine-operable form. In most scenarios, the machine-operable form of the target information has been IFC (International Organization for Standardization, 2024) in one of its many representations such as SPF, ifcOWL, ifcJson, or ifcXML. IFC provides a structured, machine-readable schema and format for building information, enabling exchange of information between BIM authoring tools and other applications. The availability of IFC has

encouraged the development of ACC by allowing researchers and implementers to avoid proprietary formats but has also limited development by fostering the assumption that only what is available in IFC (i.e., BIM) is relevant to ACC, neglecting other sources such as GML (i.e., GIS) and other material such as application forms.

The conventional approach to the initial examination of the normative material has been to ask actors from the regulatory domain, programmers, or even experts in the target information domain to review the source regulatory material and to hold that understanding in mind as it is interpreted into a machine-operable form. Two alternatives have emerged which eliminate the need to hold the knowledge of the text in mind. NLP has been applied to the source text, and specifically to the well-formed sentences. This has achieved high levels of accuracy in identifying the named objects, properties, and values. However, many NLP toolkits systematically exclude or discount the conjunctions and case indicators that potentially identify the logical role of the identified phrases. More detailed structural analysis is beginning to yield some of the implied logical structure, for example (Kabzhan et al., 2025). RASE (Nisbet et al., 2009), a markup technique, which consists of four operators: Requirement, Applicability, Selection, and Exception, has been proposed as an alternative approach. Using RASE, experts are asked to identify the phrases and sections along with one of the four logical roles. The use of mark-up makes the scope and accuracy explicit and available for review and then correction or endorsement.

Given this examination, the second stage is to express the understanding in a persistent machine-operable form. The oldest and most pervasive is ‘procedural programming’: this maps the understanding of the normative content into programming formalisms (such as Fortran, Express-X as used in Singapore ePlanCheck 2000 (Solihin, 2004), or Python). Generic programming languages are usually structured into reusable functions contributing to the individual clauses and overall structure of the regulation. Estonia is using commercial bespoke application for its checking initiative (Future Insight, 2024). There is scope for mistakes in this mapping process. In one published example, around half the concepts found in the coding were not matched by concepts in the source material (Rooth et al., 2017). The unbounded flexibility of programming is countered by the need for extensive validation and checking. Extensive verification may still leave openings for doubts and lack of credibility. The mapping may focus on the terms found in the normative material or in the terminology of the target information. The mapping between terms may be intermediated by a dictionary/thesaurus of equivalences. Alternatively, methods such as semantic enrichment of BIM models could be implemented to bridge the gap (Bloch & Sacks, 2020); however, we have not seen yet practical implementations in that direction. Procedural code embodies an assumed flow from available information into a normative decision.

An alternative to procedural coding is the use of more declarative forms, such as query languages like Structured Query Language (SQL) and SPARQL Protocol and RDF Query Language (SPARQL), which are provided to the

execution engine that develops an execution plan to obtain the required results (e.g. pass or fail), typically without explanation. SQL-based checking is being used in Dubai (Dubai Municipality, 2025). Functions specific to the domain, such as BIMQL (Mazairac & Beetz, 2013), as suggested by Preidel et al. (2017), and ePlanCheck FORNAX (Solihin et al., 2004), can simplify the top-level code. Query languages are often opaque with logical operators replaced with punctuation, especially as the number of metrics involved increases and the depth of the logical structure increases. One attempt to reduce or eliminate this obtuseness has been to develop ‘structured natural language’ which limits the vocabulary around prepositions and conjunctions, increasing the ability to review and endorse interpretations. Aiming to bridge between human-readable text and machine-executable logic, the CODE-ACCORD project (Hettiarachchi et al., 2025) created a corpus of sentences extracted from building regulations in England and Finland. These sentences were selected for expressing complete rules without external references, making them particularly suitable for ACC. The sentences were annotated manually aiming to support further NLP tasks. Some query engines adopt a ‘closed world assumption’ (CWA) which, in return for greater efficiency, demands that all variables be properly defined with values. This is relatively easy to ensure when developing test cases for simple clauses but may be unrealistic when clauses offer alternative target objects and alternative methods of compliance. In the UK, the pull-strength of doors is limited, but only for non-automatic entrance doors of public buildings. CWA rule engines may demand that the pull-strength be provided on all doors. Demanding the over-supply of properties and values may be an unacceptable burden to the building modeling process.

An alternative approach to the expression of the understanding or normative content has been to map clauses and requirements into templates, which are effectively specialized functions that take a limited number of parameters. Eastman’s work on courtroom design (Eastman et al., 2009) identified 14 templates that could accommodate the rules found in court building circulation design. Zhang and El-Gohary (2016) identified over 200 templates to accommodate the results of their NLP pipeline. The recursive nature of language suggests that there is unlikely to be a limit to the number of templates needed. buildingSMART’s Information Delivery Specification (IDS) (buildingSMART International, 2024) provides a template structure with five main clauses available for expressing filters and for expressing requirements. Commercial tools have usually aimed to support designers by allowing users to compose a number of subject filters along with a number of rule templates. Solibri Office (Solibri Inc., 2025a) offers one generic filter template and 55 rule templates. Solibri Checkpoint (previously Xinaps Verifi3d) (Solibri Inc., 2025b) allows a selection of parallel filters and three generic rule templates. Some filters allow the arbitrary selection of instances to be checked, allowing the designer to focus on items of interest but conversely to omit other objects, possibly incorrectly.

AI may be seen as shortcut to automated compliance checking and solution generation in the private domain. However, it seems likely that the

accuracy and explainability arising from rule-based systems will dominate as increasing interoperability allows applicants and inspectors to operate using the same normative, declarative, and informative information. Alternative approaches such as rewriting the regulations or making software implementations definitive are unlikely to be realized in the foreseeable future: Regulations, sometimes referred to as ‘secondary legislation’, are usually extensions of laws. Their legal basis means that they are likely to remain as written text. Similarly, proposals to rewrite regulations to suit the regulated parties (Soliman-Junior et al., 2021) would undermine the regulators’ ability to regulate in response to social demands.

Bridging the gap between human written regulations and machine-readable logical statements is only part of the challenge when dealing with ACC. In practice, some regulatory concepts are usually not modeled explicitly, which makes it difficult to exactly align between the design information and the logical statements extracted from the regulations. Manually preprocessing the design information to match the exact representation expected by the rules is yet another time-consuming task. This shifts the manual effort from compliance checking to information normalization (Amor & Dimyadi, 2021), reducing the benefits of automation. An alternative is normalizing the information in an automated manner, using semantic enrichment of BIM models (Bloch & Sacks, 2020). However, this has not yet been adopted in practice. Furthermore, since the accuracy of enrichment will have a great impact on the accuracy of ACC, further methods, testing, and evaluation are needed to reach a high level of confidence in the results.

Incorporating ACC into the Building Permitting Process

BIM is a full digital representation of a building. By examining designs in a digital environment integrated with GIS, BIM facilitates more accurate and comprehensive control, enabling a clearer understanding of the proposed design in its environment. The building permitting process can include regulations prescribing extrinsic ‘zoning’ criteria affecting the site, and intrinsic ‘technical’ criteria concerned with the performance and characteristics of the building. In some cases it can also include validating through ‘inspection’ of the as-built (or as-being-built) building against the scheme as submitted and/or against the regulations.

Traditionally, building permitting involves manual checks by municipal officials or auditors, a time-consuming process prone to human error and inconsistencies. ACC transforms this by automatically evaluating digital building models created in BIM software and site descriptions, often presented as GIS information, against predefined regulatory standards. The process is often complicated by its reliance on legal frameworks, the involvement of numerous stakeholders, and a general lack of transparency, which can result in significant delays. As technology rapidly advances and the construction industry increasingly adopts innovative solutions, the digitization of processes in the construction sector has

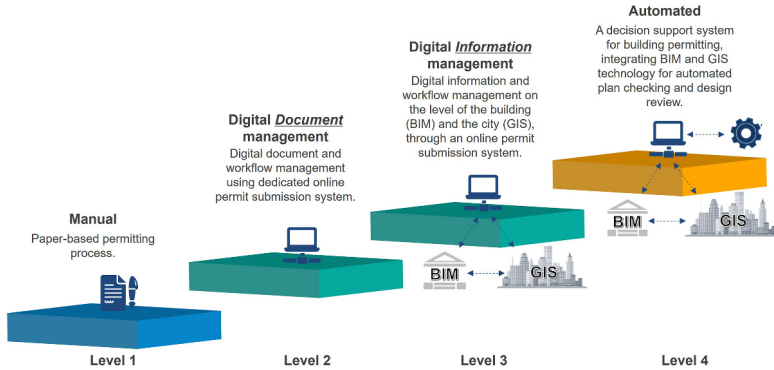


Figure 8.1 The levels of automation in building permitting. Adapted from Bloch and Fauth (2023).

become a critical area of focus. This includes the digitalization of the building permitting process, which has received considerable attention in recent years (Bloch & Fauth, 2023; Nawari & Alsaffar, 2017; Noardo et al., 2022; Olsson et al., 2018; Onstein & Tognoni, 2017; Shahi, 2018).

In practice, as illustrated in Figure 8.1, many authorities worldwide are moving away from paper-based, manual permitting systems (Level 1) and implementing digital platforms for submitting and issuing permits (Level 2). However, these systems still rely on two-dimensional design information and offer only basic document management capabilities. The shift to online submission platforms streamlines the submission of building permit applications, but these systems still lack the advanced capabilities necessary for an automated building permitting process. The next step in the digitization journey involves the integration of planning and building information within the broader urban context. This transition requires adopting BIM-based building permit submission systems and facilitating the integration of BIM with GIS. At the highest level, the building permitting process can integrate decision-support tools such as automated compliance checking.

The shift toward higher levels of digitization in the building permitting process has gained significant attention in both research and practice. While many studies focus on the technical aspects of BIM adoption in building permitting (Guler & Yomralioglu, 2022; Piazza et al., 2019; Ullah et al., 2022), there is also a growing body of research addressing the challenges of implementing advanced technologies in the public sector. For example, a case study of Tallinn's application of BIM for building permitting revealed numerous technological, organizational, and environmental challenges (Ullah et al., 2020). In some countries, the primary barrier to adoption is not technological but rather the lack of knowledge about BIM. A 2021 survey in Florida found that 58% of public sector officials and 60% of contractors and design professionals were unfamiliar with BIM technology. Although most design professionals support

BIM integration in building permitting, only 50% of public sector respondents expressed support for its adoption (Messaoudi & Nawari, 2022).

Integrating automation (such as ACC) into the building permitting process presents a complex set of challenges that span beyond the development of technology. Embedding an intelligent automated compliance checking system into the complicated process of building permitting involves overcoming organizational and procedural challenges (Fauth et al., 2024) that stem from the process complexity, the involvement of many stakeholders (often in a fragmented manner), legal complexities, the general nature of the industry which is often less open to change (Austern et al., 2024), and concerns about accuracy and accountability of automated systems. Not surprisingly, the few examples of automated systems successfully integrated into the building permitting process are the result of many years of effort.

Nevertheless, the concept of digital building permitting is gradually transitioning into practical implementation, with open BIM based on the IFC standard as its technical backbone and ACC a significant part of the system. Open BIM enables not just digital collaboration between all the stakeholders involved in the process but also automation. Several countries are leading in the adoption of such workflows within the building permitting. Estonia is a standout example of a country implementing a fully digital platform, which integrates BIM-based design submissions with partially automated rule-checking and links to national building registries. Finland as well is developing a digital permit infrastructure that supports BIM validation tools (RAVA3Pro, 2024). Singapore has long been a pioneer in regulatory technology with its CORENET X initiative (CORENET X, 2024), aiming to create a unified digital delivery system for regulatory approvals. Dubai has implemented an advanced BIM mandate and a system that supports model-based reviews for large-scale projects (Dubai Municipality, 2025). Solibri Office is being used in the Finnish regulatory roll-out (Sulonen & Vastamäki, 2022) and in the City of Vienna implementation (Urban et al., 2024). These examples demonstrate not only technical leadership but also strong governmental commitment and stakeholder engagement.

The underlying technical approach for ACC across these leading countries remains largely consistent. At its core, ACC is still concerned with turning regulatory requirements and building design into information that machines can process and reason over.

Conclusions

Automated Compliance Checking has significant potential to streamline regulatory processes in construction. However, most research and implementation of ACC has been developed without much consideration of the process into which it has to fit. Applicants need ACC to deliver timely options and solutions to deliver Quality Assurance prior to any formal Quality Control such as the permitting process. Authorities need solutions that deliver usable and

evidenced results that can contribute to the final decision-making process. Both needs can only be met by developing generic applications that can consume regulations that are both human-readable and machine-operable and can connect to additional services when required. The availability of machine-operable regulations will also support the development of relevant information requirements for the building models using standards such as building-SMART IDS and the more generic ISO 12911 (International Organization for Standardization, 2022).

However, not all design information is stored in the BIM model. Permitting applications often include detailed documentation, such as building type, material specifications, and special considerations, which provide critical context for the proposed design. These sources can offer insights into regulatory intent, project-specific constraints, or exemptions that may not be fully captured in BIM models. By integrating this information, ACC systems can achieve more comprehensive and accurate compliance checks. In other words, ACC needs to be developed with less emphasis on what BIM can support, but instead focus on where the information to answer regulatory requirements can be found. Another way forward is to reduce its dependency on the development and maintenance of procedural coding. Manual mark-up such as the RASE method and the use of AI-based analysis should enable this shift in focus.

An automated process should deliver accuracy supported by more explanation and consistency, including handling situations where some information is unknown. Unknown information may or may not be relevant depending on the available paths through the regulations. This should include tracking the results such as which building elements have passed which regulations, for example as now demanded in some UK processes. ACC should offer efficiency in the checking process if both the rules and the building models can be captured efficiently. Industry may be challenged to achieve the completeness in their models that ACC requires. These tools will also need to efficiently integrate with the preceding process of making applications and the following decision-making processes. A third criterion is the completeness of the coverage of the ACC system. Some checking may need to be delegated to specialized algorithms, for example, for energy performance, structural sufficiency, or geometric checks such as wheel-chair accessibility. Anything not covered may still have to be handled ‘manually’ and the two workstreams integrated. Some alternatives such as waivers from inspectors or special permissions will need to be handled.

Researchers are increasingly interested in automation to support code checkers, reduce manual work, and overall support the entire review process. While automation offers clear benefits, not all tasks are equally suited for it. Currently, our ability to fully automate is limited to simple prescriptive regulations and performance-based regulations where there are agreed algorithms. Some can be checked by reviewers in minutes, so the benefit of automating them is mild. The complex regulations sometimes require approaches much more sophisticated than rule sets and expert systems, and while their automation can have a greater effect on the time spent for design review, we

have not yet reached a sufficiently high accuracy in their automation (see, for example, Bloch et al., 2024). This raises some critical questions: What constitutes ‘sufficient accuracy’? Should automated systems aim to match or surpass human experts, and how do we benchmark human performance? Usually, we assume that the rule-based system is always 100% accurate, but this assumption lacks rigorous validation. Regulatory compliance is a contested social function with the interests of the applicant being opposed or at least moderated by the interests of the inspectorate. Technical implementations can be used to support one or other actor, but ultimately, automated compliance checking must create a common ground, as otherwise the process will revert to reviews and appeals.

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9 AR, VR and XR in Building Permitting

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Introduction

The advancing digitalisation in the construction industry enables access to new technologies through the introduction of openBIM. These include Augmented Reality (AR), Virtual Reality (VR) and Extended Reality (XR). A model-based approval process enables these technologies to be used in the process for the first time. This includes, for example, the automatic checking of building codes, the generation of explicit data from implicit data (e.g., escape route analysis) and robotics. One example of the use of XR is the plan checking and construction hearing that currently rely on 2D plans. In future, these important sub-processes of the building approval procedure can be improved by using XR, for which a model-based submission is required. This change is both a challenge and an opportunity: on the one hand, new processes and applications need to be developed and current procedures fundamentally adapted, while on the other hand, these new developments allow existing weaknesses to be eliminated and transparency and efficiency to be increased (Gerger et al., 2025). The broad spectrum of available technologies should therefore be considered when developing digital building permit processes. In-depth knowledge of the advantages and disadvantages, as well as possible areas of application within the authority, is essential here.

This chapter examines the use of XR technologies in the context of digital, model-based building permit processes by building authorities. The focus is on their potential to promote understanding, transparency and efficiency within the official permit process. Using concrete application examples—particularly in the context of the City of Vienna—the extended possibilities offered by an openBIM-based submission in the context of XR technologies will be demonstrated—from immersive visualisation to interactive participation in the approval process. To this end, an introductory explanation of the most important XR terms will be given at the beginning. A special focus is placed on AR. Subsequently, case studies, especially from the BRISE-Vienna research project (the digital building permit process of the City of Vienna, see Stadt Wien, 2023a), will be used to highlight practical implementations, challenges and future perspectives. In the course of BRISE-Vienna, these use cases were

also evaluated by various stakeholders in the approval process. The results of this survey can be found at the end of this chapter and provide an insight into the feasibility and relevance of the individual use cases. This chapter is based on the publications of Schranz et al. (2021), Gerger et al. (2023) and Urban et al. (2024).

Background

The generic term ‘Extended Reality (XR)’ covers immersive technologies such as AR, Augmented Virtuality (AV) and VR. Essentially, digital systems are used to extend or replace the real environment (RE) with virtual content. The enhancement is usually achieved through visual elements, for example, by superimposing digital objects. Acoustic or olfactory additions are also possible. In most cases, users can interact with this virtual content. The various forms of immersive technologies differ primarily in the relationship between the real and virtual worlds and the type of virtualisation. Milgram and Kishino (1994) systematically captured this ratio using the term ‘virtuality continuum’ (Figure 9.1). This spectrum describes the transition between a RE and a virtual environment (in the form of VR), with the latter replacing the former entirely. AR, AV and VR can be classified on this spectrum according to their degree of virtualisation. Another distinguishing feature is how the elements and the environment are depicted.

Augmented Reality: This refers to the expansion of the RE with additional virtual information. This content can be visual or audio elements. The advantage of AR is that virtual elements can be precisely superimposed

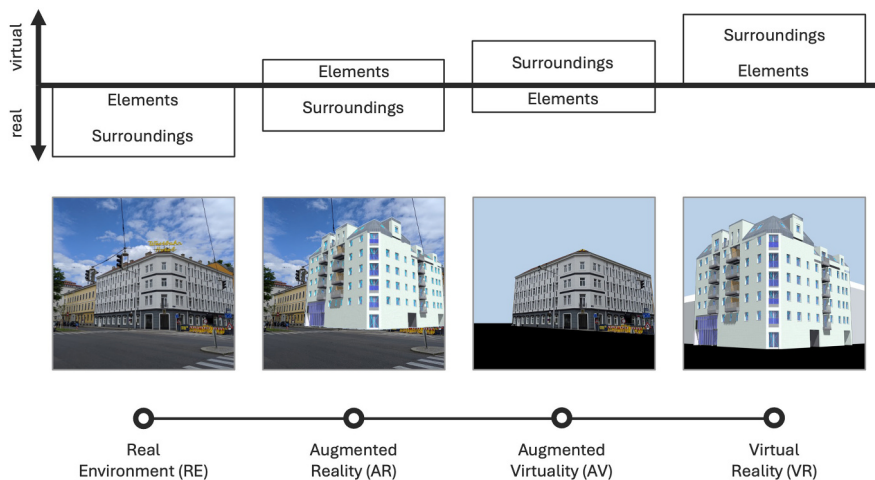


Figure 9.1 Reality-virtuality continuum. Based on Milgram and Kishino (1994).

on the RE in real time. Azuma et al. (2001) define the term AR based on three characteristics:

- Combines real and virtual objects in a RE;
- Runs interactively and in real time; and
- Registers (aligns) real and virtual objects with each other.

AR is currently being used in the consumer market, for example, in mobile devices for applications such as Snapchat (Lens Studio, Snap Camera) and in the industrial sector (e.g. support for standardised service work). Another example of an AR application is AR-supported Teaching (Urban, Pelikan, & Schranz, 2022). This enables the creation of AR teaching scenes based on IFC files and GLTF files. AR can be used on mobile devices such as smartphones and is referred to as mobile augmented reality (mAR). This leads to lower acquisition and operating costs. In addition to mAR, there are also AR headsets (Head Mounted Display (HMD)), for example Apple Vision Pro and Microsoft HoloLens 2. In AR, only elements are displayed virtually; the environment remains real. Compared to VR, dizziness (known as ‘VR sickness’) is therefore much less pronounced.

Augmented Virtuality: AV has a higher proportion of virtual information. In contrast to AR, AV is a technology in which the virtual environment is enhanced with additional elements from the real world.

Virtual Reality: VR has the highest content of virtual information. The term VR, also referred to as Virtual Environment, describes a virtual environment including virtual elements that can be interacted with. Users experience the virtual environment using their sense of sight and hearing. They get the impression of being part of this digital world. This technology is therefore described as highly immersive.

Mixed Reality (MR): The generic term MR summarises the different perceptions of reality between complete reality and a completely virtual environment. This includes AR and AV.

Extended Realities: XR is used as an umbrella term and abbreviation to summarise various immersive technologies such as VR, AR and MR. The term refers to all forms of perception in which reality is augmented, superimposed or completely replaced by computer-generated content.

Overview of Use Cases

Gerger et al. (2023) identified eleven use cases for XR technologies, in particular AR, in chronological order according to the life cycle of a building (Figure 9.2). Different authorities are involved in the phases of a building’s life cycle. In the figure, the circles represent the authorities involved in the corresponding use case. A distinction is made between the zoning authority (ZO), the surveying authority (SU), the architecture authority (AT), the building authority (BA) and the fire department (FD). The eleven use cases are discussed below, with a particular focus on the *digitisation of plan*

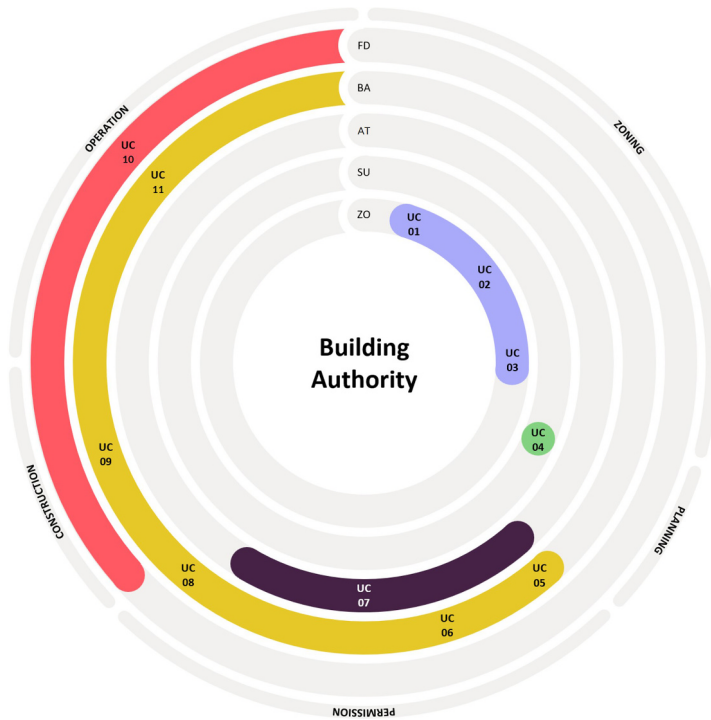


Figure 9.2 XR use cases during the life cycle of the building concerning the building authority. Adapted from Gerger et al. (2023).

checking and hearing at the authority's office using AR (UC 05). Although some use cases do not take place directly during the permission process, they influence it or are influenced by it. A key aim of integrating XR into the planning application process is to encourage citizen participation. As citizens are usually non-experts, they are often unable to interpret technical drawings. XR offers the possibility of simplified visualisation through model-based representation. However, citizen participation begins long before the actual approval process as part of neighbourhood development (zoning).

UC 01: Cooperative Planning Workshops with AR/VR

In a cooperative process, the planners work together with citizens, local stakeholders and politicians to develop initial ideas that are to be taken up in subsequent urban development competitions. The aim is to collect and analyse the needs of the stakeholders and define objectives as a basis for the plan authors. The current process can be expanded through XR and gamification. Gamification is understood as an increase in intrinsic motivation using game elements (Sailer et al., 2017). Participants can place prefabricated virtual elements (e.g. rough building masses, green spaces, cycle paths) from a kind of toolbox in the environment. They are positioned using drag and drop gestures. In XR, the

effects are not only easier to visualise through virtual elements, but can also be represented through further simulations, for example shadow casts or urban heat islands. These designs/concepts can be saved and serve as input for further planning. Communication is important here—the aim of this phase is not the concrete design of building projects, but the rough categorisation of land uses and considerations regarding building class. Finland has already trialled this approach in the design of public spaces using VR (Boenisch et al., 2017).

UC 02: AR/VR in the Context of Information Exhibitions

XR can be used as a visualisation for existing urban development concepts. Information exhibitions serve as information for the public (neighbours, interested parties). Up to now, either plans, real scale models or other visualisation concepts have been used. However, scale models are associated with high production costs. Depending on the chosen scale, such models also require physical space. Plans are more cost-effective and space-saving, but the spatial visualisation is limited. By using AR, for example, a virtual spatial model of the district could be called up via a QR code on a poster and viewed on a tablet or smartphone. If several planning drafts are available, they can be visualised and compared with each other cost-effectively and efficiently by overlaying them. A purely virtual representation of the elements is possible, as is a combination of real elements (e.g. a simple white model). The latter variant has the advantage that there is no need to create a detailed model, but a reduced haptic model is still available. This leads to the inclusion of less tech-savvy people (people without smartphones, older people, etc.). Figure 9.3 shows an example of a purely virtual representation of building masses in an urban development area of the City of Vienna.



Figure 9.3 Visualisation of building masses in an urban development area in Vienna, including a city map, using Apple Vision Pro.

UC 03: XR as Support for Decision-Makers

XR can support decision-makers in various phases, with the advantages of XR increasing with the level of detail (planning progress). In the development phase of urban planning, drafts with a low level of detail are used. In this context, XR can, for example, support juries of urban planning competitions or political decision-makers as a visualisation tool. The digital building models only need to be exported from the authoring software into a suitable format (IFC or OBJ) and loaded into an XR viewer. There is also no need to create complex real models, as in *UC 02 (AR/VR in the context of information exhibitions)*. With the implementation of an evaluation tool, designs could be evaluated and feedback obtained for planners and decision-makers. The feedback collected from citizens during the information exhibition can then be integrated into the decision-making process.

UC 04: AR-Supported Surveying

In some countries, the exact building lines and the existing buildings are recorded and defined by a surveyor. The result is a survey plan which, in conjunction with the development plan, defines the boundaries of the building. The survey plan shows the property boundaries and the building lines. As this is a 2D plan, it can only be used to a limited extent as part of a digital building permit process. For this reason, a ‘spatial’ survey plan in the form of a reference model (REM) was developed as part of BRISE-Vienna. This depicts the development plan of the building site and neighbouring buildings as a BIM model in IFC format and can be generated from the 2D survey plan. It consists of spatial lines and surfaces and displays additional information in the form of attributes. AR can be used in combination with an HMD as an alternative to computers and CAD software (Figure 9.4). The HMD can be used to

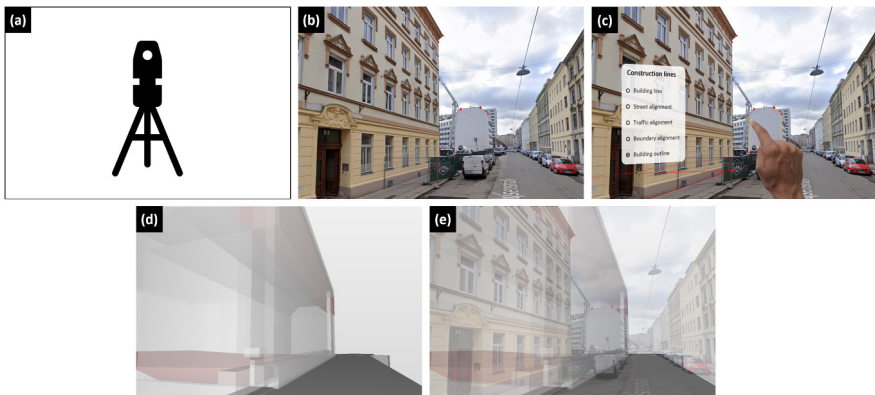


Figure 9.4 Exemplary process of AR-supported surveying from point cloud acquisition (a) to control of the REM (e) (Gerger et al., 2023).

record survey data (point cloud) (a). The individual points (b) can then be connected to lines and surfaces with the help of AR. Lines, for example building lines, are defined using alphanumeric information (c). The development plan is displayed as a floor plan for this purpose. AR can also be used to check the plausibility of the REM (d). For this purpose, the REM is projected onto the construction site using AR (e). The surveyor can now assess the quality of the results on site and take further measurements if necessary. The aim is to reduce the amount of re-surveying work by increasing the quality of the survey plans based on visual checks on site. AR thus represents a two-stage quality assurance instrument for checking the survey results and the REM.

UC 05: Digitisation of Plan Checking and Hearing at the Authority's Office Using AR

In Vienna, plan checking and hearing provide neighbours with the opportunity to exercise their subjective public rights as neighbours. These are listed in the Vienna Building Code (Stadt Wien, 2023b) and include, for example, maintaining distances from the property boundary, complying with the maximum permitted building height and protection from immissions and emissions of any kind. If neighbours indicate a violation, they have the opportunity to raise an objection during the plan checking and hearing process. This objection is then reviewed by the building authority. If an objection is admissible, the planned building must be adapted by the planner. In terms of time, this review takes place before construction and before building permission is granted.

In the context of digital building submission, good cooperation with the citizens involved is an important factor for an efficient process. According to Hamedinger (2023), 63% of building authority officers experienced regular difficulties in communicating with neighbours. The reason is that the neighbours often lack technical knowledge and have difficulties reading technical plans. Residents do not feel involved and often raise objections that prolong the process. For this reason, it is important to promote good communication between the building authority and those involved. This can be supported using AR, as the technology can act as a link between the authority and the stakeholders.

In a BIM-based building permit process, the creation of 2D plans represents a media break and should therefore be avoided. However, plans are necessary for conventional plan checking and construction hearings. For this reason, an AR-supported plan checking and hearing process was developed as part of BRISE-Vienna. This is based entirely on the submitted Building Application Model (BAM). The BAM is the architectural model (LOI300, LOG300) of the building and is created by a planner.

The AR-supported plan checking process is shown in Figure 9.5. The models are reduced in advance by the building authority's officer to the process-relevant elements (03a). The aim is to create a BAM containing all the elements that could be the subject of an objection, while also keeping it as simple as possible so that neighbours are not overwhelmed. For example, the furniture

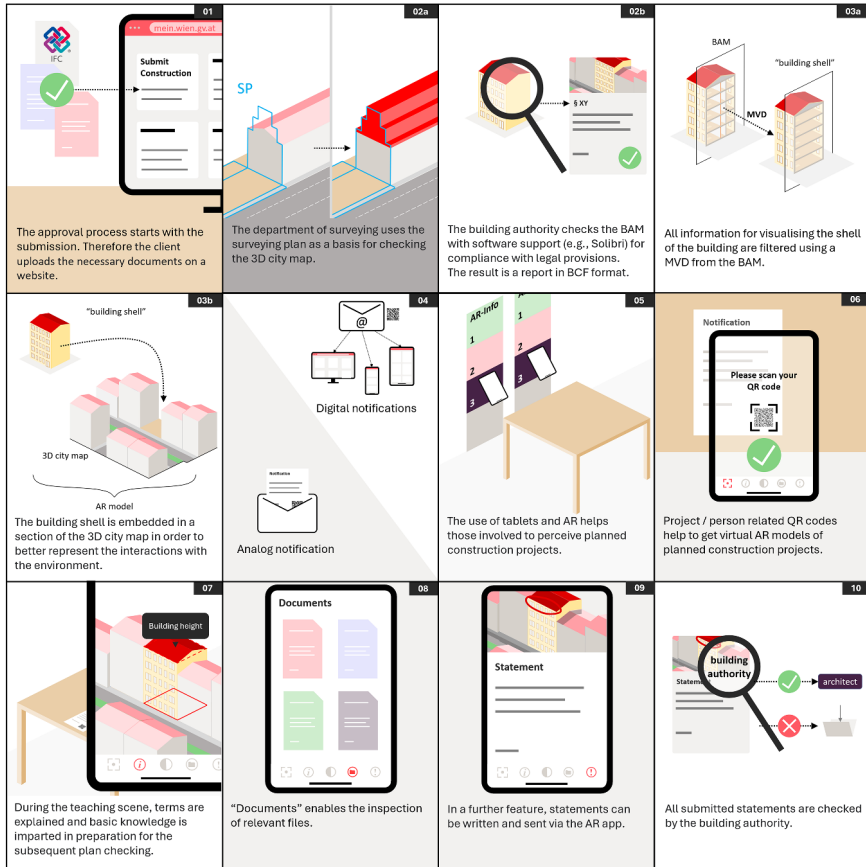


Figure 9.5 Plan checking process. Adapted from Schranz et al. (2021).

and interior walls are removed. This can also be done automatically via transfer configurations (MVDs). In addition, the officer can define additional views (e.g. displaying neighbouring buildings, displaying the semi-transparent REM) which are then available to the neighbours (03b).

The officer then creates a personal QR code and sends it to all relevant neighbours (04). They can now visit the building authority at defined times and scan the QR code with a tablet provided there (05 and 06). This launches the AR viewer. Here, neighbours have the opportunity to complete a teaching scene in advance of the actual checking (07). This serves to clarify basic terms (e.g., What is the building height?) and convey basic knowledge (e.g., What can I actually object to?), which is then necessary during the plan checking. The actual checking can be completed by the neighbour independently after the teaching scene (08). Objections can be written directly in the AR Viewer app (09). This is intended to reduce the workload of the building authority.

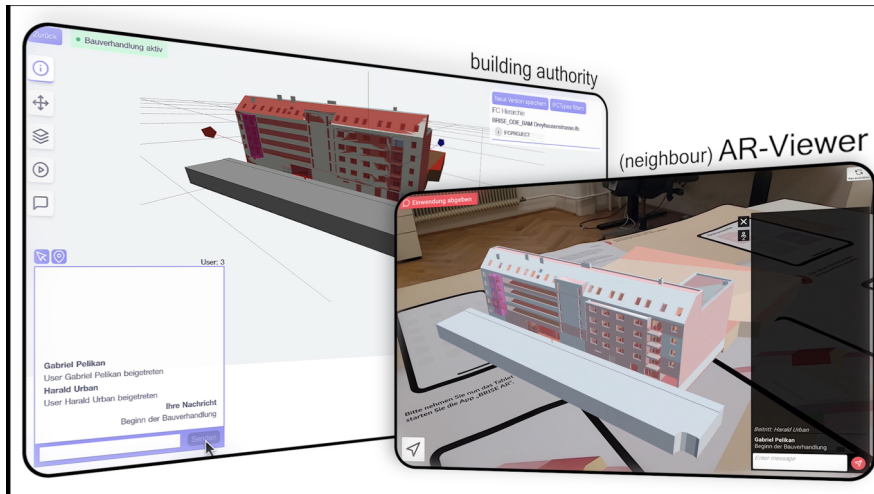


Figure 9.6 Live session during hearing (left: the building authority's view; right: the neighbours' view).

The objections submitted are personalised using the QR code. They can be viewed collectively by the building authority after the plan checking (10).

After the checking, the hearing takes place. For this purpose, the building authority invites all relevant parties to a hearing on the premises of the building authority. Similar to the plan checking, the neighbours also receive a personal QR code. They can use this to access the AR viewer with tablets during the hearing. At the same time, the building authority officer starts a live session in the editor. The live session connects the devices with each other, allowing live synchronisation of model data across multiple devices. Before the actual hearing, the neighbours again have the opportunity to complete the teaching scene. The building authority officer then presents the construction project using AR. She/he has the option of placing markers in the model, which are also displayed in the neighbours' AR model as a result of the live session. Selected building elements are also transferred (Figure 9.6). If objections have already been submitted during the plan checking, these will now be addressed. Those present can ask questions about the project and, if necessary, submit new objections. This can again be done in the AR application. The objections submitted, which are personalised using the QR code, are collected and visible to the building authority after the construction hearing. A video of the AR application is available from Pelikan and Urban (2025).

UC 06: AR Plan Checking for Citizens On-Site

The process at the building authority's office explained in *UC 05 (Digitisation of plan checking and hearing at the authority's office using AR)* is strongly oriented towards the current model of communication. The use of AR enables a

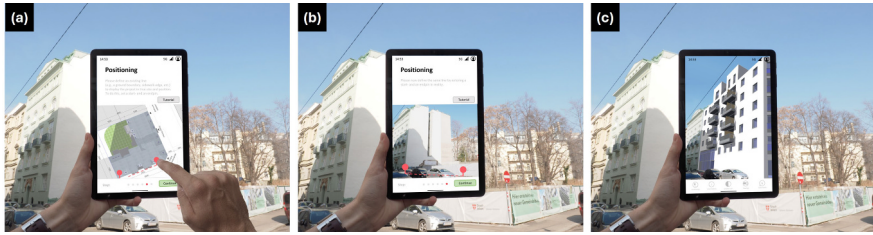


Figure 9.7 Mock-up of an AR plan checking for citizens on-site, including localisation of the AR model via a vector (a: identification of two reference points in the virtual model; b: marking of these points in the RE for alignment; c: teaching scene and plan checking). Adapted from Schranz et al. (2021).

completely new possibility—on-site inspection. Neighbours can get a picture of the planned building project in the RE and at any time, regardless of the times of traffic at the authority (e.g., at the weekend). Unlike *UC 05*, in which the BIM model is placed next to the digital as-built neighbouring buildings, the digital model can be inserted directly into the RE with the correct size, positioning and orientation. One challenge in this case, however, is the restriction of access to the information. For data privacy reasons, not all citizens are allowed to have access to the digital model. This can be solved by QR code access, which requires further authentication (e.g., by means of a pre-generated personal password). The QR code could be displayed on information boards. Another challenge is spatial localisation. Localisation via a vector is the most suitable method for this (Figure 9.7). When localising using a vector, the user is shown two points in the virtual model (e.g., corners of buildings) (a) which they should mark in the RE (b). This enables the scale, position and orientation to be determined, allowing the digital model to be placed relatively accurately in the RE. Similar to *UC 05*, a teaching scene can also be carried out in advance and objections can be submitted directly in the application (c).

UC 07: Checking the Cityscape with AR

This form can be used locally by both citizens and authorities. In Vienna, the extent to which the building project fits in architecturally with the cityscape is checked by a special department of the City of Vienna when new buildings are built. This requires on-site plan reviewing. AR enables the RE to be overlaid with spatially located virtual elements. This is precisely the content of site inspections to determine the design integration of the planned project (virtual) into the existing environment (real).

UC 08: AR as Support for the Building Authority Agents On-Site

The tasks of the building authority also extend to the construction and operation phases. One of these tasks is to inspect that the building complies with the

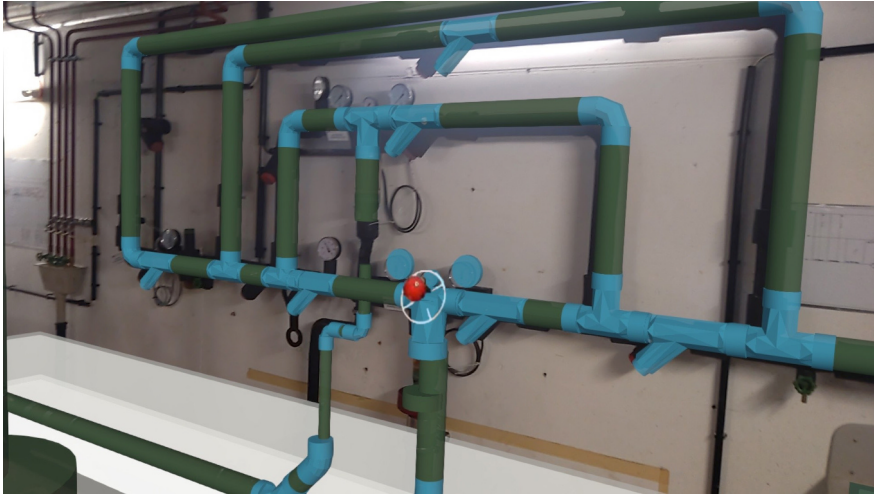


Figure 9.8 Overlaying the semi-transparent BIM model with reality using HMD in the context of a piping system (Urban, Breitschopf, & Schranz, 2022).

approved building plans or models. These checks can be carried out during or after the completion of the construction work. The inspection on the construction site is carried out based on the submitted plans and is often very time-consuming, as the officers have to familiarise and orient themselves in advance. An HMD could make the process easier for the building authority. In one corner of the field of vision, for example, a small floor plan including a marker of the current position could help with orientation. Checking compliance can be made easier by overlaying the actual state of the building with a semi-transparent representation of the BIM model. Figure 9.8 illustrates an example of an overlay within a piping system. This eliminates the need to measure distances. Any deviations can be saved directly in the AR application if a component of the actual state protrudes beyond the semi-transparent BIM model. In addition to a screenshot, further information (e.g., type of deviation) can be saved. The resulting documentation can be used to create BCF files, which are stored and sent to the building owner.

UC 09: Digital Building Books and XR

In Vienna, building operators are responsible for the safe condition of buildings in accordance with legal regulations. A building book is kept for this purpose, which contains the following information:

- Designation of the components that require regular inspection (e.g., roof truss, stairs).
- Date of initial inspection and schedule for future inspections.
- Results of the inspections carried out.

At present, the building book is usually kept digitally using Excel or specialised software. However, they must be stored in paper form at the building for possible inspection by the building authority. In future, BIM models will enable a model-based building book. Like *UC 08 (AR as support for the building authority agents on-site)*, the inspection can be carried out with an HMD. Defects can be entered directly in the XR application using screenshots and additional comments. These defects can then be exported and evaluated collectively. The progression of defects can also be monitored (How has the crack in the wall changed compared to last year?). The collected defects can then be sent to the building authority in the form of a BCF file.

UC 10: XR-Assisted Firefighting Operations

A model-based submission allows the models to be accessed by other actors within the municipal sphere. One exciting use case is designed for the fire department, which can use the models in combination with XR during their operations. The particles present in the smoke gas significantly reduce the firefighters' visibility. In addition, operations often take place in the dark. This makes it considerably more difficult for firefighters to find their way around. In contrast, the infrared sensors of HMDs are less restricted. This allows the surroundings to be scanned and a spatial model to be generated. The recorded model of the surroundings is, in turn, superimposed on the field of vision via the AR glasses, making it possible to bypass the restrictions caused by smoke or darkness. It can also be compared with the submitted model to improve orientation. In addition, the user's own position and that of other firefighters can be marked in a corner of the field of vision on a floor plan.

The ProFiTex research project (Kaufmann, 2014) and the C-Thru system from Qwake Technologies Inc., 2025 focus on reducing the risks for emergency personnel. Both approaches are based on AR technology. With the C-Thru system, the entire scan is not superimposed, but only edges are highlighted in order to avoid visual overload. In addition to highlighting edges, other relevant information, such as the fill level of the oxygen cylinder, the temperature in rooms or a small map from the model, can be displayed for orientation. A very similar approach was taken in the ProFiTex research project. In addition, the field of vision can be overlaid with a thermal image from the infrared sensors. This makes it easy to recognise unconscious people, for example, who are difficult to see due to heavy smoke development. Figure 9.8 shows the overlay of the scan model with the thermal image.

The semi-transparent overlay of parts of the BIM model is also an obvious choice in this case. However, it should be noted that BIM models currently contain hardly any information on pieces of furniture. Even furniture that has been drawn in may have been adjusted by the user.

However, the operations commander benefits from the submitted BIM models. The position of the individual team members determined via HMDs can be displayed live in the BIM model. This makes it easier for the operations

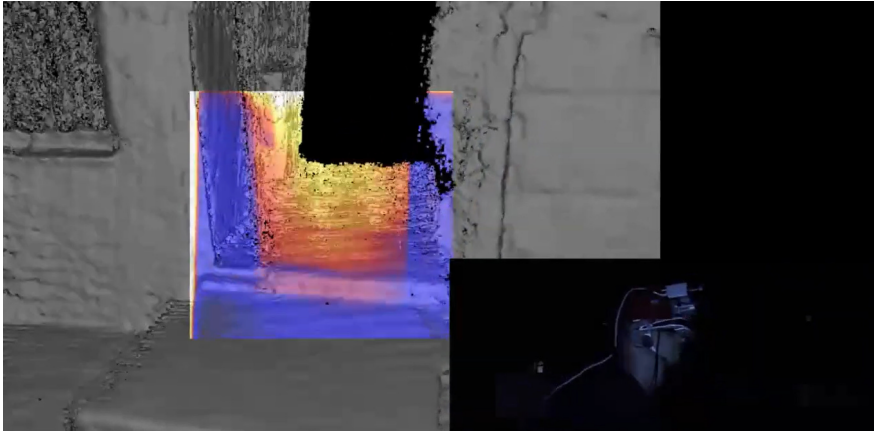


Figure 9.9 View of a firefighter using ProFiTex (Kaufmann, 2014).

commander to coordinate his team and guide them through the building (Where is the nearest staircase? Are there any apartments on this level? How has the escape route been defined? How are the fire compartments defined?)

UC II: Use of AR as Part of the Assessment of the Building Stock

AR can be used to support the assessment of damage to existing buildings, for example after a fire. In this case, the real building condition is overlaid with the virtual BAM. By selecting individual layers, it is possible to display only load-bearing elements. This allows the RE to be overlaid exclusively with the statically effective spatial model. This makes it easier to distinguish damage to structural components from non-structural components. However, AR can also provide support in identifying which covering levels need to be removed to be able to assess the structural component or, in special cases, with complex, unusual load-bearing systems. Thanks to this workflow, it is no longer necessary to search for the as-built plans on site.

Relevance of the Use Cases

This section provides an assessment of the XR use cases. This is intended to support the decision as to which applications can be implemented first. Interviews were conducted with the respective stakeholders (authorities of the City of Vienna: building authority, urban design, district planning, surveying) as part of the elaboration of the various possible applications for XR. The assessments of the experts from the respective authorities and the authors were compiled into an evaluation table. The individual XR use cases are evaluated in terms of their benefits for the target group and their feasibility. The assessment used a 4-level scale ranging from 1: “very helpful” to 4: “obstructive” for

Use Cases	Benefit for target group	Feasibility
UC 01: Cooperative planning workshops with AR	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 02: AR in the context of information exhibitions	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 03: AR as support for decision-makers	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 04: AR-supported surveying	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 05: Digitisation of plan checking and hearing at the authority's office using AR	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 06: AR plan checking for citizens on-site	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 07: Checking the cityscape with AR	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 08: AR as support for the building authority agents on-site	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 09: Digital building books and AR	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 10: AR-assisted firefighting operations	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊
UC 11: Use of AR as part of the assessment of the building stock	😊 😊 😊 😊 😊	😊 😊 😊 😊 😊

Figure 9.10 Result of the interviews conducted with stakeholders of the City of Vienna.

benefit, and from 1: “directly implementable” to 4: “implementable within 10+ years” for feasibility. The results are shown shaded to the right of the respective use case in Figure 9.10.

In particular, *UC 05 (Digitisation of plan checking and hearing at the authority's office using AR)* and *UC 06 (AR plan checking for citizens on-site)* can provide massive support for those involved using AR in the presentation of the planned building project. Building projects are presented virtually embedded in the RE or the virtual 3D city map. Until now, plan checking was limited by many factors—one's own spatial imagination, the presentation as 2D plans, the times when the authorities were open to the public, etc. The new possibilities offered by AR should make the neighbours feel more involved and thus increase cooperation, ultimately speeding up the process. However, AR should not only provide advantages for the neighbours involved, but also help to reduce the workload of building authority officers. The teaching scene should provide support. Gerger et al. (2025) and Urban et al. (2025) investigated the effects of AR in the context of AR-supported plan checking (part of *UC 05*). The authors developed an AR platform for use in AR-supported plan checking and then simulated AR-supported and traditional plan checking with test participants. Both qualitative and quantitative effects on the building authority and neighbours were recorded. Advantages were evident on both sides. For example, the use of AR reduced the time spent by building authority officers by 40% compared to the 2D plan method. Neighbours reported feeling less mentally overwhelmed by AR and being able to visualise the construction project better compared to the 2D plan method. However, older test participants (>40 years) had more difficulty using AR. In addition, the information content presented in AR was rated as too low.

During the development, benefits for other authorities and symbioses were also identified. The possibility of visualising planned building projects in the

RE is also interesting for urban design, for example, for assessing the integration of the external appearance into the local cityscape. The visualisation of planned building projects, embedded in the 3D city plan, can be of considerable help not only for viewing during the building permit process but also for decision-makers or expert juries in competitions and can replace costly model construction, for example. The integration of BAM XR models into the 3D city map not only enables new visualisation options with XR, but can also be expanded in the long term to create a highly accurate and up-to-date 3D development plan for the City of Vienna. The fire department can also benefit from the use of XR. The interviews conducted support this statement in terms of benefits for the target group and short-term feasibility. *UC 04 (AR-supported surveying)*, on the other hand, is more difficult to implement due to the accuracy required when locating the REMs in the RE.

Discussion and Conclusions

This chapter focuses on the application of XR technologies, particularly AR and VR, within the digital building permit process. Eleven use cases were defined based on the submitted BIM models, using the City of Vienna as an example. These were then evaluated by various stakeholders in the building permit process in terms of their usefulness for the respective target group and their feasibility.

Using XR in the digital building permit process was found to be a significant advantage, particularly for non-experts involved (e.g., neighbours). The virtual and spatial representation of the planned building means that technical plans do not need to be understood or interpreted spatially. In the context of inspections and building hearings, the model can be filtered to show only the content relevant to the process. This facilitates more precise discussions about objections and improves communication between building authorities and neighbours. XR also facilitates gamification approaches and the design of didactic teaching scenarios.

The examined use cases are primarily intended to provide an overview of possible applications. As current building permit processes vary from state to state, the use of XR technologies will also vary from country to country. Nevertheless, XR technologies offer a wide range of possibilities for closing existing gaps in the digital building permit process.

In most XR use cases, the submitted openBIM model forms the basis. A model-based digital building permit process and the precise definition of the information it contains are, therefore, central. This can be achieved through Exchange Information Requirements and verification of compliance with Information Delivery Specification (IDS). The information requirements and the associated IDS for the City of Vienna's openBIM building approval process are defined as a use case in buildingSMART International's use case management (Urban et al., 2025). After submission, the model is accessed in the

various life phases of the building (Figure 9.2) and expanded with new information. It is therefore also important that the openBIM model is centrally managed and maintained by the authority.

However, some technical challenges still need to be overcome to ensure successful implementation in practice, such as precise localisation in *UC 04*. This particularly affects applications in the construction and operation phases. The hardware required for the approval phase, however, is already available. The next step is to carry out practical application studies and subsequently integrate them into the digital building permit process, including defining the required data. Trials have already been conducted as part of *BRISE-Vienna* for *UC 05*. The initial trial results confirm the stakeholders' assessment that the use of AR brings noticeable improvements for both neighbours and building authority employees. There was room for improvement, particularly in terms of the amount of information displayed. For example, no dimensions are visible in the AR platform developed for the trial. Neighbours are therefore unable to check compliance with minimum distances. Further development of the AR platform (e.g., the use of IfcAnnotation) and renewed trials are therefore necessary. Subsequently, AR-supported plan checking and AR-supported hearings should be tested under real conditions (real plan checkings and hearings). Since real plan checkings and hearings are strongly influenced by emotions, which can only be simulated to a limited extent in laboratory experiments, it can be assumed that further improvements will be necessary.

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10 Semantic Web Technologies for Building Permitting

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Introduction

Unlike many fields, most “products” in the AECO (Architecture, Engineering, Construction, Operations) industries are unique: a building project exists in the real world, designed for or adapted to a specific programme, influenced by its natural surroundings, and integrated with social and economic human infrastructure. From design to demolition, individuals with diverse backgrounds interact with this asset. Consequently, information is stored in a highly decentralized manner, and the number of interactions with external partners is very high compared to other industries (Werbrouck et al., 2024). Intensive collaboration and information exchange between these partners are crucial. Until recently, this collaboration mainly happened based on paper-based information exchange. However, in recent years, the production and consumption of data, as well as the use of digital services in the AECO sector, have significantly increased, due to the advent of specialized Building Information Modelling (BIM) software, cloud technologies such as Common Data Environments, and the general availability of contextual information on the web.

The process of building permitting is a prime example of illustrating the opportunities of an automated, web-based approach for information exchange. Unlike many other industries, where regulations and approvals follow standardized and automated procedures, building permits remain highly dependent on manual review and decision-making. The complexity arises from the intersection of legal, architectural, engineering, and administrative considerations, each of which involves different stakeholders and jurisdictional interpretations. Building regulations exist worldwide and define the legal framework within which construction projects must operate. However, despite the significance of these regulations, the review and approval processes vary widely between countries and even between different local jurisdictions. Moreover, the procedural complexity of obtaining a building permit has historically been compounded by the reliance on paper-based documentation and manual cross-referencing of regulatory requirements. As a consequence, despite the digital submission of files on governmental web platforms, the actual review process remains largely manual, requiring human intervention to verify compliance with planning and

building regulations. While digital submission portals have been introduced in some regions, they often serve merely as repositories for PDF documents, still to be manually validated by human professionals. However, recently several steps have been taken to get closer to fully integrated digital workflows that allow the establishment of Automated Compliance Checking (ACC).

The increasing complexity of construction projects, coupled with the need for faster and more transparent permitting processes, has driven the development of digital solutions for building permitting. In this sense, the ability to link cross-domain data (BIM, GIS, governmental data, etc.) is a key requirement for achieving a higher technological maturity. Such linking must be possible in a decentralized way, as data streams will not be handled by a single entity but will be owned by multiple actors. Ideally, these actors can share a subset of their available data to allow the compliance check and the resulting permit decision to be carried out. The FAIR principles (Findable, Accessible, Interoperable, Reusable) (Wilkinson et al., 2016) offer guidelines designed to foster data exchange and reuse across different use cases. They were devised in 2016 and have been widely adopted across the globe ever since. Although the FAIR principles are technology-agnostic in themselves, they are indeed often implemented using Semantic Web Technologies (SWT), which currently comprise one of the few technology stacks that can be used to achieve fully FAIR-compliant data stewardship (Mons et al., 2017). In this context, the integration of BIM with SWT offers significant potential to streamline regulatory compliance and automate permit checks. In this chapter, we will outline how current research approaches these challenges by means of SWT.

Recent efforts in Germany within the master plan for BIM for federal highways (Bach et al., 2024) emphasize the need for machine-readable regulations that are directly linked to digital building models. Similarly, the IDiS initiative for interoperability of digital standards highlights the importance of semantic interoperability through SMART standards, ensuring that regulatory information is not only digitally accessible but also interpretable by machines (Puppan et al., 2024). SMART standards refer to regulations that are Structured, Machine-readable, Applicable, Relevant, and Traceable, enabling seamless automation and digital processing across regulatory and permitting workflows. A foundation for these approaches is the progressive classification of standards from Level 0 to Level 4, describing the evolution from static documents (Level 0) to fully machine-readable, interoperable, and executable rules (Level 4) (Ehring et al., 2021). Current research highlights the potential of combining BIM with semantic and regulatory knowledge to enhance permitting processes (Zentgraf et al., 2023). Their study emphasizes the need for formalized digital regulatory frameworks that link semantic knowledge, rule-checking mechanisms, and BIM data, enabling both ACC and increased transparency across stakeholders. By combining BIM as a central data source with SWT, such as ontologies and linked data, regulatory frameworks can be formally represented and automatically checked against project data. This enables more consistent, efficient, and scalable permitting processes, paving the way for a fully digital permitting lifecycle across different regulatory domains.

Semantic Web Technologies

General Overview

SWTs enable the representation of information in graphs. The Resource Description Framework (RDF) forms the foundational data model of the Semantic Web, enabling structured, machine-interpretable representations of information through subject–predicate–object triples that form a directed labelled graph (Berners-Lee, 2006) (see Figure 10.1 and Listing 10.1).

RDF facilitates the integration and interlinking of heterogeneous data across domains via Linked Data principles, which rely on the use of dereferenceable Uniform Resource Identifiers (URIs) to establish connections between datasets (Berners-Lee, 2006). URIs serve as a globally unique identifier for resources in the Semantic Web, enabling unambiguous reference, linkage, and integration of data across distributed systems. In the context of the Semantic Web, graph databases, such as GraphDB, Blazegraph, and Stardog, serve as efficient storage and retrieval engines optimized for RDF data, enabling semantic reasoning and advanced querying. The Web Ontology Language (OWL) extends RDF in expressivity and formal semantics, allowing for the definition of complex ontologies that support automated reasoning and inference over classes and relationships. Ontologies are formal, structured models that define the concepts, relationships, and rules within a specific domain, enabling a shared understanding between humans and machines. Combining RDF instances adhering to the formal specifications in ontologies, Knowledge Graphs (KGs) build upon these Semantic Web foundations by organizing RDF data into semantically rich

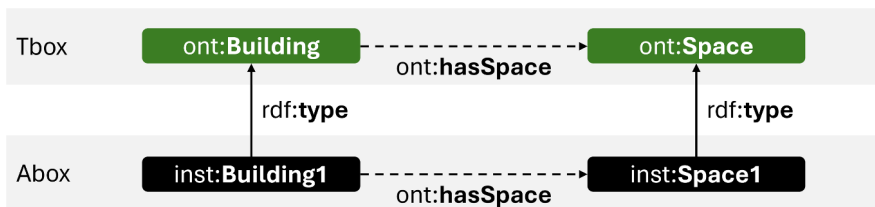


Figure 10.1 An RDF instance graph (in the Abox) and a simple ontology (in the Tbox).

Listing 10.1 RDF turtle representation of the RDF graph.

```
@prefix ont: <http://www.example.org/ontology#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix inst: <http://www.example.org/> .

inst:Building1    ont:hasSpace    inst:Space1 ;
                  rdf:type        ont:Building .
inst:Space1       rdf:type        ont:Space .
```

networks that enable context-aware querying, reasoning, and knowledge discovery across complex domains through encoded knowledge in the ontologies. KGs are split into the Terminology box (Tbox), which covers terminology axioms such as ontologies, and the Assertion box (Abox), which covers instantiations of those terminology axioms (see Figure 10.2).

Semantic data querying is predominantly performed using the SPARQL Protocol and RDF Query Language (SPARQL), which allows for expressive pattern matching across RDF graphs, including support for federated queries, filters, aggregates, and entailment regimes (see Listing 10.2). SPARQL enables both data retrieval and updates in RDF stores and is essential for integrating semantic data

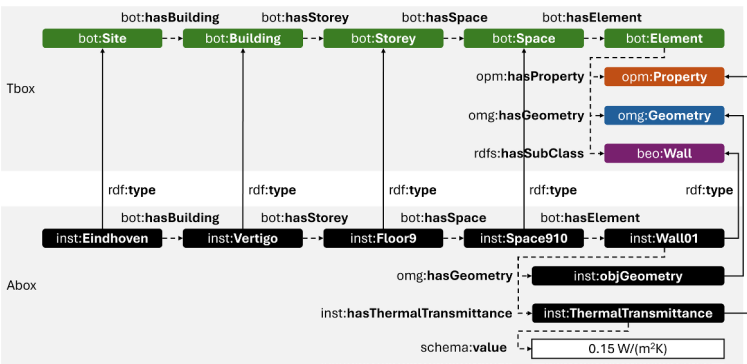


Figure 10.2 Linked building data ontologies (in Tbox) and instance data (in Abox).

Listing 10.2 A SPARQL query that returns elements in Vertigo and their properties.

```
PREFIX bot: <http://www.w3id.org/bot#>
PREFIX beo: <http://www.w3id.org/beo#>
PREFIX opm: <http://www.w3id.org/opm#>
PREFIX schema: <https://schema.org/>
PREFIX inst: <http://www.example.org/>
SELECT ?element ?value
WHERE {
  inst:Vertigo bot:hasStorey | bot:hasSpace | bot:hasElement ?
  element .
  ?element rdf:type beo:Wall .
  ?element opm:hasThermalTransmittance ?thermalTransmittance.
  ?thermalTransmittance schema:value ?value}
```

into operational workflows. Federation mechanisms allow SPARQL queries to be executed across distributed endpoints, supporting seamless data integration across organizational and domain boundaries by leveraging the inherent web architecture (i.e., through URIs).

To ensure data quality and compliance with ontology constraints, the Shapes Constraint Language (SHACL) provides a validation framework for RDF data, allowing for the specification of structural and value-based constraints (see Listing 10.3). SHACL supports both simple integrity checks and complex conditionals using SHACL rules or SPARQL-based constraints. Complementary to SHACL, the Semantic Web Rule Language (SWRL) enables the formulation of rules that extend OWL reasoning capabilities. While SWRL is not natively supported by all triple stores, it plays a key role in enabling rule-based inference in knowledge-intensive applications, especially when combined with custom reasoning engines. A key difference between those languages is that SPARQL and SWRL naturally operate under the Open World Assumption (the assumption that a statement can be true, even if it is not known to be true), while SHACL operates under the closed world assumption (the assumption that if a statement is true, it is also known to be true). The Closed World Assumption is closer to how humans would perform constraint checking, making SHACL more applicable as a representation format for building codes.

These querying, validation, and reasoning capabilities are particularly valuable in the context of the built environment, where data heterogeneity,

Listing 10.3 A SHACL shape putting a restriction on the thermal transmittance of walls.

```
@prefix beo: <http://www.w3id.org/beo#> .
@prefix opm: <http://www.w3id.org/opm#> .
@prefix schema: <https://schema.org/> .
@prefix inst: <http://www.example.org/> .
@prefix sh: <http://www.w3.org/ns/shacl#> .

inst:RegulationAboutThermalTransmittance
rdf:type          sh:NodeShape ;
sh:targetClass    beo:Wall ;
sh:property       [
    sh:path        ( opm:hasThermalTransmittance schema:
value ) ;
sh:minInclusive    0.17 ;
sh:message         "The thermal transmittance is lower than 0.17." ;
] .
```

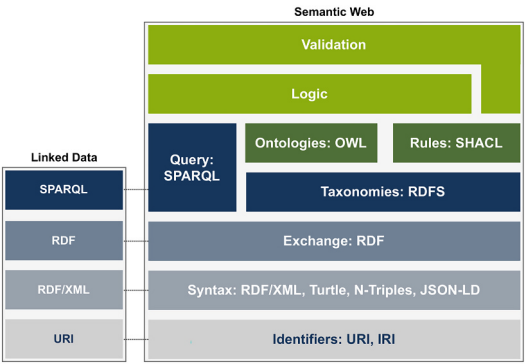


Figure 10.3 Graphical representation of the semantic web technology stack.

complexity, and compliance requirements necessitate robust semantic frameworks. As digital representations of buildings become increasingly interconnected and machine-interpretable, SWTs offer a promising approach to integrating and reasoning over diverse data sources across the construction lifecycle. An overview of how these technologies rely on each other can be found in Figure 10.3. For further reading, the authors want to refer to the book *Semantic Web for the Working Ontologist* by Allemang et al. (2020).

Semantic Web Technologies for the Built Environment

The usage of SWTs for representing building data has seen a significant uptake since the mid-2010s (Pauwels et al., 2017). Two foundational ontologies are relevant in this sense. First, the Building Topology Ontology (BOT) is a lightweight, domain-neutral ontology designed to represent the core topological structure of buildings, including elements such as zones, spaces, storeys, and their spatial relationships (Rasmussen et al., 2021). BOT serves as a foundational vocabulary for linking building data with other ontologies in the Linked Building Data (LBD) ecosystem.

In contrast, ifcOWL is a direct OWL-based serialization of the Industry Foundation Classes (IFC) schema, enabling semantic interoperability of detailed BIM models by translating the EXPRESS-based IFC standard into RDF (Beetz et al., 2009). While ifcOWL offers comprehensive coverage of BIM semantics, its complexity often motivates modular or hybrid approaches, using BOT for high-level structure and ifcOWL for detailed engineering semantics. These ontologies are necessary to transfer building models into RDF to make information accessible for checking purposes. Since the BOT ontology facilitates modular information modelling, several other ontologies can be used to align and extend information, for example, for particular domains. A detailed overview of LBD and KGs for the built environment can be found in Pauwels et al. (2022).

Moreover, there are repositories that promote ontologies on a global level, like the Linked Open Vocabularies,¹ or specifically for the AEC domain, like the BDTA catalogue² or the EC3 ontology catalogue (Akbarieh et al., 2025).

Ontologies Related to Building Permitting

General Taxonomy for Building Permit Systems

A comprehensive, high-level taxonomy to structure the complex and multidisciplinary domain of building permit systems is presented in the article by Fauth et al. (2024). The taxonomy is not an ontology in itself, but a strategic classification structure that facilitates clarity, alignment with existing standards, and integration with semantic resources such as IFC, ISO schemas, and geospatial vocabularies. It provides a foundational step towards scalable and effective digital building permit systems and may serve as a basis for ontologies to be developed. Recognizing that digitalization in this field is hindered by fragmented approaches and diverse stakeholder perspectives, the taxonomy is grounded in system theory and validated through expert knowledge across Europe. In the used approach, the building permit domain is systematically decomposed into interrelated subsystems, thereby enabling consistent interpretation, evaluation, and comparison across national contexts. Unlike previous fragmented efforts, it aims to offer a unified framework to support interoperability, shared understanding, and roadmap development for digital transformation. A short review of ontologies for the building permit review is conducted by Hagedorn et al. (2025).

Ontologies for Compliance Checking

ACC in the built environment requires regulatory information from building codes to be available in a structured, machine-readable format. Ontologies for compliance checking can roughly be divided into two categories, one that captures knowledge related to building information and one that captures normative knowledge (Donkers and Petrova, 2024).

State-of-the-art ontologies that capture building information are typically some kind of enrichment of the BOT or ifcOWL ontologies, and can be seen as plug-and-play modules that can be used based on the domain in which compliance checking is intended. Some of these ontologies are more generic, and typically stem from already existing standards or methods.

ISO 23386, for example, provides a framework for the consistent definition and management of properties and property groups used in construction data. The ISOProps ontology is designed to semantically model properties and property groups based on ISO 23386, enabling the digital representation of requirements found in building codes (Zentgraf et al., 2022; Mellenthin Filardo et al., 2024). Their approach captures detailed information of properties such

as value constraints, units, allowed enumerations, and metadata, providing a machine-readable format for regulatory information that can be checked on building data. These properties can be linked to building elements and evaluated using technologies like SPARQL and SHACL. In this way, regulatory requirements (e.g., minimum clearances, material properties) become part of a semantic data model that supports automated validation throughout the design and construction process. This semantic modelling approach complements the enrichment of NISO-STS standards by enabling extracted properties and constraints to be represented in a structured form aligned with ISO 23386 (Zentgraf et al., 2023), thus supporting the transformation of traditional text-based standards into machine-interpretable, queryable knowledge bases for use in BIM workflows.

Other ontologies are more content-focused and capture domain-specific knowledge related to terms in specific sub-sectors of the AEC industry, such as the Fire Safety Ontology (Fitkau and Hartmann, 2024) or the Subway Construction Safety Checking Ontology (Li et al., 2022). For example, the FireBIM Building Ontology (Donkers and Petrova, 2024) explicitly maps terms to national normative definitions to enable mapping LBD to regulatory constraints.

Moreover, there is a category of ontologies that describes normative knowledge and aims to represent building codes in a machine-readable format. The AEC3PO ontology (Dridi et al., 2024) introduces a more comprehensive ontology framework that formalizes the full structure of regulatory documents, including statements, checking procedures, and required evidence. It focuses on decomposing normative texts using the RASE pattern (Requirement, Application, Selection, Exception) and associates these components with executable checking logic via a modular ontology design. This allows AEC3PO not only to represent the semantics of individual properties but also to capture procedural, contextual, and actor-related dimensions of compliance in a fully machine-executable manner. The FireBIM Regulation Ontology (Donkers and Petrova, 2024) captures the structure of regulatory documents across multiple European member states and enables the description of complex regulatory decision trees using cross-referencing between snippets of regulatory text. It is mostly focused on structuring regulations using SHACL and IDS. Some ontologies focus less on describing strict regulatory information, but describe softer performance metrics in a similar fashion as the previously mentioned ontologies, such as the Performance Assessment ontology (Corry et al., 2015) or the Building Assessment Ontology.³

Ontologies for Administrative and Process Management

Regarding the digitization of application documents and forms, Hinkelmann et al. (2010) present a layered ontology framework for e-government that models domain concepts, organizational context, and information resources, while

enabling interoperability and adaptability, and using the building permission process as a key example. A key feature is the lifecycle ontology, which captures design decisions and their legal justifications to support change management. Business rules, expressed in OWL and SWRL, govern execution through constraints, guidelines, computations, and inferences.

In the context of building permitting, ontologies can define and formalize the various stakeholders involved, particularly regulatory officials of the building authorities and their specific roles, responsibilities, and interactions within the process (Fauth and Seiß, 2023). The participation of these actors is formalized in the Ontology for Building Permit Authorities (OBPA) through the agent module, which links individuals to specific roles and activities within the permit process. Furthermore, the assignment of building officials is facilitated through rule-based reasoning using SHACL, allowing for both decision support and automated assignment based on criteria like experience, expertise, and project location. This structured approach enhances transparency, reduces manual effort, and ensures objective, rule-compliant actor participation in the permitting workflow.

The Ontology-based Building Permit Review (OntoBPR) serves as a semantic framework for the digitalization and automation of building permitting by integrating process-oriented and regulatory knowledge into a machine-interpretable ontology (Hagedorn et al., 2025). It extends the digital permitting process through a horizontally aligned modular architecture that links specialized ontologies, in the standard configuration, the OBPA and the ISOProps ontology, to the building permit review processes that are modelled as a core of OntoBPR. In this semantic framework, OBPA models organizational structures, responsibilities, and procedural workflows within permitting authorities, enabling individualized assignment and traceability of process steps. In parallel, ISOProps formalizes information requirements and property definitions derived from technical regulations and standards, following the principles outlined in ISO 23386/87.

OntoBPR orchestrates these ontologies into a shared framework that spans from high-level legal frameworks (e.g., planning and building law) to granular rule representations suitable for compliance verification using SHACL. OntoBPR acts as a link between the different ontologies to bring together the involved parties, the applied rule sets, checking processes, and checking results (see Figure 10.4). The ontology links directly to SHACL shape sets derived from building codes. Building permit applications are submitted as ISO 21597-compliant information containers for linked document delivery (ICDD), in which data and documents are semantically annotated and validated. This enables OntoBPR not only to automate administrative and content-based reviews but also to ensure contextual completeness and regulatory compliance across jurisdictions. OntoBPR has been prototypically implemented into a web platform that demonstrates the feasibility of the approach and extends it by using the semantic knowledge in the building application, for instance, to generate issuance letters.

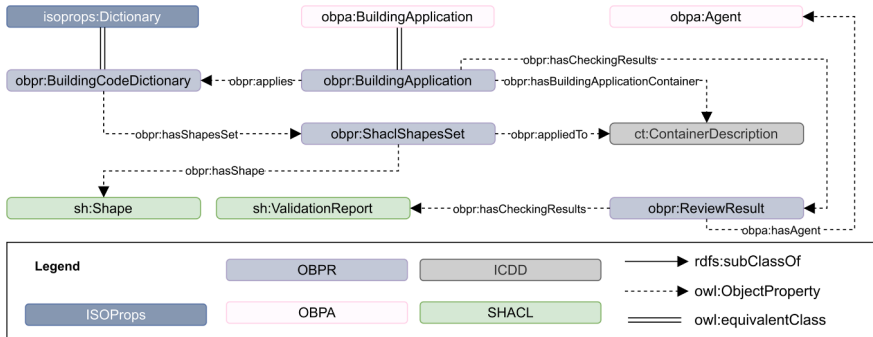


Figure 10.4 The OntoBPR ontology.

Source: Hagedorn et al. (2025).

One of the outcomes of the Horizon Europe project DigiChecks is the DigiChecks Ontology, which defines, on a high level, the process of requesting a permit using SWT. The DigiChecks Ontology defines the high-level terminology of permits and permit requests, which are described in the context of a project. It links specific permit requests, initiated by specific actors, to a “project”. Permit requests are, in turn, linked to specific permits with an associated set of requirements. A decision, also linked to a particular permit request, indicates whether the permit is granted or denied. Following general recommendations for publishing ontologies, the DigiChecks Ontology reuses terms from well-established ontologies such as PROV-O and SML.

Generation of Machine-Readable Rules

In order to perform (automated) compliance checking, regulations in natural language should be converted to machine-readable rulesets. The EUNet4DBP (Noardo et al., 2022) describes a set of requirements for the creation of digital rules in the building permitting context. They state that the mindset of public officers should be taken into account; that the digitalization process should not just cover digital rules, but the entire process of digital building permit checking; that digital regulations should be interpretable by humans; that building codes should come in machine-readable format; that multiple types of input data should be checkable; that standardization of terms, scope, and ambition in Europe is necessary (and can be facilitated using common dictionaries); that there is a need for modelling conventions and guidelines; and that digital rules should be accessible, for example using APIs.

Nuyts et al. (2024) performed a review to compare different approaches to capture building codes as machine-readable rulesets, including SMC, IDS, XSD, JSON schema, OWL, SWRL, SPARQL, and SHACL. Various approaches have been explored to convert normative texts into such machine-readable rulesets, both manually and (semi-)automatically. Al-Turki et al. (2024) created a method

in which human experts are actively collaborating with LLMs to improve the generation of machine-readable regulations in a YAML format using the RASE methodology. Chiappini et al. (2024) used BERT and ChatGPT to generate SPARQL queries from regulatory texts.

Recently we can see a trend of neurosymbolic AI approaches towards rule digitalization, where symbolic AI (ontologies) are applied to improve the results of neural AI approaches (Panchendrarajan and Zubiaga, 2024). Donkers and Petrova (2024) used an ontology with fire safety terms to improve the mapping to terms from natural language regulations to SHACL shapes using predefined SHACL templates. Zhang and El-Gohary (2016) used terms from ontologies and gazetteer lists as features to tag terms from natural language regulations and showed that this semantic tagging outperforms syntactic-only tagging. Zheng et al. (2022) also used terms from ontologies and mapped results from BERT-based semantic annotations to those terms based on semantic similarity.

Checking Methods for Building Permitting in the Semantic Web

By leveraging RDF-based representations and formal rule languages such as SHACL, a more transparent and scalable validation approach can be established. This is particularly important for complex rule types, including geometric constraints and vague requirements. Various studies have shown how such representations can be used to check whether building information models comply with building regulations. Pauwels et al. (2024) present a semantic rule-checking system capable of validating traditionally human-readable requirements automatically using SHACL, including challenging cases involving 3D geometry. Donkers and Petrova (2025) later enrich this method to enable more complex geometrical rule checking. Nuyts et al. (2023) used SHACL shapes to encode exchange information requirements, value constraints, relational constraints, mathematical constraints, and conditional statements.

In order to enhance transparency, SHACL produces validation reports when building information does not comply with the digital regulations. Listing 10.4 shows the validation report resulting from running Listing 10.3 (shape graph) against Listing 10.2 (data graph). The report contains both a machine-readable and a human-readable representation of the violation.

Conclusion

The highly decentralized process of permitting requires input from many independent actors and domains to be linked and validated, making a centrally coordinated approach impractical and unfeasible. In this chapter, an overview was given of how SWTs can be used in the interconnected and collaborative context of building permitting. Using the infrastructure of the web, multiple actors can contribute to a network of Linked Data, both with data and data models (ontologies). The Semantic Web is compatible with the FAIR principles, making it a robust and future-proof approach for further digitization of

Listing 10.4 A SHACL validation report of a wall that does not comply with a regulation.

```
[
  a sh:ValidationResult ;
  sh:resultSeverity sh:Violation ;
  sh:sourceConstraintComponent sh:MinInclusiveCon-
  straintComponent ;
  sh:sourceShape          _:n1495 ;
  sh:focusNode             inst:Wall101 ;
  sh:value                 "0.15"^^xsd:decimal ;
  sh:resultPath            _:n1497 ;
  sh:resultMessage         "The thermal transmittance is
  lower than 0.17." ;
] .
```

building permits, and facilitating the above-mentioned decentral linking. After a general introduction to the topic, an overview of SWT for the built environment was given. Then, specific ontologies related to building permitting were discussed, both focusing on compliance checking and on the administrative processes. A workflow for the generation of machine-readable rules from regulations based on natural language was sketched. The results of this workflow, structured in RDF, may then serve as the input for automatic checking processes, increasing efficiency in time and resources.

SWTs are based on open web standards; they offer a context that is broader than custom, in-code data models. In many cases, it is not necessary to “replace” those custom data models: wrapping them in a context that enlarges their scope to the Web already offers quite some benefits. Discussing technologies that allow to do so, such as JSON-LD, was out-of-scope for this chapter, but the reader is encouraged to explore these topics using other references.

The time since SWTs were considered a purely academic matter has been long gone. Implementation-wise, over the last years, many programming libraries have been published for multiple programming languages (JavaScript, Python, Java, etc.), providing a high-level layer of abstraction for programmers to easily write code that is compatible with Semantic Web standards. As for the adoption by policy makers, governmental institutions in multiple countries have embraced these technologies, reaping the fruits of interconnected, semantic datasets. Examples include the OSLO2-initiative in Flanders, the Platform Linked Data in the Netherlands, or the TwinGen project in Germany.

Looking ahead, practitioners aiming to utilize the Semantic Web, not limited to the ontologies and resources mentioned in this chapter, should start by exploring existing open datasets, vocabularies, and reference implementations, many of which are already accessible through public portals or GitHub repositories. For researchers, the next steps involve harmonizing and aligning the

discussed ontologies for a broader applicability, formalizing additional regulatory domains, refining methods for converting natural language regulations into machine-readable formats, and integrating these approaches into practical permitting workflows. Close collaboration with authorities, software vendors, and standardization bodies will be key to ensuring that future developments are both technically robust and widely adoptable in real permitting environments.

SWTs provide an approach to addressing interoperability challenges for building permitting, rather than a “solution”. The following quote

People think RDF is a pain because it is complicated. The truth is even worse. RDF is painfully simplistic, but it allows you to work with real-world data and problems that are horribly complicated.

– Dan Brickley and Libby Miller (Gayo et al., 2018)

seems to be very accurate with regard to the built environment and building permitting in particular. However, they hold a promise for the future as well – streamlining and automating the complex, decentral process of building permitting.

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Notes

- 1 <https://lov.linkeddata.es/dataset/lov/vocabs>, last accessed: 25.05.2025.
- 2 <https://ontologies.buildingdigitaltwin.org/>, last accessed: 25.05.2025.
- 3 <https://alexdonkers.github.io/bao/>

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11 Integrating Emerging Technologies to Streamline Urban Planning, Cadastral Registration, and Building Approvals

Davood Shojaei, Soheil Sabri, and Abbas Rajabifard

Introduction

Contemporary land development workflows rarely resemble the neat, linear diagrams found in policy manuals. In practice, cadastral registration, statutory planning, and building approvals occur in parallel, often administered by different tiers of government, private certifiers, utilities, and community stakeholders. Each step relies on similar datasets such as parcel boundaries, planning overlays, and design documents, yet duplication, manual data transfer, and piecemeal change tracking remain the norm. The result is an approval pipeline that can stretch from months to years, costing the public sector in administrative overheads and the private sector in holding costs and foregone productivity.

Converging technological trends offer a timely motivation to re-engineer this pipeline. Artificial intelligence (AI) models now classify documents, extract entities, and detect code non-compliance with near-human accuracy; city-scale digital twin (DT) platforms can integrate cadastral, planning scheme, and building-permit processes into a continuously updated three-dimensional (3D) city model; and metaverse-style, multi-user Mixed Reality (MR) environments permit geographically dispersed actors to co-visualise and manipulate proposals at real-time scale. While each technology has been piloted in isolation, systematic integration remains limited (Pouliot et al. 2018).

This chapter proposes an integrated Technology-Organisation-Environment (TOE) framework that unifies cadastre, planning, and building approvals. We have considered applying this in an apartment with overlapping ownership spaces to make this integration more logical. Our findings demonstrate how the framework can collapse administrative hand-offs, increase data provenance, and create a single “source of truth” from lot subdivision through to the occupancy certificate. The chapter concludes with steps to move beyond fragmented digitisation towards truly interoperable land administration ecosystems.

Background

The Land Development Lifecycle

A typical urban development touches three regulatory domains. Cadastre establishes and maintains parcel extents and tenure. Urban planning determines permissible land use, density, and built form. Building approvals assure compliance with structural, safety, and amenity codes. Although conceptually sequential, in practice the domains overlap, as shown in Figure 11.1 Various studies have noted that siloed information systems increase these feedback loops, with manual, error-prone processes and latency (Williamson et al., 2009).

In this section, cadastre, planning permit, and building permit are discussed, and their processes and nature are presented.

Cadastre

The cadastre is the authoritative, parcel-based record of land ownership, tenure, and rights. It underpins every downstream regulatory decision, from planning through to the issuance of an occupancy certificate after construction. Below,

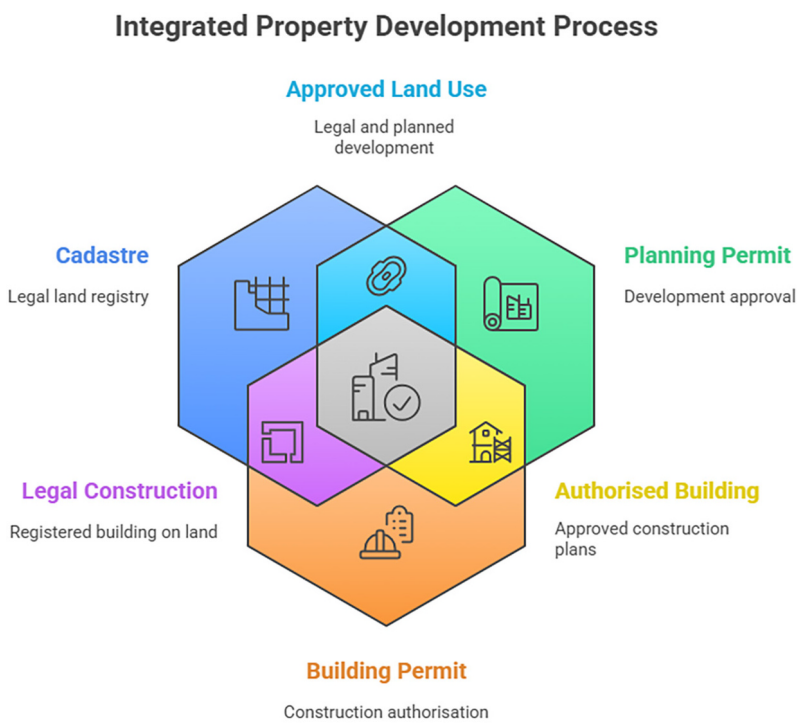


Figure 11.1 The interconnection among cadastral registration, planning permit, and building permit.

the cadastral process in Victoria, Australia, illustrates both the traditional workflows and the technology-driven reforms currently being implemented.

The subdivision of an apartment building in Victoria is a multi-stage statutory workflow that links three regulatory regimes, including the Planning and Environment Act 1987, Subdivision Act 1988, and Building Act 1993/Owners Corporation Act 2006, and is transacted almost entirely online through a cadastral portal. Below is a simplified walk-through of the current process, highlighting the key steps, the digital tools, and the most recent policy reforms. The step-by-step process for apartment subdivision is presented below and illustrated in Figure 11.2.

1 Pre-application Due-Diligence

The initial stage involves verifying whether the land is located within a zone that permits apartment developments and identifying any applicable planning overlays, such as heritage, flood, or design and development controls that may impose additional restrictions. Following this, an architect is engaged to prepare a conceptual design, while a licensed surveyor is appointed to accurately re-establish the property's title boundaries and define the building footprint in accordance with site constraints.

2 Planning Permit Application

The next step involves lodgement, where the licensed surveyor initiates a new application through the designated portal by uploading the architectural drawings, a draft plan of subdivision, and all relevant planning permit documentation. Once submitted, the local council undertakes an assessment of the application against the planning scheme, taking into account factors such as service authority requirements, open space contributions, and any necessary environmental audits.

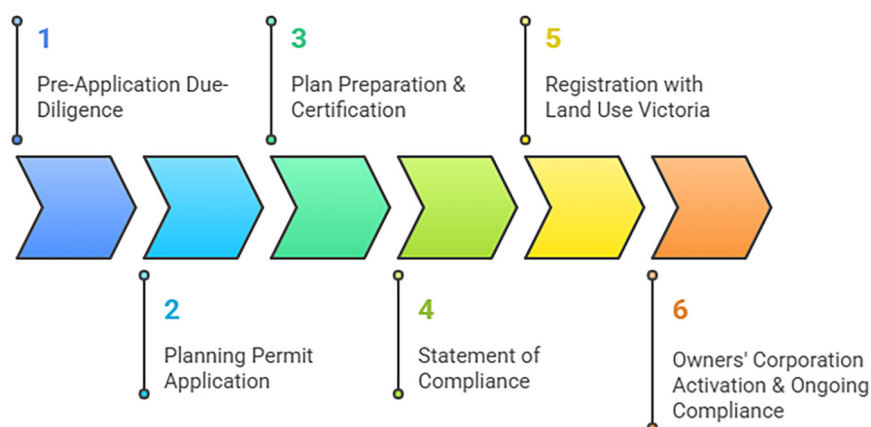


Figure 11.2 Step-by-step process for apartment subdivision.

3 Plan Preparation and Certification

In the plan preparation stage, the surveyor translates the building's layout into a detailed plan of subdivision, defining strata or volumetric lots, allocating common property, and outlining owners' corporation entitlements. This plan is then submitted to the local council for certification, where it is reviewed for accuracy and assessed for consistency with the approved planning permit. Upon satisfaction, the council certifies the plan as suitable for registration. Simultaneously, relevant referral authorities such as water, electricity, road, and fire services are automatically notified through the online portal and may impose specific conditions that must be fulfilled before a statement of compliance can be issued.

4 Statement of Compliance

At this stage, the developer must satisfy all permit conditions by completing required engineering works, such as drainage infrastructure, submitting any necessary legal agreements, and lodging all compliance documentation. Once the council confirms that all conditions have been met, it issues the statement of compliance, indicating that the subdivision is ready to proceed to the registration phase.

5 Registration

Following council approvals, the certified plan of subdivision and the statement of compliance are electronically lodged with the land registry office. Upon successful registration, new land titles are generated for each apartment lot and the designated common property. This process also automatically establishes one or more owners' corporations, complete with their associated entitlements, liabilities, and governing rules.

6 Owners' Corporation Activation and Ongoing Compliance

After registration, the developer is responsible for convening the first meeting of the owners' corporation, during which common property assets are formally transferred and essential documentation, such as the register and maintenance plan, is provided. Concurrently, a private or municipal building surveyor must issue the required building permits, carry out mandatory inspections throughout the construction process, and ultimately grant the occupancy permit, allowing residents to legally move into the building.

As noted earlier, the cadastral process often involves multiple interactions and iterations with planning and building workflows. Currently, cadastral submissions in Victoria are primarily conducted using PDF documents, with limited adoption of the ePlan system, which allows lodgement in XML format. These PDFs serve as the main medium of exchange among various land administration stakeholders such as planners, developers, architects, councils, real estate agents, strata managers, and utility providers. However, this reliance on static documents presents several challenges and limitations, as outlined by Olfat et al. (2019):

- PDF plans, typically prepared by licensed surveyors to represent ownership spaces, can be particularly difficult and time-consuming to create, especially for complex developments.

- These plans are not machine-readable, making them inefficient for automated processing or data extraction.
- The examination and validation of PDF submissions remain largely manual, requiring significant time and technical expertise.
- Registered PDFs are not easily searchable or analysable, limiting their usefulness to stakeholders who need to query or cross-reference cadastral data.
- Moreover, PDF plans are often difficult for the general public to interpret, reducing transparency and accessibility in the land administration process.

With these limitations, Victorian land registry has developed the ePlan project to receive submissions in the LandXML format (Shojaei et al., 2017) and has a plan to move towards designing a 3D digital cadastre (Rajabifard et al., 2014; Atazadeh et al., 2019). This move brings significant improvement towards land administration processes (Shojaei et al., 2019).

Planning Permit

Urban planning is a complex field that is increasingly leveraging digital technologies to address the challenges of urban development and management. It involves guiding the use and development of land to meet economic, environmental, and social objectives, ensuring a safe, efficient, and pleasant living and working environment for communities. Urban planning is concerned with the short- and long-term social, environmental, and economic objectives for an area, achieved through strategic plans and environmental planning instruments (Sabri et al., 2022).

Despite advancements in digital technologies, such as cloud computing, high-performance systems, and customised sensor manufacturing, planning processes in many jurisdictions remain manual, paper-based, and tedious, leading to issues like a lack of data harmonisation, inaccurate results, delays, and limited predictability. The current system often lacks essential functionalities like workflow capabilities, template management, easy access to council data, integration of statutory clock management, and efficient document management (Sabri and Witte, 2023). In this section, we explore the challenges in planning permit process and investigate the state-of-the-art technologies used to address these challenges.

The planning permit assessment process faces numerous challenges, impacting its effectiveness, efficiency, and predictability. These challenges can be broadly categorised into issues related to current processes, data, technological adoption, and human/organisational factors (Sabri and Witte, 2023; Shojaei et al., 2021).

Current Process and Regulatory Complexity:

- **Manual, Paper-Based, and Tedious:** The planning process in many jurisdictions remains largely manual and paper-based, especially the assessment, decision-making, and review stages. Shojaei et al. (2021) reviewed the planning approval process in two Australian states of Victoria and NSW, which

highlighted the dominant use of paper-based documents, often in PDF format. This leads to a lack of data harmonisation, inaccurate results, delays, and limited predictability. Sabri et al. (2022) indicated that according to the Victorian Planning Scheme, the design parameters are described by diagrams, plans, or written descriptions, or a combination of these. As a result, the two-dimensional plans and diagrams and written policies can be easily misinterpreted.

- **Crowded and Contested Regulatory Space:** The planning and building regulatory space is crowded, contested, complex, costly, and changeable. It involves numerous state and non-state actors, formal legal instruments, and various types of decisions and permits. Different actors and government agencies often have conflicting interests, values, and objectives, complicating the process (Shojaei et al., 2021).
- **Multiple Authorities and Referral Processes:** The planning assessment involves numerous decision-making authorities, including environmental, economic, and transportation groups, leading to significant costs and delays as they navigate the system. The referral process, while designed to reduce applicant burden, can be cumbersome, time-consuming, and lead to confusion or rework if inconsistent decisions are made by different authorities. Sabri and Kurnia (2025) illustrated that there is a lack of connection among relevant planning permit authorities, which hinders efficient reporting and consent procedures.

Data and Information Issues:

- **Data Unavailability and Exclusivity:** Non-sensitive data from public planning processes, including development approvals and 3D/4D modelling, are often not fully available as open data (Agius, Sabri and Kalantari, 2018). The public generally lacks full access to the computer code representing planning rules used in automated decision-making processes.
- **Inconsistent Data Formats and Decentralised Management:** Inconsistent data formats of lodged documents and decentralised management of issued permits across local councils lead to inaccessibility of information and hinder the establishment of state-wide strategic plans and central repositories (Shojaei et al., 2021). This also makes tracking records difficult, especially with design changes for staged permits.
- **Misinterpretation of Rules:** Planning and design rules, often communicated through texts and diagrams, are prone to misinterpretation, uncertainty, and dissatisfaction in urban development processes (Sabri et al., 2022). This requires significant experience and expertise to clarify 3D dimensions of Land-use Regulations represented in 2D, leading to potential errors (Emamgholian, Pouliot and Shojaei, 2024).

Technological Adoption and Integration Challenges:

- **Limited Technology Adoption:** Despite advancements in digital technologies, their adoption in planning and building approval processes remains

limited in many jurisdictions. Many existing Planning Support Systems are not fully integrated into actual planning practices and often fail to generate expected knowledge and wisdom (Sabri and Kurnia, 2025).

- **Lack of Scalable Automated Workflows:** There is a lack of end-to-end automation and scalable workflows for 3D building models based on planning rules and associated features like roads and open spaces (Agius, Sabri and Kalantari, 2018; Sabri et al., 2022). While there are some initiatives for automated compliance checking, such as eComply in Victoria (Victoria, 2025), the process is not yet fully functional across different jurisdictions and building types.
- **High Software Development Costs:** The cost of software development for agencies is high, and not every agency can afford to provide software, necessitating public funding and collaboration.
- **Lack of Integration with Urban Features:** The literature indicates a lack of integration of other urban features like road networks, open spaces, and green spaces as influencing factors in optimising building yield for sustainable city development (Sabri et al., 2022).
- **Unclear Alignment of Coded Rules:** It is not always clear whether digitally coded rules align with intended planning outcomes or comply with relevant legislation.

Human and Organisational Factors:

- **Insufficient Resources and Skills:** There are insufficient resources and skills within organisations to administer digital systems effectively. This includes a shortage of building surveyors, leading to heavy workloads and increased costs/delays.
- **Lack of User-Focused Culture and Support:** A lack of user-focused culture in organisations administering the system hinders adoption. There are risks from inadequate support when introducing digital systems, leading to potential reductions in application and assessment quality.
- **Resistance to Change:** Resistance to change from senior management and organisational structures can cause the abandonment of digital transformation projects and the cancellation of investments. Adequate education and training for users are crucial for successful adoption and to ensure high-quality applications and assessments.
- **Local Government Capacity and Funding:** Local governments are often unwilling to invest in comprehensive digital development due to limited capacity and uncertainty about future value. They struggle to secure adequate funding for less “glamorous” but necessary elements like data maintenance and cataloguing.
- **Risk of Undermining Local Roles:** There is a concern that digital systems might undermine the need for local planning roles, potentially leading to a loss of local workers, knowledge, and authority.

The literature highlights the fact that, beyond technical hurdles, human and organisational factors significantly impede digital transformation efforts (Sabri and Kurnia, 2025; Sabri and Witte, 2023). A pervasive issue is the “disconnection” between “planning strategy and IT strategy” within organisations. This often arises because planning specifications and requirements are not clearly communicated during digital strategy development (Sabri and Kurnia, 2025). A fundamental challenge is the insufficient resources and skills within the planning sector. There is a recognised shortage of building surveyors, leading to heavy workloads, increased costs, and delays. More broadly, a lack of digital skills and literacy among planners, particularly at the council level, limits effective interaction between planners, IT, and Geographic Information System (GIS) teams. The capability for adapting to change is also identified as lacking within organisations. These interconnected technical, organisational, and external environmental factors collectively highlight the systemic nature of the challenges in automating planning permit assessment, underscoring the need for holistic strategies that address all these dimensions for successful digital transformation.

As a solution, new studies emphasised the role of digital technologies and enabling methods such as Generative AI (GenAI) to address these challenges. Xu et al. (2024) highlighted that the planning applications are powered by technologies like Urban Digital Twins, which organise and visualise massive amounts of data in a single virtual location to create a 3D digital version of the world, integrating rich 3D and 4D (real-time) spatial data, AI, and sensor data. Building Information Modelling (BIM) and Geospatial data are crucial for shifting 2D document-based information to integrated 3D digital information for planning permits.

The goal is to provide citizen-centric outcomes that improve places and the efficiency of approval processes. This includes the ability for applicants to monitor progress 24/7 and communicate with permit issuers, enhancing transparency and predictability. These advancements are expected to lower costs, reduce delays, and improve data-driven decision-making. Ultimately, the integration of GenAI models into urban DTs is envisioned to lead to more intelligent, reliable, and autonomous systems for smart city development and operations, promoting human-AI partnership for more participatory and collaborative urban management (Xu et al., 2024).

Building Permit

The Victorian building-permit process for apartments is based on a single decision-maker, the building surveyor, but it is dependent on many stakeholders, digital portals, consultants, and inspections (Shojaei et al., 2021). In practice, the permit cannot be issued until a planning permit is issued. Once granted, the permit allows construction, triggers inspections, and results in an occupancy permit. The overview below sets out the legal frameworks, the step-by-step workflow, recent digital reforms, and typical time frames for a mid-rise (eight-storey) apartment building. The current process of building permit is summarised as follows, illustrated in Figure 11.3:

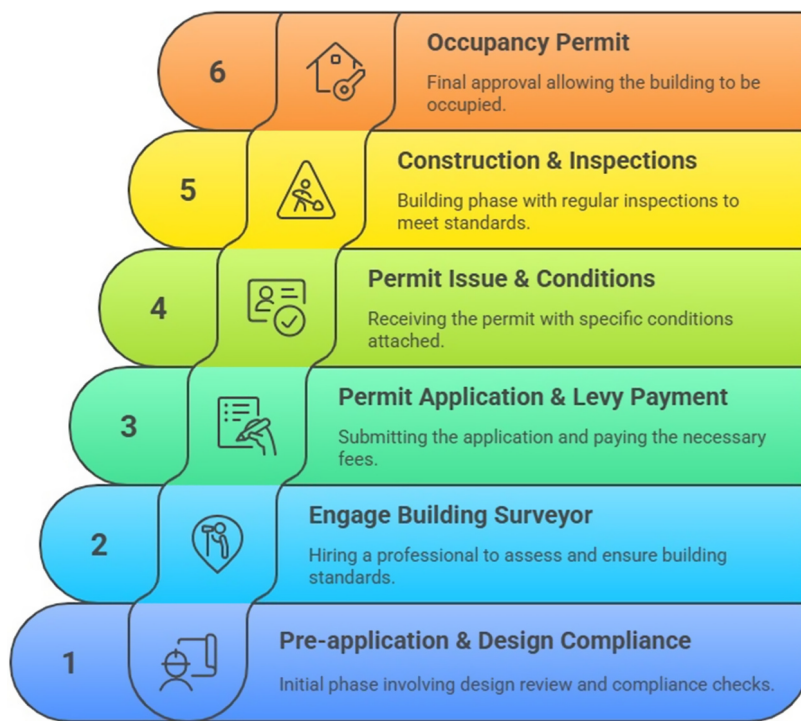


Figure 11.3 Process for Victorian building-permit pathway (Shojaei et al., 2021).

- a Pre-application and Design Compliance
In this phase, applicants will be informed if their application requires a planning permit before building permit can be issued. In this step, the applicant required to provide necessary documents such as engineering computations, energy-rating report, soil test, and title search.
- b Engage the Relevant Building Surveyor
The applicant needs to assign a building surveyor for the permit and inspections.
- c Permit Application and Levy Payment
The applicant can lodge their application to the building surveyors with all documentation.
- d Permit Issue and Conditions
The building surveyors may issue the permit with or without conditions with several stages to be checked.
- e Construction and Inspections
The construction is started with mandatory inspections by the building surveyor throughout the developments with several reports and visits.
- f Occupancy Permit
The builder provides compliance certificates, and the building surveyor issues an occupancy permit.

As evident from the process, a wide range of information must be submitted at various stages, often in different formats and for different purposes. The primary data format used remains PDF, which carries the same limitations outlined earlier such as poor machine readability; limited automation potential; and challenges with data extraction, analysis, and public interpretation. These constraints contribute to inefficiencies and hinder seamless integration across the planning, cadastral, and building approval processes.

By examining the interconnected processes of cadastre, planning, and building permits, it becomes clear how extensive and multi-layered the overall workflow is, from initial site assessment through to final occupancy. Each stage involves a series of approvals, document submissions, stakeholder interactions, and regulatory checks, often with overlapping dependencies. Figure 11.4 illustrates a timeline of these interconnected processes, highlighting their sequential and parallel components and the cumulative effort required to bring a development from concept to completion.

These three processes, cadastre, planning, and building permits, are highly interdependent, with numerous documents and data exchanged among stakeholders to facilitate progression. Despite their interconnected nature, the overall workflow remains largely manual, fragmented, and prone to errors. These inefficiencies lead to significant delays in project approvals and delivery, contributing to broader challenges such as the housing crisis in Australia and other jurisdictions with similarly structured land administration systems. To address these systemic issues, a comprehensive reform is needed, one that leverages digital innovation, automation, and integration to streamline processes; reduce turnaround times; and support more responsive and sustainable urban development.

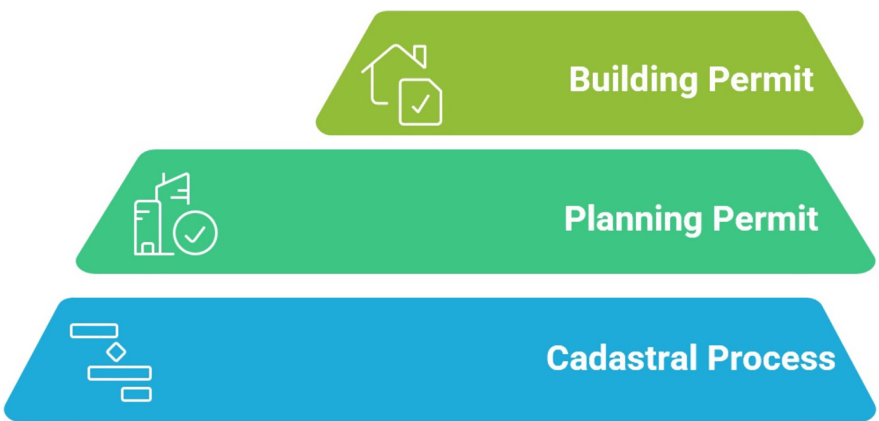


Figure 11.4 The connection of processes and their timelines.

Digitalisation Efforts and Remaining Gaps

Most jurisdictions have digitised individual components: electronic planning registers, e-lodgement of subdivision plans, or online building-permit portals. Yet disconnected schemas, proprietary file formats, and inconsistent identifiers prevent end-to-end processes. A 2024 UN-Habitat review concludes that “smart city initiatives concentrate on service front-ends, leaving back-office regulatory workflows largely untouched” (Beckers et al., 2025). Therefore, this highlights a remaining gap to be bridged.

Emerging Technologies and Their Integration Potential

Although we have these limitations and challenges, new digital technologies are emerging on a daily basis. Digital technologies, ranging from AI models and spatial DTs to extended reality collaboration spaces and real-time Internet of Thing (IoT) sensor networks, have matured to the point where they can be integrated into a single, service-oriented fabric that spans cadastre, planning, and building-permit workflows. When orchestrated through open standards (e.g., CityGML, IFC, 3D tiles) and deployed on efficient infrastructures, these components can receive, assess, and make decisions in near real time. The result is a continuously updated “single source of truth” that collapses very long and time-consuming processes into days and enables proactive, data-driven governance across the entire land administration lifecycle. In this section, these new technologies are discussed further.

Artificial Intelligence for Decision Automation

Machine-learning (ML) and deep-learning models have advanced rapidly in recent years, reaching a level of maturity where they can reliably analyse complex documents and datasets to assess compliance with a wide range of statutory regulations. These models are now capable of performing sophisticated tasks such as document classification, entity recognition, rule-based filtering, and anomaly detection, all of which are critical in cadastre, planning, and building approval processes. By learning from regulations and the large pool of historical planning permits, building codes, and cadastral plans, ML systems can flag inconsistencies, predict likely objections, and suggest improvements in real time. This represents a major shift from reactive, manual compliance checks to proactive, intelligent assistance.

One of the most transformative developments in this space is the integration of GenAI, particularly large language models (LLMs), into regulatory workflows (Abedi, Miller and Ahmad, 2025). These models leverage advanced Natural Language Processing to interpret, summarise, and even codify regulations written in legal or policy language. Recent studies, such as Fuchs et al. (2024), have demonstrated how GenAI can bridge the semantic gap between human-readable planning instruments and machine-executable rule sets. By translating narrative

planning schemes or building codes into structured, logic-based models, these systems can support automated reasoning and facilitate digital compliance checking directly within design tools like BIM software.

Jurisdictions in Europe, North America, and the Asia-Pacific region are actively investing in the deployment of AI for regulatory processing. These initiatives aim not only to speed up approvals but also to increase consistency, transparency, and legal certainty. For example, LLM-powered tools are being developed to review development applications, assess their alignment with zoning provisions, and provide real-time feedback to applicants, reducing the reliance on expert interpretation and minimising costly revisions.

As these technologies continue to evolve, they will play an increasingly central role in shaping the future of land administration. While full automation of regulatory decisions may remain a long-term goal, the current trajectory points towards highly capable decision-support systems that augment professional judgement, streamline workflows, and reduce bottlenecks. In the context of a unified digital land administration framework, AI models could serve as embedded compliance agents, continuously monitoring submissions, generating alerts, and adapting to changes in legislation, all while maintaining audit trails and justifications for every decision. This level of intelligent automation will be key to realising faster, fairer, and more responsive development systems.

Digital Twin Platforms as the Spatial Backbone

DTs can serve as the foundational infrastructure that unifies data, users, analytical tools, and regulatory processes across the entire land development life-cycle. Rather than functioning solely as static visualisation tools, modern DT platforms are evolving into dynamic, real-time systems capable of integrating diverse spatial and non-spatial datasets such as cadastral boundaries, planning overlays, BIM models, sensor streams, and legal instruments into a single, interoperable environment. Significant investments in DT infrastructure have been initiated by a growing number of countries and regions aiming to improve governance and service delivery. For example, Australia's NSW Spatial Digital Twin offers 3D+time visualisation integrated with cadastral parcels and environmental datasets, while Singapore's Virtual Singapore links geospatial data with real-time analytics for emergency response and urban simulation. The UK's National Digital Twin programme emphasises federated data sharing across sectors through open standards, enabling system-wide insights that were previously unattainable (Trade, 2023). These efforts reflect a broader recognition that DTs are not just visual interfaces but operational backbones that facilitate automation, predictive modelling, and stakeholder collaboration.

In the context of land administration, a DT can provide a consistent and authoritative spatial framework where planning rules, building codes, and cadastral data can be linked to physical structures and real-world conditions (Shojaei et al., 2025). A key feature of DTs is the direct connection to the

real-world reference, including receiving live data and sending signals and triggering actions. By embedding rule-based engines, AI compliance checkers, and open APIs into the twin's architecture, governments and developers can streamline approvals, validate design changes instantly, and maintain an up-to-date "single source of truth." This positions DTs as a critical enabler of the integrated, technology-driven land development systems envisioned in this chapter.

Metaverse and Mixed Reality

MR head-mounted displays, such as Microsoft HoloLens or Meta Quest Pro, have the potential to transform how urban development proposals are communicated, assessed, and understood by extending DT data into fully immersive, interactive 3D environments. In these environments, planners, certifiers, surveyors, and community members can physically walk through and interact with proposed developments at true-to-scale, observing spatial relationships, shadow impacts, sightlines, and compliance constraints in ways that are far more intuitive than traditional 2D plans or static 3D models.

Early research and pilot studies have already demonstrated the feasibility of integrating cadastral data into MR systems. Shojaei et al. (2019), for example, explored the use of immersive environments to visualise property boundaries, volumetric lots, and rights restrictions, enabling stakeholders to gain a clearer understanding of legal and spatial constraints on land. These immersive systems not only enhance public engagement by making complex spatial and legal data more accessible but also support professional decision-making by allowing real-time overlay of planning rules, subdivision boundaries, and structural components.

The true potential, however, lies in combining all three core elements, cadastre, planning, and building approval, within a single immersive platform. By doing so, users can navigate an end-to-end scenario: starting from proposed land subdivisions, progressing through zoning overlays and design assessments, and culminating in virtual walkthroughs of permitted buildings. Each step can be enriched with real-time data feeds from DTs and interpreted using AI-driven compliance feedback. For example, planners can immediately see whether a proposed structure violates a setback rule; surveyors can confirm whether volumetric lots align with legal title boundaries; and citizens can understand how a new development might affect their views, sunlight access, or neighbourhood character.

This holistic, immersive integration not only enhances transparency and understanding but also has the potential to significantly reduce the friction and ambiguity often experienced during the approval process. It supports better-informed decisions, faster feedback cycles, and more inclusive engagement, paving the way for a more collaborative, data-driven, and user-friendly urban development ecosystem.

An Extended Technology-Organisation-Environment-Based Integration Framework

Emerging technologies are revolutionising urban planning, cadastre, and building approvals. Virtual and Mixed Reality, DTs, BIM, AI, and GIS enhance citizen participation and speed up permit processes in urban projects (Shojaei et al., 2021). These technologies improve predictive analytics, decision-making, and automate complex geospatial tasks (Shojaei, Jafary and Zhang, 2024). The IoT and DTs can enhance public services and community satisfaction (Sabri and Witte, 2023). BIM technologies are being applied in urban planning and cadastral systems in various countries (Olfat et al., 2021). While these advancements offer significant benefits, challenges such as data privacy, ethical issues, and the need for cross-disciplinary knowledge must be addressed (Shojaei et al., 2021). Accordingly, a proper framework is required to look at different aspects, including technology, organisation, and environment. The TOE framework suggests that adoption hinges on three mutually reinforcing dimensions. This framework was adopted for land administration (Figure 11.5), which is explained here:

1 Technology Dimension

- Core services: AI-enabled document intake, rules-based compliance engines, and event-driven micro-services.
- Data layer: Linked-data identifiers unifying cadastre, planning overlays, 3D designed models (BIM).
- Interface layer: DT with MR collaboration environment.

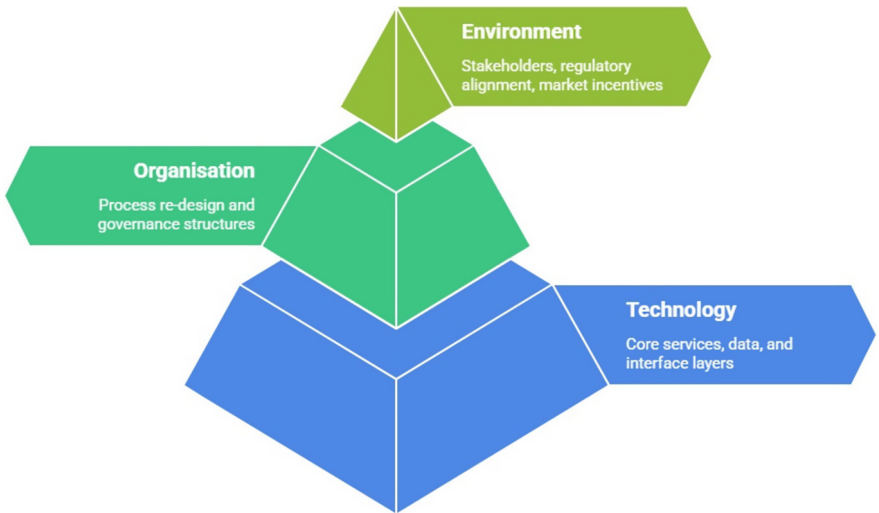


Figure 11.5 The proposed framework to cadastre, planning, and building approvals together.

2 Organisation Dimension

- Process re-design: Shift from serial processes to parallel and a single source of truth sharing in a single portal for all stakeholders.
- Governance: Data-steward charters assigning custodianship, privacy guardians, and AI-ethics oversight committees.

3 Environment Dimension

- Stakeholders: Land surveyors, planners, building surveyors, certifiers, utilities, environmental regulators, and city councils.
- Regulatory alignment: changes to the regulations to support data provisions across cadastre, state planning, and building ordinances.
- Market incentives: Faster approvals tied to lower service fees.

This proposed framework and its components can bring the three domains together to enhance decision-making in the permit processes. It can also bring digital innovations into the traditional methods of slow assessments and improve decision-making.

Conclusions

The growing interest in AI, DT technologies, and metaverse platforms signals a shift from traditional approaches towards fully integrated, digital, data-driven land administration systems. When applied in practice, the proposed TOE-based framework enables jurisdictions to connect cadastral management, planning regulations, and building approval workflows into a single, coordinated pipeline. Such integration supports near real-time data analysis; policy testing; and transparent, explainable decision-making across agencies, while maintaining auditability and public confidence. In doing so, it can shorten assessment time frames, clarify the basis for approvals and refusals, and provide more engaging opportunities for citizens, industry, and regulators through interactive and visual interfaces.

The framework offered in this study serves as both a practical implementation guide and a basis for ongoing research. It outlines reference architectures, process models, and governance considerations to support phased adoption, while also highlighting the organisational and policy adjustments required to use these technologies responsibly. As cities continue to respond to pressures such as population growth, climate risk, and housing demand, this approach presents a scalable and adaptable pathway for improving service efficiency and enhancing institutional transparency.

Future work will focus on advancing several interrelated areas:

- Developing and governing small and large language models capable of interpreting complex regulatory structures, generating explainable outputs, and supporting human oversight;

- Examining the ethical, legal, and social implications of applying AI in land administration, particularly regarding fairness, accountability, and data rights;
- Establishing interoperability standards that harmonise cadastral, planning, and building data through shared ontologies, event models, and API-based integration; and
- Creating operational assurance mechanisms, including shared testbeds, benchmarks, and monitoring practices to ensure reliability and accountability at scale.

Progress across these areas will help move jurisdictions beyond small-scale pilot projects and towards stable, mature systems that support more consistent decisions; shorter processing times; and clearer, more accessible development pathways for all stakeholders.

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12 Integrating 3D Geodata-Based Spatial Plans into 3D Land Administration for Digital Building Permits

Dogus Guler

Introduction

The increased urban population rate requires more efficient planning of cities. Land use planning significantly benefits from spatial data when making decisions because different kinds of spatial analyses are needed to support these decisions scientifically. Land use planning is also a crucial factor in implementing sustainable land management due to the need for robust land development (Emamgholian et al., 2024). There is also a notable interrelation between land use planning and land management because of cadastral rights, restrictions, and responsibilities (RRRs). RRRs are a main component of land management, and some parts of RRRs, especially restrictions, are defined within land use planning. Land management is technically realised by means of land administration systems. These systems commonly encompass the cadastral and registry information together based on two-dimensional (2D) spatial datasets. However, there is a significant intention to practise land administration systems such that they can store and manage data representing RRRs in three-dimensional (3D), in order to address the challenges posed by the complexity of buildings and the built environment. For instance, efficiently planning underground spaces requires 3D data pertaining to both existing structures and ownership information of the subsurface (Guler, 2024).

Spatial planning involves information on how developments can be implemented based on specific regional specifications. These specifications may include land use, allowable building heights, and road widths. They are represented through spatial plans at different scales. These plans serve as the foundation for planning and building permit applications, which are an essential mechanism for controlling the alignment of new developments and ensuring sustainability and safety in urban areas. Currently, digitalisation is being widely adopted in different sectors, such as construction, to improve the effectiveness of procedures. Digital building permitting, which promotes automation through the use of digital, machine-readable data instead of manual processes, is a popular research topic (Noardo et al., 2022). Building Information Models (BIMs) are the main resource for obtaining digital data on designed buildings and facilities. On the other hand, digitalisation involves storing spatial plans as

geographic datasets that cover spatial information and semantics. In some countries, such as Germany, this is already happening (Zahid et al., 2024). Specifically, these plans must be created and validated based on developed data standards from the geoinformation domain. The main idea behind this development is exchanging standardised digital data representing spatial plans between different applications. Simulating these plans with their geometries and attributes that encompass different land- and building-related restrictions in 3D could facilitate the implementation of digital building permitting. Therefore, this chapter presents how the core schema of the geoinformation standard can be extended to create 3D spatial data that depicts land use plans. This increases the usability of these plans for further applications, such as urban simulations and compliance checking within building permitting.

The chapter is structured as follows: the next section provides background information on related standards and studies. Then, the methodology is explained. The “Results” section explains how the datasets are created and provides demonstrations. The “Discussion” section presents insights regarding the applied methodology and the obtained results. The final section concludes the chapter with recommendations for future studies.

Background

Standards

Enabling the reusable data models relies on the well-established data standards that promote interoperability. The 3D modelling of the built environment covers two fields, namely Building Information Modelling (BIM) and 3D Geographic Information Systems (GIS). BIM has more focus on digital representation and management of buildings/facilities. Regarding this, Industry Foundation Classes (IFC) is the main open standard that paves the ways of exchanging digital models in an interoperable manner.¹ 3D semantic city models are beneficial for implementing efficient decision-making regarding different fields of applications in the built environment. In this regard, CityGML provides a data model for the 3D modelling of physical objects and logical spaces in urban areas with their semantics through different data themes such as building, construction, and land use.² The standard provides a foundation for modelling on these themes but its core model can be extended with feature classes and attributes for specific needs of the various fields/sectors such as land registry and cadastre and energy modelling through Application Domain Extension (ADE) mechanism. In addition, another standard called CityJSON is proposed as the JavaScript Object Notation (JSON)-based encoding of the CityGML core model in order to improve the implementation of CityGML-based data since there might be some inefficiencies because of the complex and hierarchical structure of Geography Markup Language (GML) (Ledoux et al., 2019). CityJSON v2 is the latest version of the standard and is compatible with CityGML v3, which is the latest version. CityJSON has also an extension

capability that can be utilised based on the identified conditions by the developers of the standard. The standards above address 3D urban modelling, covering both physical objects and logical spaces. In addition, there are data models for enabling interoperable spatial data infrastructures such as Infrastructure for Spatial Information in Europe (INSPIRE).³ It covers different data themes, and Data Specification on Land Use is directly related to land use planning. It covers different feature classes for representing the spatial plan information through standardised spatial data. Further, the Land Administration Domain Model (LADM) provides a conceptual model for modelling of land registry and cadastral activities. The next version of the standard will contain a specific part titled Spatial Plan Information (SPI) that encompasses the conceptual model for representing the spatial plan objects in the context of land administration practices (Kara et al., 2024). This conceptual model is developed by considering the related, existing models such as INSPIRE. XPlanung is a data standard that was developed to enable the beneficial and lossless transformation of different types of spatial plans digitally within Germany. It covers modelling of the feature types and the relationships using Unified Modelling Language (UML), and XPlanGML is the GML-based encoding of the standard that is provided by adopting ISO 19118 and ISO 19136.⁴

Related Studies

There exist studies focusing on the use of the SPI part of the LADM standard for integrating spatial plan objects within land administration practices. For example, Poulaki et al. (2024) provided a conceptual model based on this part in Greece's spatial planning context. Similarly, Yılmaz and Alkan (2024) redesigned the SPI part for the Turkish planning system and presented a demonstration of 2D spatial data based on the content of feature classes in the conceptual model.

The control of land use suitability represents a critical component of spatial planning, particularly within the context of building permit processes. However, the use of only 2D spatial data proves insufficient for conducting effective evaluations in complex urban environments. This limitation has led to the growing demand for digitalising permit workflows, thereby necessitating the development and utilisation of 3D spatial plan data.

In response to these challenges, recent research has explored the applicability of 3D spatial models in a range of spatial suitability assessment scenarios, including noise exposure, shadow analysis, and the identification of protected areas (Emamgholian et al., 2024; Tezel et al., 2021). These studies emphasised the importance of 3D data models in supporting digital building permitting procedures. Moreover, the growing complexity of urban environments requires the explicit consideration of the third dimension in planning processes, which is strongly associated with the concept of cadastral RRRs. Relying solely on 2D data may fall short in adequately supporting spatial planning decisions, reinforcing the need for a 3D spatial planning approach that can address

multi-level planning requirements and spatial characteristics (Guler & Yomralioglu, 2022; Šiško et al., 2022).

Despite these advancements, the literature addressing the integration of 3D data in planning and permitting remains limited. However, Guler (2023) focused on integrating the SPI component of the LADM into the CityJSON core model. They presented 3D visualisation of spatial plans that are generated as CityJSON format. In Estonia, research has examined the feasibility of producing zoning plans based on the SPI part of the LADM using IFC-based building models as part of a national initiative to digitalise building permitting with BIM (Batum et al., 2024). In Germany, researchers have proposed a linkage between the XPlanung spatial planning standard and the CityGML data format, aiming to establish interoperability between planning and 3D urban models (Zahid et al., 2024).

A growing area of interest within 3D spatial planning involves underground space planning, which has become increasingly critical in addressing urban challenges stemming from surface-level land use constraints. In this sense, 3D property information and cadastral restrictions are vital for planning in sub-surface contexts. Although fewer studies exist compared to those focused on aboveground modelling, important research has demonstrated the feasibility of modelling underground legal spaces in 3D (Döner et al., 2011; Kim & Heo, 2017). More recent efforts have investigated the interoperability of CityGML and IFC standards for such purposes (Ramlakhan et al., 2023; Saeidian et al., 2023). Guler (2024) conducted a study exploring the use of the CityJSON format to represent cadastral RRRs in 3D, such as underground condominium units and restrictions related to subsurface heritage structures. Additionally, recent research has indicated that incorporating underground information within the SPI part of the LADM may enhance spatial planning responses to climate change (Kawasaki Tarozzo et al., 2024).

In light of this information, this chapter aims to provide integration between XPlanung and CityJSON by creating an extension covering a feature type for further applications. For this reason, it shows the usability of the extension by creating and visualising a CityJSON dataset based on 2D plan data and demonstrates how a designed building can be enriched using this dataset.

Methodology

As shown in Figure 12.1, the methodology starts with a review of related developments. In this sense, the XPlanung is selected as an exemplary data model, which is one of the comprehensive data models for generating and sharing land use plans in a standardised and digital manner.

XPlanung data model covers a number of modules that contain feature types for comprehensively modelling the content of the spatial plans. For example, FPlan (Flächennutzungsplan), which means land use plan, is utilised for creating spatial data corresponding to the land use information regarding different use type areas such as urban development, waste disposal, mineral

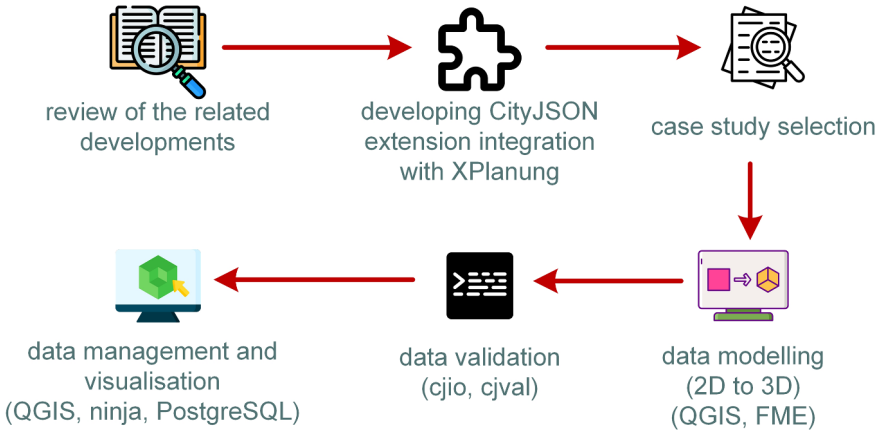


Figure 12.1 Methodology of this study.

resources, sports facilities, nature conservation, and green spaces. This module and its subsections indicate the land use type; however, elaborations on zoning are modelled through BPlan (BebauungsPlan), which means development plan.

The idea of matching some feature types and attributes within the XPlanung data model and CityGML was previously presented by Zahid et al. (2024). They, for example, associated the BP_PartialBuildingAreaSurface (BP_BaugebietTeilFläche) feature type that covers land use specifications with the LandUse object within the CityGML core model. The authors also proposed relations between attributes of BP_FestsetzungenBaugebiet (BP_Building-AreaDeterminations) and different CityGML feature types such as Building and BuildingUnit. These attributes encompass various restrictions on how designed buildings can be built. This chapter selects the BP_Ueberbaubare-GrundstuecksFlaeche (BP_BuildableArea) class to demonstrate how land use plans can be modelled through 3D urban model standard and be demonstrated regarding different restrictions. This class is selected because it delineates a specific part of the land parcel where the buildings can be constructed, and thereby it is related to the land administration context. Therefore, the CityJSON extension is developed based on the BP_UeberbaubareGrundstuecksFlaeche class and their selected attributes for demonstration purposes. The upper-level city objects such as Building, Tunnel, and Transportation are all subclasses of _AbstractCityObject within the CityJSON core schema. Hence, a new city object called +BP_UeberbaubareGrundstuecksFlaeche is modelled as a subclass of _AbstractCityObject. In the next step, an exemplary development plan (BPlan) is selected and then converted to CityJSON dataset. After that, created CityJSON dataset is validated based on both the specifications of the standard and compatibility with the developed extension. In the last stage, the visualisation of created CityJSON dataset is provided via different tools, and a case through the PostgreSQL system is presented to show the usability of the proposed approach.

Results

There exist test datasets that are shared within the website of XPlanung.⁵ Therefore, exemplary BPlan data in GML format is selected among these datasets. Figure 12.2(a) shows the representation of the selected development plan. The dataset covers different sub-layers that encompass the classes within XPlanung, for example, BP_PartialBuildingAreaSurface (BP_Baugebiet TeilFläche), BP_BuildingBoundary (BP_BauGrenze), and BP_GreenArea (BP_GruenFlaeche). Figure 12.2(b) illustrates the BP_UeberbaubareGrundstuecksFlaeche class within the aforementioned dataset which is exported in the Geo Package format for data conversion and modelling process. This data also contains a number of attributes aligned with the data schema within XPlanung, for example, Z (maximum number of aboveground storeys) and ZU (maximum number of underground storeys). The EPSG 25832 is used for coordinate system consistency throughout data conversion processes.

As mentioned before, a CityJSON extension file, which is a JSON file, is created to be able to represent the BP_UeberbaubareGrundstuecksFlaeche class in CityJSON format. In addition, some attributes that are related to the BuildingUnit class of CityJSON schema are included within the extension



Figure 12.2 (a) BPlan test data and (b) 2D spatial data representing the BP_UeberbaubareGrundstuecksFlaeche class.

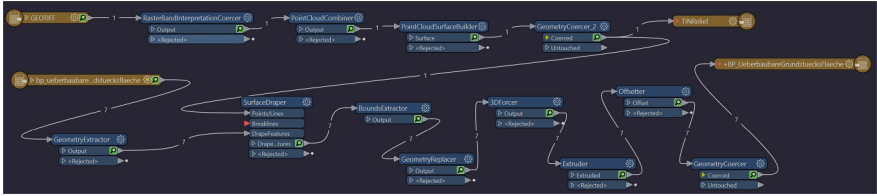


Figure 12.3 FME workbench for creating 3D CityJSON dataset.

in order to delineate the restrictions within the BP_UeberbaubareGrundstuecksFlaeche class for designed buildings. An exemplary plan is then converted to CityJSON dataset through the created workbench within FME⁶ software (Figure 12.3). This software enables the amending of different types of spatial and non-spatial data together and also transforms these data into desired data formats. To obtain a 3D model that is compatible with the elevation of the surface, the OpenDTM-DE dataset with 1 m resolution is included in the workbench. This open dataset is compiled by using the high-resolution terrain models that are provided by the federal states in Germany and can be accessed through a website.⁷ The availability of this dataset enables two beneficial issues regarding modelling. First, the TINRelief object within CityJSON covering the extent of the exemplary development plan is created. Second, this terrain dataset is used to obtain height values for each feature within BP_UeberbaubareGrundstuecksFlaeche dataset, which is shown in Figure 12.2(b). By doing so, the objects within CityJSON can be created by having real-world height values. BP_UeberbaubareGrundstuecksFlaeche instances are extruded using the h attribute that represents the maximum allowed building height in the development plan. The workbench writes two types of city objects, namely TINRelief and +BP_UeberbaubareGrundstuecksFlaeche, as shown in Figure 12.3.

The proposed extension file is created based on the specifications of CityJSON v2. Because FME exports only CityJSON v1, the dataset was upgraded to v2 after conversion. This upgrade can be done via cjio,⁸ which is a Python command line interface. The validation of created CityJSON files is quite important to enable the reusability of the dataset and interoperability between the applications that use this dataset. In this sense, the created CityJSON file is successfully validated according to the different considerations, for example, JSON syntax, CityJSON schemas, and consistency between parents and children properties. The validation can be utilised within cjio with the help of cjval⁹ which is a rust library and also has Python bindings. It is significant to further validate the CityJSON file and whether it is in line with the structure of the developed extension. This can also be completed through cjio. While Figure 12.4(a) shows a part of the extension file, Figure 12.4(b) illustrates the city object instances within the created CityJSON file.

To simulate the usability with the created CityJSON file that is compatible with the extension, exemplary IFC dataset pertaining to a building is used. As mentioned before, extra attributes are added to the BuildingUnit class of the CityJSON schema to demonstrate the restrictions regarding the building units. Figure 12.6 illustrates the building and its defined spaces through the IfcSpace entity within IFC.

It is meaningful based on the schema specifications of IFC and CityJSON that the IfcSpace entity can be matched and used to create the BuildingUnit feature class. Therefore, a workbench is created to convert the IfcSpace instances within the building to BuildingUnit classes, as shown in Figure 12.7. For demonstration purposes, a Building feature class is also created within the workbench such that it is composed of BuildingUnit instances. It can be noted that there must exist the child and parent relationship of some object types within the CityJSON core schema. One of these relationships should be ensured between Building and BuildingUnit objects. In other words, a BuildingUnit instance must have a parent property that indicates the object ID of the related Building object. This is also enabled within the created workbench.

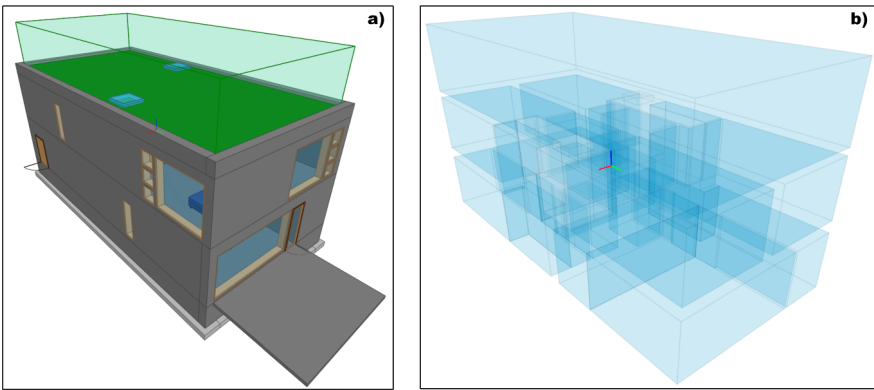


Figure 12.6 Visualisation of exemplary IFC dataset (a) and its spaces (b).

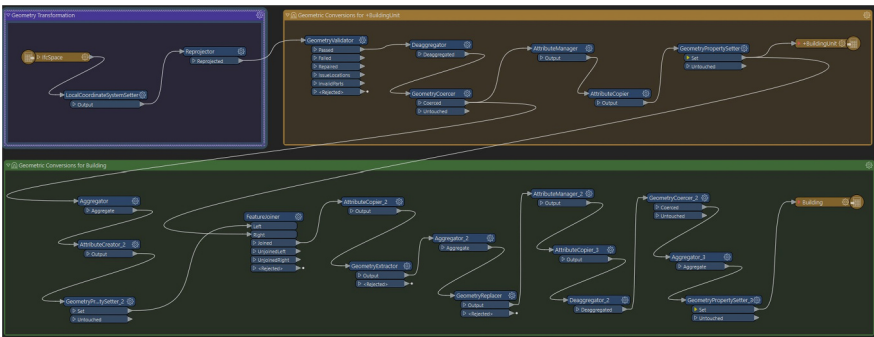


Figure 12.7 A workbench for creating BuildingUnit and Building objects within CityJSON dataset by using IfcSpace instances.

The created CityJSON dataset covering Building and BuildingUnit objects is georeferenced within the workbench for demonstration purposes. The original dataset does not include any projected coordinate system information; instead, it uses local coordinates. As mentioned before, EPSG 25832 is selected as coordinate reference system. It is therefore used to reproject the IfcSpace instances within the workbench similar to creating the CityJSON dataset pertaining to BPlan. While the Building object is generated with a level of detail (LoD)1, the BuildingUnit objects are modelled as LoD2. Similar to created CityJSON data representing BPlan, obtained datasets are also upgraded to CityJSON v2 and successfully validated through *cjio*. As shown in Figure 12.8, the BuildingUnit object has a parent property, and the Building instance has children property, which indicates the BuildingUnit objects that are related to the Building object within CityJSON data.

Figure 12.9 demonstrates the 3D visualisation of created CityJSON files within QGIS through the plugin. Figure 12.9(a) illustrates the plan data based on the object type, that is +BP_UeberbaubareGrundstuecksFlaeche. Figure 12.9(b) presents the visualisation of two datasets together. While BuildingUnit objects are delineated within building dataset, BPlan data is visualised based on the ZU attribute value. For demonstration purposes, the exemplary building dataset is georeferenced as close to plan data.

To enhance the content of the building model with the BPlan that is spatially related, created CityJSON files are imported into the spatial database that is stored within PostgreSQL. The plugins, namely PostGIS and SFCGAL, are enabled to store spatial data and implement the functions that provide spatial analysis in 3D. In this study, a query is executed to add the related attributes in +BP_UeberbaubareGrundstuecksFlaeche table into BuildingUnit objects where their geometries intersect in 3D. The content of this query is presented in Table 12.1.

The query first adds new attributes (i.e., h, z, and zu) to the BuildingUnit table and then identifies the attributes within +BP_UeberbaubareGrundstuecksFlaeche table that are inserted into the BuildingUnit table. This insertion is successfully executed if the geometries of two objects are intersected in 3D. This

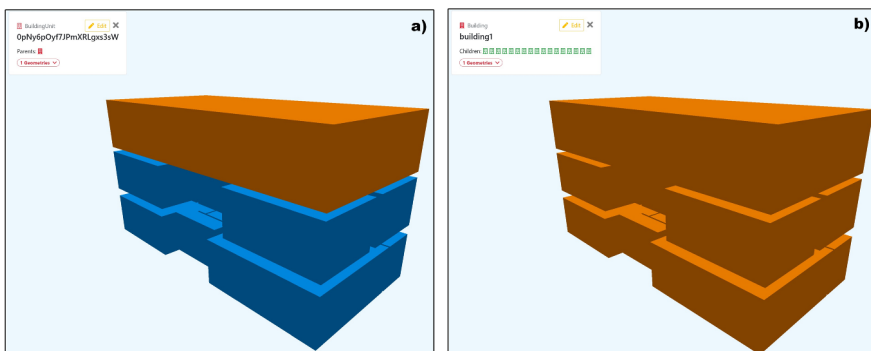


Figure 12.8 Visualisation of BuildingUnit (a) and Building (b) instances.

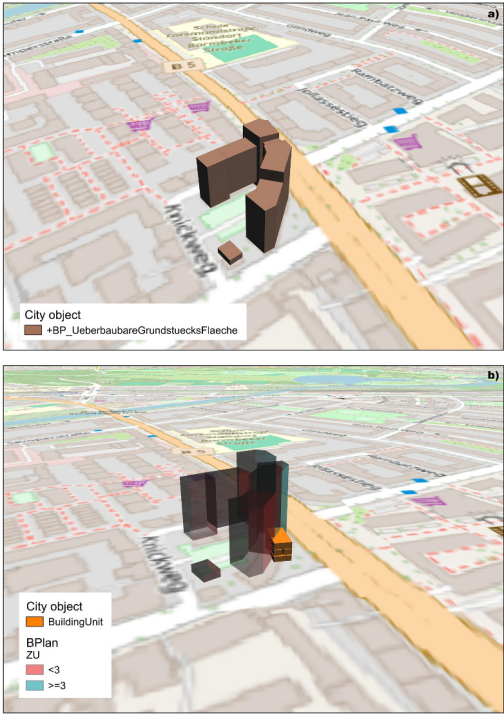


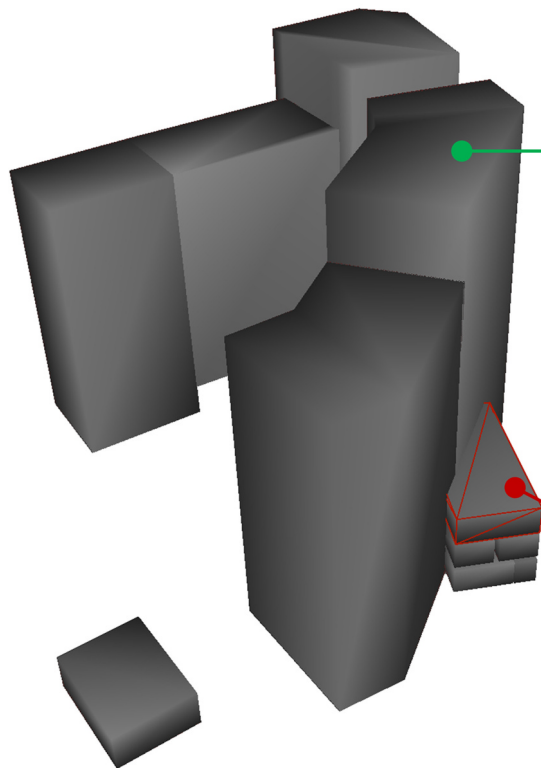
Figure 12.9 3D visualisation of plan data (a) and together with the created building data (b).

Table 12.1 Query for Inserting Different Attributes into Another Table

Query 1

```
alter table public. "BuildingUnit" add column h double precision, add column z
double precision, add column zu double precision;
update public. "BuildingUnit" b
set h = s.h,
    z = s.z,
    zu = s.zu
from public. "+BP_UeberbaubareGrundstuecksFlaeche" s
where ST_3DIntersects(b.geom,s.geom)
```

intersection is implemented through the ST_3DIntersects function that provides true or false results depending on whether the geometries intersect. Figure 12.10 illustrates the result for Query 1. As can be seen from this figure, different BuildingUnit objects intersect with different +BP_UeberbaubareGrundstuecksFlaeche objects in 3D. Therefore, BuildingUnit objects have different values for identified attributes. For example, in Figure 12.10, selected +BP_UeberbaubareGrundstuecksFlaeche and BuildingUnit object have the same attribute values after execution of Query 1 as they intersect.



+BP_UeberbaubareGrundstuecksFlaeche

	fid	text	z	zu	h	h_uom	geom
			bigint	bigint	double precision	text	geometry
1	GML_55177fec-7599-4785-a8e2-806742a9b2d9		5	2		22.5	010F0000A0990F...
2	GML_bff033ce-687f-48fe-b27c-542b545fb292		6	3		30	010F0000A0990F...
3	GML_d43355f7-ac29-4763-82ea-57c2b5c4be9f		7	3		30	010F0000A0990F...
4	GML_e0c8b0e8-7b8c-4ead-ae77-f2f1551b9136		6	2		26.5	010F0000A0990F...
5	GML_e1568a2b-1768-4889-aedb-95449c029c25		4	1		22.5	010F0000A0990F...
6	GML_e21981e2-40a7-4dac-84b0-c88d371030af		5	2		23.5	010F0000A0990F...
7	GML_ea917a61-3dcc-4889-9be0-0d56cbad94f		1	1		0.001	010F0000A0990F...

BuildingUnit

	fid	geom	h	z	zu
	text	geometry	double precision	double precision	double precision
1	0BTBFw6f90Nfh9rP1dlXrc	010F0000A0990F...	30	7	3
2	0BTBFw6f90Nfh9rP1dl_3S	010F0000A0990F...	30	7	3
3	0BTBFw6f90Nfh9rP1dl_CZ	010F0000A0990F...	30	7	3
4	0pNy6pOyf7JPmXRLgxs3sW	010F0000A0990F...	30	7	3
5	0BTBFw6f90Nfh9rP1dlXr\$	010F0000A0990F...	30	7	3
6	2gRXFgjRn2HPESYoDLX3FC	010F0000A0990F...	30	7	3
7	0BTBFw6f90Nfh9rP1dl_3P	010F0000A0990F...	30	7	3
8	0BTBFw6f90Nfh9rP1dl_3C	010F0000A0990F...	30	7	3
9	0BTBFw6f90Nfh9rP1dl_3A	010F0000A0990F...	23.5	5	2
10	0BTBFw6f90Nfh9rP1dlXr2	010F0000A0990F...	23.5	5	2

Figure 12.10 Demonstration of the result for Query 1.

Discussion

This chapter focuses on generating CityJSON data to represent spatial plans as 3D geoinformation. There are several reasons for selecting CityJSON. Firstly, the created data is clearer in terms of syntax thanks to the JSON formatting. This makes the resulting dataset easier to understand and amend. Secondly, CityJSON's extension mechanism allows different types of objects, attributes, and relationships specific to an application area to be modelled with minimal effort. Thirdly, the version can be updated and the resulting datasets validated openly using the provided tools. This enhances the reusability of the datasets for further applications.

It should be noted that the use of the geodata standard can be extended to different applications in several ways. One way is to match the attributes of a standard to feature types within the geodata standard. There are examples of this in the literature. The second option is to extend the core schema of the geodata standard, which is also used in this study. For example, the BP_UeberbaubareGrundstuecksFlaeche feature type within the XPlanung schema is added to the core schema of the standard as a new object type. The attributes of this object within XPlanung are also included in this new type.

As mentioned before, there are different feature types corresponding to various planning objects within the XPlanung schema. In this study, BP_UeberbaubareGrundstuecksFlaeche is selected for demonstration of the created CityJSON extension. This is because it defines the restrictions regarding the buildability of a land parcel. Therefore, +BP_UeberbaubareGrundstuecksFlaeche is one of the key elements used in compliance checking during building permitting and is related to cadastral restriction. For this reason, obtaining the 3D geodata depicting this object type can be helpful for simulating the different restrictions.

In this study, an exemplary BPlan dataset is used as input for data conversion. As in previous studies, FME software was used to create a CityJSON dataset. It is important to note that inadequate software support constitutes a significant impediment to the effective implementation of data standards. This is because, even though data standards are updated at regular intervals, software versions may not be updated to support the latest versions of the standard. A similar situation exists between FME and the CityJSON standard. In other words, while the latest CityJSON standard is version 2.0.1, the latest FME version can only read/write version 1.0.1. Since updated versions of standards may offer more accurate modelling and extension capabilities, it is notable to create datasets using the latest versions. This has been achieved for the CityJSON dataset created in this study thanks to the open-source tools provided that upgrades the dataset to the current version of the standard.

Moreover, providing an extension paves the way for obtaining 3D spatial plans, which can present land use planning content from spatial and semantic contexts comprehensively. One of the reasons for this is that both the spatial

planning and the building datasets can be validated in accordance with the created extension, thereby ensuring interoperability and lossless data exchange through standardised datasets.

In addition, making spatial plans available as 3D standardised geodata can provide a useful foundation for land use planning and controlling developments in underground spaces. This study uses an exemplary CityJSON dataset that also covers restrictions regarding subsurface development, that is the number of underground storeys permitted. From a visualisation perspective, the conditions of these restrictions and the designed buildings can be investigated using this dataset. Furthermore, the designed buildings in CityJSON format can be enriched with attributes related to subsurface restrictions using the 3D spatial analysis capabilities of a spatial database. Checking designed buildings against various subsurface restrictions can also be utilised through different types of objects within the CityJSON standard, such as underground historical sites, utility networks, and ownership.

Conclusions

This chapter presents an approach for creating 3D geodatasets that represent land use plans in CityJSON format. To accomplish this, a feature type that is selected from the XPlanung standard as related to buildability within land parcel is included in the created CityJSON extension. Converting a 2D spatial plan to 3D CityJSON and validating the resulting dataset based on the extension demonstrates that standardised datasets can be obtained with minimal effort. Additionally, the case for enriching designed buildings within the borders of spatial plans with these plans' attributes through 3D spatial context is presented. Thus, 3D spatial plans can efficiently serve simulation purposes and other applications, such as building permit compliance checking.

This study uses only the +BP_UeberbaubareGrundstuecksFlaeche feature type for demonstration. However, future studies may investigate integrating other XPlanung feature types into the CityJSON extension to obtain an overarching representation of spatial plans. This would enhance the enrichment of the designed building by providing more attributes from different feature types. The created extension can also be amended to cover other attributes from the BP_FestsetzungenBaugebiet feature type, which provides values for building area determinations. Furthermore, the web-based prototype can be developed to demonstrate the usability of the created dataset for various applications, such as verifying cadastral restrictions regarding the subsurface.

Acknowledgements

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Data Availability

The data in this study can be accessed via https://github.com/geospatialstudies/3D_spatial_plans.

Notes

- 1 <https://technical.buildingsmart.org/standards/ifc>
- 2 <https://www.ogc.org/standards/citygml>
- 3 <https://github.com/INSPIRE-MIF/technical-guidelines/tree/main>
- 4 https://xleitstelle.de/XPlanung/ueber_XPlanung
- 5 <https://gitlab.opencode.de/xleitstelle/xplanung/testdaten>
- 6 <https://fme.safe.com/>
- 7 https://www.opendem.info/opendtm_de.html
- 8 <https://github.com/cityjson/cjio>
- 9 <https://github.com/cityjson/cjval>

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13 Using Information Delivery Specification for Compliance Checking in Building Permitting

Anshika Karn, Simon Fischer, and Jernej Tekavec

Introduction

The building permitting process is a critical regulatory mechanism that ensures that construction projects are executed in accordance with safety, environmental, and zoning regulations. Traditionally, building permitting processes were performed manually, using paper-based documentation. Such approaches can lead to inefficiencies, delays, and increased costs. The development of digital technologies, particularly Building Information Modelling (BIM), has opened new possibilities for transforming the building permitting process into a more streamlined, transparent, and efficient system. BIM enables the creation of detailed digital representations of physical and functional characteristics of buildings, facilitating improved collaboration and decision-making across the project lifecycle (Sacks et al., 2018). However, integrating BIM into regulatory processes, such as building permitting, remains a complex challenge.

One of the primary challenges for digitalisation of the building permitting is the translation of regulatory requirements, written in natural language, into machine-readable form. Differences between requirements across departments or regions have led to the development of individual customised solutions. An approach to move into a more standardised, harmonised way of automated compliance checking (ACC) is the adoption of open, interoperable solutions. This could be realised by the Information Delivery Specification (IDS) (bSI, 2025a). IDS, developed by buildingSMART International, addresses this need by providing a standardised, machine-readable format for specifying information requirements in BIM workflows (bSI, 2025a). By integrating IDS into the permitting process, authorities can automate the verification of submitted BIM models against predefined requirements, thus enhancing the efficiency and consistency of compliance checks. Furthermore, IDS supports interoperability by aligning with open standards such as Industry Foundation Classes (IFC) (ISO, 2024b).

Recent studies have demonstrated the potential of IDS in automating code compliance checking (Fischer et al., 2024; Nuyts et al., 2024). Fischer et al. (2024) additionally proposed possible extensions to the IDS schema to improve

its functionality in the context of building permitting. Despite the advancements, challenges remain in fully realising the benefits of IDS in the building permitting context.

This chapter aims to explore the application of IDS in the context of building permitting, examining its capabilities, limitations, and potential for integration into ACC systems. By analysing current practices and identifying areas for improvement, the chapter seeks to contribute to the development of more effective and scalable digital permitting solutions.

Automated Compliance Checking

Overview

In general, ACC can be defined as a process, where computer programs are utilised to review design documents (Peng & Liu, 2023). In the past and in many cases even today, traditional manual reviews are opted for many processes in building design, construction, and operation, which are more tedious, complicated, and prone to human errors, sometimes leading to significant consequences, especially in large-scale projects. On the contrary, ACC produces computer-verified results, streamlining the process, reducing errors, and saving valuable time and resources, proving to be highly advantageous to designers and other involved authorities. According to Amor and Dimyadi (2021), the ACC process is comprised of three major components: the design documents, which can either be 2D drawings or 3D models integrated with machine-readable metadata; regulations, which have to be transformed into machine-readable form; and software that combines the first two components by checking the building data and metadata against codes and standards (Figure 13.1).

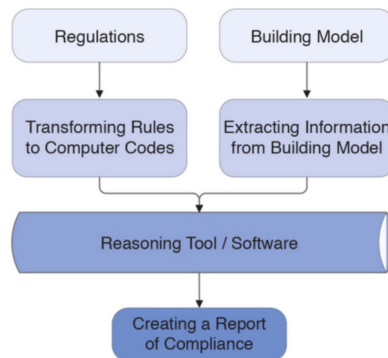


Figure 13.1 Concept for automated compliance checking (Shahi et al., 2019).

Developments of ACC

There has been a significant advancement of ACC in the past few decades which has led the Architectural, Engineering, and Construction (AEC) community towards practical systems for validation of design documents against the rules in the laws and codes. Singapore, being the pioneer in this field with its CORENET (Construction and Real Estate Network) system, initiated the checks with 2D drawings as early as 1995 (Sing & Zhong, 2001). Over the years, with the developments in the field of BIM-based design, the AEC industry has shifted towards the utilisation of BIM models. Research and practice related to ACC consequentially also shifted towards BIM-based processes. Korea developed Kbim code and Kbim Assess for verification of design using KbimLogic (Lee et al., 2016). Other notable developments include Australia's design check (Ding et al., 2006), U.S. Smart CODES, and Norway's eByggSak (Hjelseth, 2015). Finland's ECIPI developed a mechanism that utilises the openBIM format IFC combined with the BIM checking tool, the Solibri model checker (Park et al., 2015).

Scope of ACC

The ACC can be applied across a wide range of processes including initial design phase of a building to its operation and management. Real-time feedback on compliance with constraints, rules, codes, and regulations like fire escape routes and accessibility in early phases of the project can significantly improve efficiency. Similarly, using ACC for validation during construction can aid site inspections and help with coordination among major disciplines involved in construction process like architecture, structure, interior design, etc. One of the applications with a big potential for ACC utilisation is building permitting where the ACC processes can be used to verify the design against nation's or municipal codes and regulations.

ACC in Building Permit Process

Nowadays, the construction industry is being increasingly transformed through digitalisation. The process of building permitting is no exception, with many initiatives and research activities in many countries (Ullah et al., 2022; Urban et al., 2024). Traditional manual checking processes are time consuming and prone to error which can result in delayed responses from the authorities and other issues related to potential errors and delays. ACC can significantly speed up the building permitting processes, offering computer-verified results against building codes, zoning laws, fire safety, accessibility, and ensuring the quality of drawings and models submitted. Moreover, ACC can improve transparency and build greater trust among stakeholders in the system.

Need for Open, Flexible, and Context-Independent Approach

With technological advancements in the field of information technology (IT) and AEC, automation of compliance checking process can be enabled with

access to process design data in machine-readable format. However, the diversity of building codes and regulations across various regions and countries prevents the development of universal solutions. This diversity is increasing the complexity of the ACC-based solutions and thus hinders full automation (Eastman et al., 2009). In addition, the ambiguity of the written legal texts and building codes represents additional challenge, as different interpretations of the same rule can exist. The translation of rules into machine-readable form thus requires extensive collaboration between the AEC and legal professionals who can interpret the regulations in a correct manner and professionals who develop ACC software. While some tools are designed to process the machine-readable codes, the translation of non-binary textual regulations into such machine-interpretable codes remains a complex task. Many model-checking processes developed in recent years either involve proprietary workflows or utilise complex processes with extensive coding and are mostly software dependent, which might not be suitable for a broader, public-oriented process like building permits (Cheng et al., 2007). These processes are often not scalable across jurisdictions, creating a need for more open, interoperable, efficient, and accessible digital building permit processes. Integration of ACC processes with openBIM standards like IFC for building models and IDS for model checking can facilitate the process and help create a more streamlined and universally applicable framework.

Information Delivery Specification

Definition

The benefits of BIM highly depend on high-quality digital data. The same is true for ACC. A BIM model can provide a huge amount of digital data that can be automatically analysed. In the early days of BIM, the aim was often to get as much data as possible into a BIM model, resulting in a huge amount of data, including a lot of unnecessary information. To avoid this inefficient use of BIM, there has been a shift in recent years towards a use case-based provision of information requirements. The information required in BIM models is derived from the purposes or use cases that the model is intended to serve. This concept, called Level of Information Need, was standardised as ISO 7817 (ISO, 2024a). Well-defined information requirements ensure data availability, accurate and efficient data exchange, and model consistency in BIM processes. The IDS schema (BSI, 2025a) has emerged as a standard for structuring such information requirements in a machine-readable way.

IDS is an open standard from buildingSMART International for defining alphanumeric information requirements for BIM models in the open ISO 16739-1 IFC standard (ISO, 2024b). IDS enables integration of textual information requirements into the automated process. IDS can specify the alphanumeric information contained in IFC models. This includes the IFC elements; their attributes, properties, quantities, and materials; relations between elements; and additional classifications. IDS is intended to be imported into

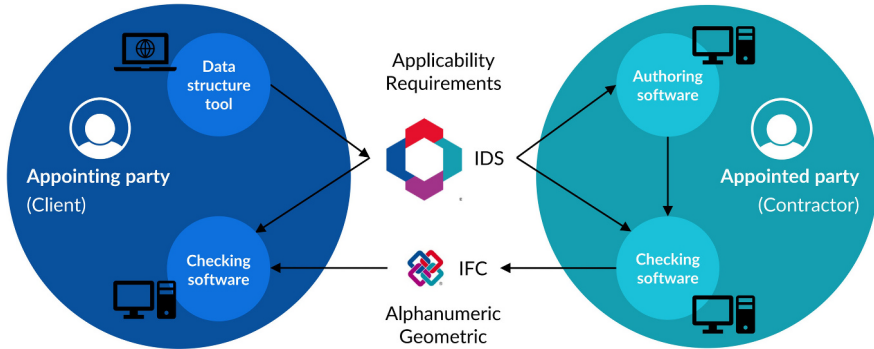


Figure 13.2 IDS workflow (Schrantz et al., 2026).

various BIM software to automatically create its configurations. For example, in BIM authoring software, IDS can automatically create the required element classes and their properties. In BIM checking software, IDS can provide checking rules, against which IFC models can be validated. In addition, its simple and lightweight schema makes it easy to understand, implement, and use. For this reason, IDS is a well-suited standard for providing information requirements, bridging the gap between their definition and verification (Schrantz et al., 2026). The buildingSMART *BIMcert Handbook* (Schrantz et al., 2026) illustrates the process from definition to verification (see Figure 13.2). Clients typically define their information requirements in a data structure tool. This information can be exported to IDS and made available to the contractors which they can use as a configuration file for their software and can also use to check their IFC models against it. After the client receives the IFC file, the IDS file can again be used to check the compliance of the model in a checking software. This process applies to any stakeholder in the project who requires information from another stakeholder. In this way, the defined information requirements are checked in a transparent and reliable way.

Structure and Working Mechanism

IDS is an open schema based on Extensible Markup Language (XML) and defined by an XML Schema Definition (XSD). The XSD defines the structure and the information that can be included in an IDS. In general, an IDS consists of a header that provides some metadata about the file and a specification list. The specification list defines the information requirements. Each specification contains two main parts: the applicability, which defines the elements affected by this specification, and the requirements, which define the actual information requirements. The content of both parts is defined by facets. The six different facets deal with the different IFC information that can be defined in an IDS:

- Entity facet
- Attribute facet
- Property facet (for properties and quantities)
- Material facet
- Classification facet (for external classification additional to the IFC entities)
- PartOf facet (for relations between elements).

Each specification can combine multiple facets within its applicability and requirements, allowing very specific information requirements to be created for very specific elements. The facets provide different facet parameters to define their content. The following generic example (Figures 13.3 and 13.4) shows a specification containing all facets with their parameters. Figure 13.3 shows the specification metadata and applicability. The applicability is defined by the entity facet and refers to all IfcWall elements with the type SOLIDWALL.

The other five facets are contained in the requirements section (Figure 13.4). The attribute facet is used to define a pattern for the name attribute of the walls. The property facet provides a list of allowed values for the fire resistance of the wall. The material facet is the simplest facet, with only one parameter for the name of a material. The following classification facet links elements to external classifications, for example from the buildingSMART Data Dictionary (bSDD) (BSI, 2025b). The example shows how to specify the system used, the classification name, and optionally a Uniform Resource Identifier (URI). In our example, the URI is a persistent link to the classification definition in the bSDD. Finally, the partOf facet defines relations between elements in a model by defining the relation used and the entity to which it is related. The example specifies that walls must be related to a building storey.

Facet parameters can be defined either by a simple value (see entity name in Figure 13.3) or by a complex restriction. IDS provides four types of complex restrictions. Patterns (see attribute value in Figure 13.4) allow patterns to be defined using regular expressions, for example to specify naming conventions. Enumerations (see property value in Figure 13.4) allow lists of possible values to be defined. In addition, and not included in the example, it is possible to restrict the length of values (number of characters) and define bounds for numeric values.

```
<specification name="Test" ifcVersion="IFC2X3 IFC4 IFC4X3_ADD2" description="This is a test
specification for a wall">
  <applicability minOccurs="0" maxOccurs="unbounded">
    <entity>
      <name>
        <simpleValue>IFCWALL</simpleValue>
      </name>
      <predefinedType>
        <simpleValue>SOLIDWALL</simpleValue>
      </predefinedType>
    </entity>
  </applicability>
```

Figure 13.3 Specification metadata and applicability example, including the entity facet.

```

<requirements>
  <attribute>
    <name>
      <simpleValue>Name</simpleValue>
    </name>
    <value>
      <xs:restriction base="xs:string">
        <xs:pattern value="Wall-[0-9]{3}" />
      </xs:restriction>
    </value>
  </attribute>
  <property dataType="IFCLABEL" cardinality="required" instructions="Fire resistance class
    according to national or regional fire protection regulations.">
    <propertySet>
      <simpleValue>Pset_WallCommon</simpleValue>
    </propertySet>
    <baseName>
      <simpleValue>FireRating</simpleValue>
    </baseName>
    <value>
      <xs:restriction base="xs:string">
        <xs:enumeration value="REI 30" />
        <xs:enumeration value="REI 60" />
        <xs:enumeration value="REI 90" />
        <xs:enumeration value="REI 120" />
      </xs:restriction>
    </value>
  </property>
  <material>
    <value>
      <simpleValue>Wood</simpleValue>
    </value>
  </material>
  <classification uri="https://identifier.buildingsmart.org/uri/dataholz/dataholz-dictionary
    /1.4/class/awmhh01a-03">
    <value>
      <simpleValue>awmhh01a-03</simpleValue>
    </value>
    <system>
      <simpleValue>dataholz-dictionary</simpleValue>
    </system>
  </classification>
  <partOf relation="IFCRELCONTAINEDINSPATIALSTRUCTURE">
    <entity>
      <name>
        <simpleValue>IifcBuildingStorey</simpleValue>
      </name>
    </entity>
  </partOf>
</requirements>
</specification>

```

Figure 13.4 Requirements example, including the attribute, property, material, classification, and part of facet.

Potentials

The IDS standard has the potential to improve the way the information requirements are created and used for BIM models. Traditional information requirements are typically defined on an entity basis. This means that all elements of an IFC entity require the same information to be defined. With IDS, the elements to which a requirement applies can be specified in a much more complex and specific way. The essential functionality of IDS is that the information used to define requirements, i.e. IFC entity, attributes, properties, quantities, materials, relations, and external classifications, can also be used to specify the applicable elements. An example is given in the buildingSMART *BIMcert Handbook* (Schranz et al., 2026):

All walls shall have the properties Load Bearing and Fire Rating (both in a property set called Pset_WallCommon). Walls with the value true for the property LoadBearing need a value for the property Fire Rating from the following list.

(REI 30, REI 60, REI 90, REI 120)

The second sentence defines that the values of one property (Fire Rating) depend on the value of another property (Load Bearing). This dependency between different characteristics represents a certain logic that a model must adhere to. Therefore, checking an IFC model against an IDS not only verifies the existence of the information, but it can also verify the information. The Fire Rating-Load Bearing example shows a simple dependency between characteristics that can be verified. By including more facets, more complex dependencies and requirements can be defined. Such functionality cannot only be used to check compliance with information requirements but also has the potential to represent actual compliance checks (Fischer et al., 2024).

Implementing IDS in Building Permitting

From Legal Text to Machine-Readable Requirements

To incorporate IDS in ACC for building permitting, one of the most important steps is the translation of the legal texts in the building code document that are written in natural language into codes that are interpretable by machines. The first step is to classify the legal texts and select the rules that can be translated among the large number of regulatory texts. The rules in the legislation are of unique character and a simple straightforward logic can't work equally. Hence, it is crucial to classify based on various parameters such as complexity, ambiguity, information extraction from the BIM model, etc.

One approach is to classify the rules in three categories, namely direct, indirect, and subjective. Direct rules are easily interpretable with clear parameters (e.g., "All walls must be of brick"), while indirect rules require additional interpretation from the professionals with some intervention in the model as well to acquire the correct information (e.g., room height requirements for "habitable rooms"). Lastly, subjective rules are more ambiguous, which require additional simplification (e.g., "All exits must be obstruction-free").

The direct rules have more potential to be translated into machine-readable codes. To translate the written regulatory texts into machine-readable formats, semantic and practical interpretation is necessary to extract the appropriate data from the texts which is dependent on human input to a large extent. Some logic-based methods have been developed for this purpose to assist in the interpretation which include a rule-based approach to translating the Korean Building Act proposed by Lee et al. (2016) and the use of Natural Language Processing as stated by Peng and Liu (2023). Solihin's work mentions a

Structured Query Language-based Domain-Specific Language called BIM Rule Language for code compliance, simplifying rules using Conceptual Graphs to reduce ambiguity (Solihin & Eastman, 2015).

One of the renowned and effective methods developed for this purpose is the RASE (Requirements, Applicability, Selection, Exception) markup developed by International Code Council under the SMART Codes initiative in 2005 which provides a semantic approach by categorising the textual regulations into four key operators: Requirements, Applicability, Selection, and Exception. Each operator is linked to four attributes: topic, property, comparator (e.g., >, <, =), and target value, allowing precise extraction of rule logic (Hjelseth & Nisbet, 2011). By identifying clear and objective parameters from the written texts, this method helps extract the requirements and applications from the rules which can be further developed into creating IDS files.

Compliance Checking with IDS

IDS has the potential to be implemented in different types of compliance checks for building permitting. One essential type is the formal check for information availability, i.e. the compliance with information requirements. The IDS structure can also support more complex checks, such as logical dependencies. A BIM model has many dependencies between different characteristics of elements. An example is the dependency between fire rating and load bearing values discussed earlier. If the load bearing property has a certain value, then only certain fire rating values are logical. If this dependency is not taken into account in a BIM model, the model may be inconsistent. This can have a negative impact on subsequent code compliance checks or evaluations of the BIM model. Finally, IDS can also directly support checks where the final values already exist in the BIM model. An example of this is the minimum dimension requirements for doors. Door dimensions usually exist in IFC models as quantities or properties. It is therefore easy to compare them with values defined in building codes.

If we compare IDS with the RASE model we can see that IDS covers the two main functionalities completely. The R (requirement) is covered by the requirements part of an IDS specification. The A (applicability) corresponds to the applicability part in IDS. The S (selection) defines alternatives for the applicability and is only partially covered by IDS. Alternative applicable elements can be defined by enumerations in the applicability, but only within individual facet parameters. This means alternatives cannot be defined by a combination of facets. The last part is the E (exception). Here, IDS also lacks some functionality. It provides the definition of cardinality to specify whether certain elements must be in the model or not, or whether certain properties must be met or not. However, cardinality is not included in the facets of the IDS applicability. Therefore, it is not possible to exclude elements from the applicability based on their characteristics. It is only possible to include them. Fischer et al. (2024) describe that the missing exception functionality for the

IDS applicability leads to problems in cases where not all possible values are known. If all possible values are known all except one can be included in the IDS applicability. However, if not all values are known and only one is to be excluded, there is currently no way to define this in IDS. Therefore, Fischer et al. (2024) proposed an extension of IDS to include the cardinality in the applicability as well, in the same way as in the requirements of IDS. When using IDS for code compliance checking, it is not only the ability to define these four aspects of a rule that is important, but also the depth of the definition. IDS is a simple and lightweight schema. This allows for easy implementation and rapid industry adoption, but has limitations when it comes to more complex compliance checks. Nuyts et al. (2024) conducted a survey on IDS for code compliance checking. They examined five types of checking conditions: information availability, target values, relational constraints, conditional and mathematical clauses. IDS can fully support the first two. Information availability and target values are covered by defining properties, attributes, materials or classifications and their values. Relational constraints can be defined using the *partOf* facet. For example, the *partOf* facet can define that a stair requires railings by using the relation *IfcRelAggregates* and the target entity *Ifc Railing* (Nuyts et al., 2024). However, it only covers six relations, and it is not possible to further restrict the related elements, for example to define required properties for the railings. Fischer et al. (2024) proposed an extension of IDS to include this functionality. Conditional clauses (IF, THEN) are possible in principle. The IF part can be covered by the applicability and the THEN part by the requirements. However, dependencies between different elements cannot be implemented. Mathematical clauses are entirely outside the scope of IDS. Only values already contained in the IFC model can be checked. In addition, geometry and spatial checks are also not supported by IDS.

The compliance checking process can be illustrated with the IDEF0 diagram (Icam DEfinition for Function Modelling) (see Figure 13.5). It is a combination of rule translation from the regulatory texts into a structured information for requirements and applicability using RASE markup and further conversion into a machine-readable code within an IDS file.

Implementation Examples

The City of Vienna is a pioneer in digital building permits and has already conducted a major EU-funded research project, BRISE-Vienna, to develop an openBIM building permit (Urban, Fischer, & Schranz, 2024). After the research project ended in 2023, the pilot phase has explored the implementation of IDS for formal, logical, and code compliance checks (Fischer et al., 2025). The information requirements for the digital building permit use case could be mapped directly into the IDS and are publicly available in the buildingSMART Use Case Management (Urban, Schneider, et al., 2024). This allows formal checks for information availability to be performed entirely based on the IDS. Next, existing information requirements were refined and incorporated as logical

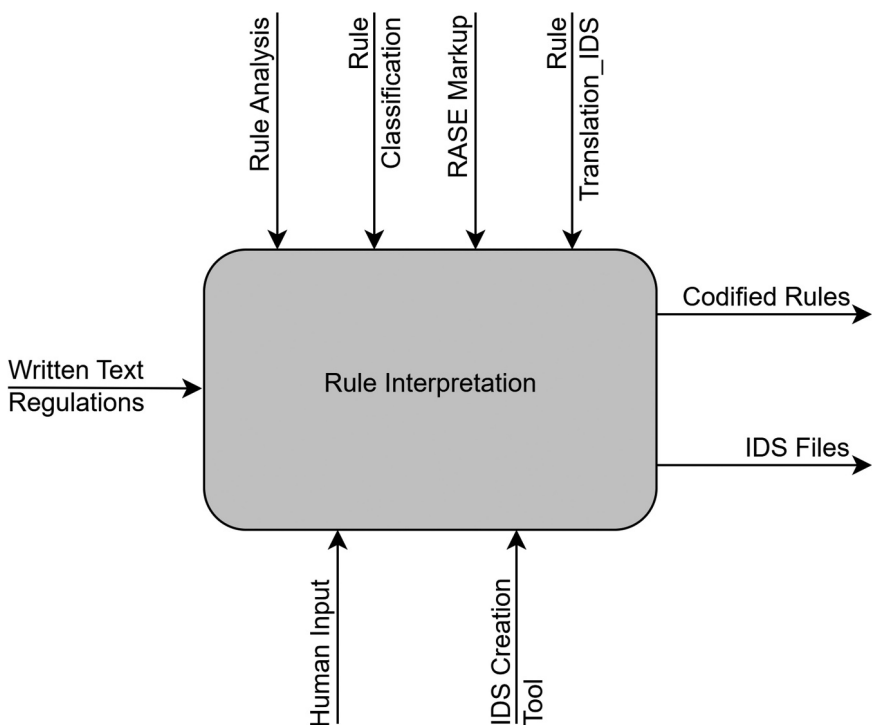


Figure 13.5 Rule interpretation IDEF0 (Karn, 2024).

checks into the IDS. Examples from the City of Vienna are the previously described dependency between the Load Bearing and Fire Rating properties and between the Fire Exit and Is External properties. A fire exit must lead to a safe place outside a building, which means that only external doors can be fire exits. Therefore, only doors with the Is External property value True (applicability) require the Fire Exit property (requirement). Some information requirements could be refined to already describe compliance checks. This is the case for the escape level of a building. In Austria, according to the OIB guidelines (Austrian Institute of Construction Engineering, 2023), the maximum allowable escape level depends on the building class. The building class describes the size and complexity of a building. With IDS, it can be defined that a detached house (building class 1) has a maximum allowable escape level of 7 m, while a residential building (building class 4) has an escape level of up to 11 m.

Another implementation example includes a framework that integrates the utilisation of IDS for ACC in building permitting process in Nepal (Karn, 2024). Three representative rules were selected from the national building by-laws document, i.e. “Nepal National Building Code 206:2015”. The semantic data regarding the requirements and applicability were extracted from each rule written in natural language using RASE markup, which was further utilised for the creation of corresponding IDS files.

First rule: No exit door, inclusive of the frame, shall be less than 1m in width and 2.1m in height except in case of residences where the minimum size of exit door shall be 0.9m in width by 2m height. The width of doors of rooms which do not form a part of general human habitation or exit media such as toilets and veranda is permitted to the width of 0.75m.

Requirements: Minimum Dimensions

Application: Doors

Second rule: “The height of all rooms for human habitation shall not be less than 2.4m measured from the surface of the floor to the lowest point of the ceiling [bottom of slab]” Application: Corridor

Requirements: Minimum Dimensions

Application: All habitable rooms

Third rule: “Width of staircase and ramps should not be less than 0.9m”

Requirements: Minimum Dimensions

Application: Stairs

These rules were further validated using an openBIM model checking software supporting IDS checks. The examples of IDS files structures and their implementations on an IFC model with visual results for the aforementioned rules are available in the BIM A+ Master Thesis (Karn, 2024).

Discussion

Using IDS as a tool for automating compliance checking in digital building permitting comes with both advantages and limitations. The case studies, especially from the City of Vienna, demonstrate that IDS can effectively support formal and logical checking of information requirements in openBIM workflows. By this, the required semantics in a submitted model for permitting can be automatically checked. This includes the correct identification of elements by IFC entities, their required properties, attributes, and materials, as well as some dependencies between different entities and characteristics. The standard’s lightweight XML-based schema, compatibility with IFC models, and alignment with existing rule frameworks like RASE provide a solid foundation for enabling machine-readable, software-independent compliance verification.

However, IDS in its current form falls short in several areas that are important for building permitting. This is limiting its usability as a standalone solution for comprehensive regulatory compliance checking. Firstly, the inability to define exceptions within the applicability section restricts its expressiveness, especially when dealing with more complex rules where exclusion logic is required. This gap, as identified by Fischer et al. (2024), limits the usability of IDS in scenarios where partial or conditional rules are the norm, such as “All elements except X must comply with Y”. Secondly, IDS currently lacks support for advanced logical, mathematical, and spatial constraints. While it accommodates conditional clauses and some relational logic, it does not yet enable more complex dependencies between multiple model elements or

calculations based on geometry (e.g., area-to-volume ratios, clearance distances). Geometry-based validation is not important only for validation within BIM environment, but also for checks that demand integration with geospatial datasets like spatial plans, environment protection zones, etc. These limitations reduce its effectiveness for full-scale building code compliance checking, which often requires these complex evaluations.

Moreover, the rapid evolution of digital standards presents a challenge. While the continuous development of open standards like IDS is essential for innovation, it also risks creating confusion or lack of implementation among industry stakeholders. If specifications change too frequently, software vendors, municipalities, and AEC professionals may struggle to maintain up-to-date tools and processes. The extension of the IDS schema can be a solution for the current shortcomings regarding ACC, but it calls for a balance between innovation and stability in standardisation efforts.

Given these constraints of IDS, it is critical to consider integrative approaches to ACC in building permitting. Rather than expecting IDS to handle all compliance checking on its own, it may be more practical to combine IDS with complementary tools or standards. IDS could provide a vendor-neutral core for ACC systems, which can be distributed across different applications. This approach standardises the basics of ACC and facilitates the implementation in different municipalities. For instance, IDS could handle formal and logical checks, while more complex rules could be performed by rule engines based on semantic web technologies or dedicated reasoning systems.

There is also a need for domain-specific rule modelling methodologies that bridge legal language and machine-readable logic. As regulatory texts remain ambiguous and subject to interpretation, the co-creation of IDS definitions by legal, domain, and IT experts is crucial. Without such interdisciplinary collaboration, automated systems risk encoding incorrect or overly rigid interpretations.

Finally, from a governance perspective, open accessibility and public participation in the creation and refinement of IDS libraries could improve trust, transparency, and wider adoption of digital permitting processes. A centralised, well-maintained, and version-controlled repository of IDS-based requirements, developed through open consensus, may be essential for scaling digital building permitting across jurisdictions.

Conclusions

The IDS represents a valuable tool for improving the efficiency and reliability of the building permitting processes. As permitting authorities increasingly move towards digital workflows, IDS can be used to define, communicate, and verify information requirements in a standardised, machine-readable format. Its alignment with openBIM principles ensures interoperability and supports transparent, vendor-neutral implementation.

In the building permitting context, IDS enables formal pre-checks of submitted BIM models to ensure their completeness and correctness. This can reduce delays and improve the overall quality of submissions, allowing

permitting authorities to focus more on substantive evaluations. By clearly specifying what data must be present in the model, such as attributes, properties, or classifications, IDS helps applicants better prepare documentation that aligns with regulatory expectations.

The use of IDS also supports greater consistency in the permitting process, particularly in jurisdictions seeking to harmonise requirements across departments or regions. It can act as a common reference between authorities, designers, and contractors, reducing ambiguity and misinterpretation.

To fully benefit from IDS, permitting authorities will need to establish standardised information requirements, integrate IDS workflows into their digital platforms, and provide guidance to industry stakeholders. With these measures, IDS can play a central role in streamlining permitting processes, improving submission quality, and supporting a transition towards more automated and transparent regulatory systems.

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14 XPlanung and the Digital Transformation of Urban Planning in Germany

Standards, Practice, and Perspectives

Kai-Uwe Krause and Carsten Pieper

Introduction

The digital transformation of urban planning is both inevitable and necessary. As cities become more complex and data-driven, the need for planning information to be accessible, interoperable, and machine-readable has never been greater. Yet much urban land-use and spatial planning still relies on document-based formats—PDFs, CAD drawings, scanned regulation texts—limiting data usability, traceability, and scalability. This often results in fragmented planning processes, slower project developments, and legal ambiguities.

Germany's response could be seen in XPlanung—a standardized data model and GML-based exchange format known as XPlanGML—designed to replace document-centric planning documents with a structured, interoperable system for spatial regulation. Complemented by XBau, XPlanung supports the data-based workflow throughout land-use planning and the building permit process. On the governance side, the XLeitstelle Planen und Bauen serves as a coordination hub, ensuring consistency, evolution, and deployment of the standards across federal, states (Länder), and municipal levels. The policy mandate from the IT Planning Council (IT-Planungsrat) in 2017 and the implementation deadline in 2023 reflect the strategic national importance of these standards. Both levels—the federal government and all 16 states—finance the XLeitstelle according to a specific financial distribution key to further develop these standards.

This chapter focuses primarily on XPlanung, exploring its technical specifications, institutional context, and operationalization in Hamburg. It also examines the use of XPlanung in Projekt PlanDigital in Niedersachsen—a cross-municipal initiative integrating planning data across diverse authorities. Ultimately, this work situates XPlanung within global digital planning movements, drawing comparisons to INSPIRE and emerging EU-level e-permit frameworks.

The Need for Data Standardization in Planning

While urban environments evolve into complex socio-technical systems, planning processes often remain rooted in outdated paradigms. Planning

authorities generate regulations through narrative descriptions, manual drawings, and styled maps—each document hard to interpret programmatically. The result is uneven data granularity and opaque regulatory context, which complicates tasks such as compliance checking, early feasibility assessment, or environmental modeling.

The limitations of non-machine-readable formats become particularly evident when digital tools—geospatial analysis platforms, automated compliance systems, or urban dashboards—attempt to integrate planning rules. Without standardized data, planning authorities, project developers, GIS vendors, and municipal systems must re-interpret regulations manually, making the process inefficient and error-prone. Data silos and inconsistent formats exacerbate these issues, hindering project coordination, digital twin integration, and institutional transparency.

Contrastingly, a structured, interoperable standard like XPlanung enables semantic clarity, multi-scale coordination, and automated regulatory interpretation. By encoding various forms of spatial plans details in a unified digital format, XPlanung provides a foundation for consistent regulatory analysis, planning simulations, and approval workflows.

The XPlanung Standard

Genesis, Governance, and Legal Mandate

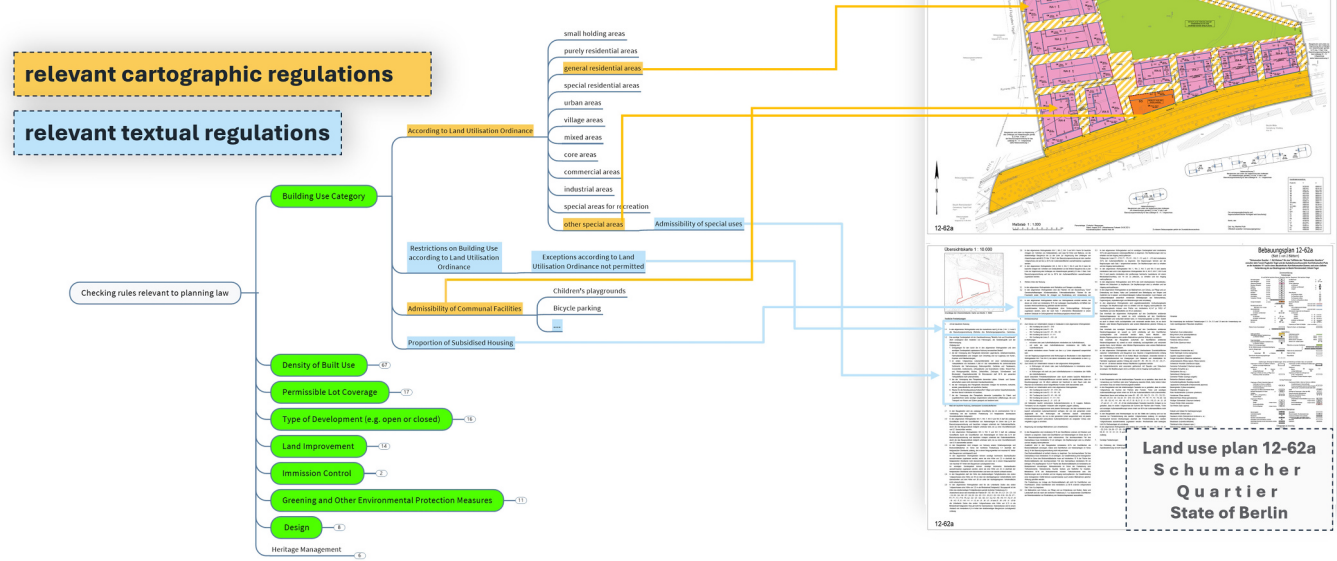
XPlanung was adopted by the IT Planning Council on 5 October 2017,¹ signaling a commitment across the federal and state governments to establish a binding, uniform standard for spatial regulation data. The standard's objective extends across urban land-use planning (BauGB), regional spatial planning (ROG), and landscape planning (BNatSchG). The IT Planning Council mandated that all federal and state authorities introduce XPlanung by 8 February 2023, effectively creating a national timeline for digital planning compliance.

Over time, XPlanung has evolved through ongoing updates by the XLeitstelle, incorporating user feedback, specifics of regional laws on the level of states, technical refinements, and policy changes. The standard is designed not just for data encoding, but as a socio-technical artifact facilitating cohesive governance and multi-level digital transformation.

The Object-Oriented Modeling Approach

At its core, XPlanung defines planning objects—such as `LandUseZone`, `DevelopmentRestrictionArea`, or `RegulatoryAppendix`—as semantic entities with spatial, descriptive, and procedural properties. Unlike raster or vector drawings, each object is precisely typed, structured, and interpretable. Spatial context (geometry), legal purpose (e.g., mixed use, green space), and procedural metadata (plan status, dates, legal texts) are embedded directly within the model (Figure 14.1).

This design allows spatial objects to be queried and processed programmatically, enabling machine-based rule checking, mapping, or simulation without



1

Figure 14.1 Connection of the semantic content of a German land-use plan into the XPlanung standard.

human interpretation. It also supports integration into wider planning systems—GIS, Building Information Modeling (BIM) platforms, and citizen planners—without losing semantic richness.

XPlanGML: The Exchange Format

XPlanGML, the GML-based encoding of XPlanung content, serves as the language for plan exchange. The language encodes geometries (GML polygons, lines, points), structured attributes (e.g., building height maximum, usage categories), and document-level metadata (plan number, status, authority, legal references). XPlanGML is both machine- and human-readable—displayable in GIS viewers, trackable in XML editors, and consumable by software pipelines.²

Importantly, XPlanGML supports lossless exchange. Every regulation, spatial delineation, and procedural note is preserved, ensuring fidelity across IT systems. Compatible service standards—Web Feature Services (WFS), Web Map Services (WMS), and modern Open Geospatial Consortium (OGC) APIs—enable dynamic access to XPlanGML-based plan data, bridging the gap between file exchange and distributed service architectures. Schemas are published in official registries.³

XLeitstelle: Organizational Structure and Mandate

The XLeitstelle Planen und Bauen operates within the Hamburg State Office for Geoinformation and Surveying. It acts as the central node for the implementation, maintenance, and support of XPlanung, XBau, and other standards within the field of planning and building processes. Despite its placement within Hamburg’s authority, it carries a national mandate—coordinating on the basis of the decision of the IT Planning Council and being steered and financed collectively by the federal and states (Figure 14.2).



Figure 14.2 Standards operated by XLeitstelle Planen und Bauen.

The XLeitstelle's core responsibilities include maintaining schemas, publishing documentation and code samples, organizing working groups to ensure legal and user-oriented development, and engaging with software vendors.

Governance is further strengthened by liaison with standards bodies (OGC, ISO, GDI), ensuring that German standards align with superior developments while preserving legal-binding national specificity.

Hamburg's Journey: Full Deployment in an Urban Context

Digitalizing Regulatory Landscapes

Hamburg's LGV digitized approximately 3,000 binding spatial and development plans according to XPlanung. The process involved detailed mapping of each plan's geometry, semantic tagging, and translation of narrative legal texts into machine-readable attributes (e.g., maximum height in meters, specified building typologies). This data is maintained in a centralized spatial database, with metadata layers indicating status, validity, and applicability.

Processes were automated to ensure daily updates, incorporating minor changes or plan supplementations, keeping the dataset current and reliable. Quality control systems verify schema adherence and data integrity prior to publication.

Process-Driven Platform and OGC-Compliant Services

The process-driven platform "DiPlanung", which is used by several states and developed by Hamburg, also hosts XPlanung content. DiPlanung is an emerging digital planning initiative in Germany that builds upon the foundations of XPlanung, aiming to enable a fully integrated and collaborative digital planning process. While XPlanung standardizes land-use and spatial planning data, DiPlanung expands this by incorporating interactive tools for planners, stakeholders, and the public—enhancing transparency, participation, and practical usability. A core function of DiPlanung is the structured storage and long-term management of formally adopted plans. This includes version-controlled retention of legally binding planning documents in standardized, machine-readable formats, along with procedural metadata such as adoption dates, legal status, and amendment history. By maintaining a centralized and persistent repository of finalized plans, DiPlanung ensures legal certainty, traceability, and reliable referencing for administrative workflows and public access. Moreover, it fosters interoperability across systems, integrates diverse datasets—such as environmental, mobility, and socio-economic data—and supports temporal and spatial analysis. Through this extended framework, DiPlanung paves the way for more responsive, data-driven urban governance.

It also provides standardized OGC-compliant interfaces. WMS enable dynamic cartographic consumption of plan layers, while WFS and OGC APIs enable clients to query, filter, and download plan features directly.

These services support broad use cases—from municipal planners visualizing layers in GIS software to developers integrating regulatory constraints into feasibility studies. The availability of well-defined endpoints ensures that digital workflows—assessments, approval checks, environmental modeling—can be built on top of an open and standardized data foundation. Scripts and tools to ensure the usability of XPlanung are published as open source.⁴

Integrations and Ecosystem Interfaces

Hamburg's XPlanung deployment could interfere with multiple systems in future:

- The city's building permit IT system reads constraint data directly from XPlanung endpoints, prompting planners to integrate zoning logic into permitting assessments.
- A growing BIM integration *layer* facilitates the transformation of XPlanGML into CityGML or IFC, enabling building envelope visualization and conflict detection.
- Urban dashboard applications and 3D digital twins link XPlanung metadata to spatial models, enabling context-aware overlays—such as heritage buffer zones or building height maxima—within interactive city simulations.

This integrated digital ecosystem underscores the practical value of the standard—not only in permitting, but in strategic planning, environmental modeling, and public transparency.

Niedersachsen's Projekt PlanDigital: A Cross-Municipal Framework

The Challenge of Heterogeneity

Niedersachsen comprises nearly 1,000 municipalities—rural, suburban, and urban—each with different GIS systems, organizational structures, and resources. The aim of Projekt PlanDigital is to harmonize land-use planning data using XPlanung across municipal boundaries, lowering digital disparities and enabling shared infrastructure.

Core Components of the Initiative

Municipalities receive access to centrally maintained XPlanung schemas and service modules, enabling them to publish plan data. The project provides:

- Standardized procedural metadata formats to ensure legal and temporal consistency
- Schema mapping tools to align diverse legacy datasets with XPlanung's object model
- A cross-municipal service hub for plan ingestion, validation, and hosting

By connecting local authorities through a federation of OGC-based services, the initiative promotes data consistency and opens avenues for regional planning, environmental assessment, and infrastructure coordination.

Achievements and Lessons Learned

Initial pilot projects in selected districts revealed both successes and challenges. On one hand, XPlanung facilitated technical interoperability and coherent cross-border planning data. On the other, legacy data—often in CAD, PDF, or proprietary GIS formats—required labor-intensive harmonization. The value of capacity building emerged as critical. Workshops and support services proved essential for municipal staff unfamiliar with GML-based web services.

Technical Foundations and Interoperability

International Geospatial Standards

XPlanung is built upon international agnostic standards: the ISO 19100 series provides the conceptual foundation for object and geometry modeling, while OGC standards—GML, WFS, WMS, and OGC API for Features—govern data encoding and service provision. This architecture ensures that XPlanung remains flexible, forward-compatible, and integrable with global geospatial systems—GIS, CAD, digital twin software.

Importantly, XPlanung extends beyond basic geometries, allowing enriched metadata, rule-oriented objects, linear regulations (e.g., depot buffer zones), and procedural context. This semantic richness ensures planning data is not just represented, but correctly interpreted.

XPlanGML Object Structure

- Features contain geometric representations and a typology—identifying land-use categories, building envelope constraints, or special-purpose areas.
- Attributes are typed (strings, numbers, enumerations) and codify regulatory details: maximum height, intended usage, open space ratio, etc.
- Relationships link objects to each other, or to external documents—e.g., heritage protection regulations.
- Procedural metadata includes plan ID, adoption date, legal validity, authority, amendment history, and references to legal texts. Namespace and schema validation ensure all data adheres to the XPlanung schema.

Because of GML's expressiveness, schema evolution is manageable—new constraints can be introduced through extension schemas or version updates. The object structure of XPlanGML is continuously expanded with additional type models that support thematic planning domains, such as landscape planning and municipal heat planning, while also ensuring interoperability with other standards, including IFC, CityJSON, and CityGML—even though GML

itself is often criticized for its complexity, verbosity, limited efficiency, and the lack of full compatibility between its various profiles.

International Context and Standards Alignment

Germany's standardized approach aligns well with international efforts. The *INSPIRE Directive* (EU 2007/2/EC) defines data models for land use across member states, emphasizing semantic interoperability and access via network services. XPlanung's schema aligns with INSPIRE land-use specifications, facilitating cross-border harmonization and enabling pan-European analyses.

The broader European push for digital building permits—under the EU's *Digital Europe Programme*—advocates for fully digital workflows from planning to permit issuance. XPlanung/XBau form a strong legal and technical backbone for these initiatives. Countries like the Netherlands, Finland, and Estonia have similarly implemented national spatial planning models.

Global inflections appear in CityGML-based 3D regulations, Smart City architectures, and Artificial Intelligence–driven planning tools. XPlanung's formal structure—spatial rules tied to code-defined semantics—is inherently compatible: regulation objects can be imported into 3D city models, city dashboards, or AI-enabled planning assistants.⁵

Discussion

Despite its progress, XPlanung still faces hurdles. Not all municipalities have the capacity or budget to convert legacy data, implement GML pipelines, or host web services. The upfront cost of schema mapping and staff training can deter slower-moving authorities. Where IT resources are scarce, smaller municipalities may rely on cloud-hosted services or external GIS providers to bridge the gap.

Furthermore, significant challenges remain in implementing federated data platforms that provide unified and legally compliant access to established planning documents. Initiatives such as DiPlanung aim to address these challenges by creating standardized interfaces and shared infrastructures for the long-term management, accessibility, and interoperability of binding spatial plans across jurisdictions.

Moreover, the future integration with BIM and automated code checking is still emerging. While early proofs of concept in Hamburg show promising results, cross-sector synergy between building permits, digital twins, and smart city platforms remains limited. Moreover, on the technical side, the limitations of GML—its verbosity, complexity, and uneven profile compatibility—raise the question of whether lighter or complementary exchange formats might be required, especially for web- and BIM-based workflows. The handling of legacy data and the establishment of robust interfaces with BIM, CityGML, and CityJSON remain only partially resolved.

However, the multi-stakeholder governance approach—through software vendors, academic cooperation, and events—creates a fertile environment for innovation. Ongoing research in AI-assisted plan interpretation, planning by objectives, and 3D spatial compliance monitoring speaks to a vibrant future. International comparisons confirm that no model is perfect, but Germany's structured, mandated, and government-anchored approach provides clarity and legal certainty.

Conclusions and Recommendations

For city and regional planners, integrating XPlanung into workflows enables programmatic analysis, compliance automation, and real-time maps. For municipal administrations, careful investment in staff training and architecture is essential. For researchers, the XPlanung corpus offers rich opportunities for urban informatics, AI-driven regulation systems, and participatory planning tools.

Nevertheless, challenges remain: Centralized data management platforms must be established in order to develop semantic linked-data technologies; the digital transition of planning documents needs to be supported; and the integration of BIM data, CityGML, and CityJSON must be actively advanced. The full potential of planning-related data will only be realized when comprehensive digital government ecosystems are developed.

Notes

- 1 IT Planning Council (2017) Resolution 2017/37.
- 2 XLeitstelle (2023).
- 3 <https://repository.gdi-de.org/schemas/de.xleitstelle.xplanung/>
- 4 <https://gitlab.opencode.de/xleitstelle>
- 5 Krause (2022).

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15 Data Profiling and Validation through Linked Data Technologies

Rob Atkinson, Francesca Noardo, Nataliya Keberle, Arkadiusz Chadzynski, Alejandro Villar, Mayte Toscano, and Vladimir Alexiev

Introduction

For digital building permits, many sources of information must be considered, along with varied localised implementation environments for managing such data. As a result, for a widely applicable approach, there needs to be a scalable and effective use of heterogeneous data sources. Analysis software should be reliable and trustworthy when checking compliance with regulations, and the level of testing required is only feasible against a common open and standardised data requirements definition, complying with well-known and standardised data models and semantics. For efficiency, common encoding formats are also important, although less critical than clear semantics. To address specific use cases, such as evaluating compliance with permit conditions, only subsets of such data sources may need to be accessed and converted to a common model.

Standard data models exist to serve as a reference for shared data structures and semantics. However, usually, only a subset of the classes and properties of such models are used. Moreover, there can be only small variations in the use of classes/properties.

This simplified view, which is a subset of the entire data model, is termed “profile”. It is possible to limit the burden of standardisation and data harmonisation to simplified profiles for specific purposes. Such profiles need to be based on the use case data requirements and become the reference for both data retrieval and data validation. Examples of profiling mechanisms are provided by the buildingSMART Information Delivery Specification,¹ for the Industry Foundation Classes (IFC) schema, and by the Open Geospatial Consortium (OGC) Data Exchange Toolkit (Noardo et al., 2024).

Therefore, there is a widespread need to support profiling data models, and the scalability of this capability becomes critical to automate analysis and processing for any application domain that spans multiple stakeholder environments. The challenge that emerges is to define a profiling mechanism that can support referencing the components of multiple data models and the encoding formats, and allow detailed descriptions of the semantic matches between source data and target profiles. Semantic technologies can address this if

identifiers can be created for the elements being described. The mappings between source and target can be described using a range of possible data models, since semantic technologies support easily augmented Knowledge Graphs (KGs) that may express these mappings in as many forms as necessary. KGs consist of terminological and assertional knowledge linked together in a set of subject–predicate–object statements.

Necessary data will be held in systems that predate mechanisms for clear semantics, such as Building Information Models (BIM), databases, spreadsheets, Geographical Information Systems (GIS), and simple Application Programming Interfaces (APIs), often with no clear standardisation. Realistically, such systems are not able to leverage recent advancements such as Linked Data and interoperable APIs. In addition, the data models tend to be very comprehensive, combining the data itself with a range of metadata to support management and update and to accommodate additional information useful for different use cases. The lack of standardised vocabularies, inconsistent data formats, and siloed systems often results in poor data quality, delayed handovers, and costly rework.

To overcome these issues, Linked Data, or semantic technologies, particularly Resource Description Framework (RDF), are considered in this chapter as a solution for the effective management of data model profiles. Semantic technologies bring a game-changing advantage. Semantic technologies, including ontologies, RDF,² and Shapes Constraint Language (SHACL),³ provide a structured and machine-interpretable way to define, integrate, and validate data across systems. They enable a shared understanding of key concepts — like “Building”, “Load-bearing wall”, or “Energy efficiency rating” — across diverse software platforms and stakeholders. Ontologies and shared vocabularies define the meaning of terms used in BIM, GIS, IFC, and regulatory data. With a shared vocabulary, data profiles can match multiple sources against a common model, and as a result, data from different disciplines (e.g., structural and mechanical) becomes easier to interoperate and compare. Using a selected composition of classes and properties with SHACL shapes, domain-oriented profile-specific rules and constraints can be defined per profile and executed automatically to validate datasets, reducing errors before construction begins or data is exchanged. The automated generation of documentation is also supported.

In this chapter, we examine mechanisms for defining and using profiles and the foundation work required to establish common semantics for data models and digital permit conditions.

Background and Literature

Mapping heterogeneous data sources to a common model is a ubiquitous concern of information management. Recent developments in interoperability standards for data exchange do provide a basis for integrating a range of capabilities into a coherent and scalable approach.

One key trend that provides new possibilities is the widespread use of the JSON encoding language and its ability to be converted to Linked Data using JSON-LD. With this, the key pre-requisite of having identifiers for each element of a data structure is met for many new information system implementations. Other approaches can be defined for other data structures, using a wide range of available tools, such as custom Extract-Transform-Load pipelines for relational database (RDB) converters to RDF–RDB to RDF (R2RML), W3C Extensible Style sheet Language Transformations + Gleaning Resource Descriptions from Dialects of Languages conversion for XML data, scripting conversions, and mapping languages (Haller et al., 2024; van der Horst et al., 2022).

Ontology Web Language (OWL)⁴ ontologies are based on Description Logics, which distinguishes two knowledge components:

- TBox: terminological (theory)
- ABox: assertional (facts)

A Knowledge Base (KB) is understood as a set of statements consisting of TBox and ABox combined (Baader et al., 2017).

The RDF is a standard model for representing data in a structured, machine-readable, and interoperable way. At its core, RDF describes information using subject–predicate–object triples, forming a flexible graph of relationships.

A dedicated query language called SPARQL⁵ enables users to retrieve or update information in a KB and other data sources that can be mapped to RDF.

GeoSPARQL⁶ is an extension of SPARQL, defining functions and vocabularies to represent and process geospatial linked data to extend the baseline SPARQL query or update language. The present 1.2 version is focused mainly on 2D data and contains geospatial data-specific vocabularies for different serialisation formats and spatial relationships. It also standardises function definitions for such data. In this way, it provides a standardised specification for consistent implementation across linked data to support a core set of geospatial data store, retrieval, and update operations in a vendor-independent and interoperable way. Once a data source can be mapped to a Linked Data form, additional standards can be applied to define machine-readable profiles, such as SHACL, and used to validate data. OGC recognises that the general structural standards need to be augmented by domain standards for the geospatial data. Therefore, OGC has provided a framework for managing profiles using simple, testable, reusable components (i.e. the OGC Building Blocks⁷). They directly support testing the validation rules for data profiles.

OGC Building Blocks demonstrate that machine-readable profiles can be simplified into reuse of common patterns, linking data structures to domain models. To fully specify a profile, however, the source and target data models must be well specified. The Findability, Accessibility, Interoperability, and

Reusability (FAIR) principles apply to ensuring that these models can be understood, and such mappings can be tested and shared in turn.

Standards are highly adopted to make combined BIM+GIS urban models self-described and related to the Semantic Web.

CityGML⁸ is an open standardised data model and exchange format to store digital 3D models of cities and landscapes. CityGML enables uniform descriptions of 3D features and objects found in cities (buildings, bridges, vegetation, city furniture, and others) and the relationships between them. It also defines different standard levels of detail (LoDs) for the 3D objects, which allow representations for different applications and purposes, such as simulations, urban data mining, facility management, and thematic inquiries.

CityGML is implemented as an application schema for the Geography Markup Language v3.

An alternative encoding of the CityGML data model is provided by CityJSON (Ledoux et al., 2019), used to compactly store geometries, attributes, and textures of city objects, flattening the structure of CityGML up to “leaves” carrying data important in the applications.

Converters (Pauwels & Terkaj, 2015; Oraskari et al., 2018; Pauwels & Roxin, 2016) and highly customisable workflows exist to transform BIM in IFC to CityGML, unlocking the plethora of possibilities to reuse BIM data in city-based applications.

For building permit digitalisation, regulatory and zoning information needs to be considered. Descriptive means for urban zoning and land use applications are provided, for example, by the European Union’s Infrastructure for Spatial Information in the European Community (INSPIRE) data model and national standards like XPlanung,⁹ which is legally mandated for digital spatial planning in Germany from 2022 to 2023 (Douay & Lamker, 2022). A plan is modelled in XPlanung classes and attributes (packages for zones, uses, regulations) using the Unified Modelling Language (UML) and serialised as GMLv3.2.2 (XPlanGML) for interoperability.

However, such standards face inherent limitations in semantic interoperability and extensibility (Zamalea et al., 2016). These rigid, schema-driven models encode meaning in a fixed format and lack formal semantics, which makes it difficult to extend their information models or to perform automated reasoning on the data. As a result, there is growing motivation to adopt Semantic Web technologies, such as OWL ontologies and RDF graphs, which provide a more expressive, extensible, and machine-interpretable way to represent domain knowledge (Métral et al., 2010).

Since a set of RDF statements is a directed and labelled graph, OWL models in general are called KGs, consisting of terminological and assertional knowledge linked together in a set of subject–predicate–object statements.

By casting BIM and GIS data into an OWL/RDF-based KG, one can achieve deeper integration and linking of heterogeneous datasets, while leveraging ontology-driven reasoning to infer new relationships and insights across previously siloed data sources (OGC, 2020).

Method

The methods presented here were developed and tested within two European projects on the digitalisation of building permits (2022–2025), namely ACCORD¹⁰ and CHEK.¹¹

ACCORD's main objective was to develop a semantic framework that facilitates interoperability between different data sources, including BIM, through the formalisation of rules and the integration of micro services for the automatic verification of urban planning regulations. Its key components include semantic interoperability, tools for the formalisation of regulatory rules, and the use of technologies to represent and reason about urban models in an automated way and in accordance with current regulations.

CHEK focused on the development of digital building permits based on interoperable technologies. CHEK's main objective was to leverage the integration of heterogeneous planning, design, and construction data into a digital workflow to support (semi-)automation and scalability. Data profiles to encode data requirements as well as input to automatic validation are a central part of the project, enabling more transparent, traceable, and efficient regulatory verification processes.

At the moment of writing, CityGML version 3.0 does not have a standardised RDF rendition. A proposal to implement a CityGML OWL representation to support RDF rendition was proposed (Vinasco-Alvarez et al., 2024). In spite of the fact that the obtained set of ontologies, called CityOWL, correctly represents CityGMLv.3 Conceptual Model, this rendition has several characteristics, showing the directions for further elaboration and enhancement towards establishing the Semantic Web best practices in foundational ontologies definition.

However, the Vinasco-Alvarez et al. (2024) approach presents some drawbacks. First of all, property names are lengthy, consisting of two parts: class name and own property name, for example “bldg:Building.usage” or “con:Elevation.elevationReference”. This is a side effect of a formal UML-to-OWL translation caused by the used conversion software (ShapeChange), and it does not make the rendition less useful. The common situation is that a lot of CityGML classes have duplicate properties, such as “usage”, “value”, “function”, “address”, and two-partite names allow the disambiguation of such properties. However, a good Semantic Web practice is to reuse properties rather than proliferate properties in different contexts with the same meaning, so that client applications do not need to be configured to understand that they are the same properties and need to be treated consistently. This reduces the overall complexity of the semantic model.

Instead, in OWL, properties are “first-class” citizens and may be defined not as class property (contrary to UML), but independently of any class, and be restricted with RDF Schema “rdfs:domain/rdfs:range” or more relaxed with Schema.org¹² restrictions “schema:domainIncludes/schema:rangeIncludes”.

Second, CityGML v.3 makes use of Application Domain Extensions (ADEs) technique to add classes and define properties to reflect extensions to

standard classes, needed in a particular domain or application. However, RDF by its nature allows statements about resources, including reification (i.e. treating RDF statements as “meta-resources” about which additional RDF statements can be made), and in general, ADEs can be modelled using standard RDF and RDF Schema expressivity.

Following the idea of having a more compact, Semantic Web coherent CityGML rendition into OWL, *CityRDF* was developed. The terminological part of CityRDF is a result of the encoding of the CityGML UML model to the OWL TBox in RDF. Concrete models describing actual city objects in CityRDF are ABoxes of this ontology. Depending on the level of detail (LoD1-4) CityRDF KG statements say: “at this location there is this 3D geometry, and it is a building” or “at this location there are multiple 3D and 2D geometries, which, taken together, are buildings with walls, roofs, doors, windows and certain functions”, and so on. The extension mechanism of RDF KGs built into Semantic Web tools allows extending them by linking their statements to the statements in other RDF graphs. Statements asserting topology relationships are one of the examples of such extension, facilitating model interoperability.

CityRDF for Data Validation in the OGC Data Exchange Toolkit

One of the goals of the CHEK project was to develop a mechanism for validating CityGML/JSON data against requirements, thus guaranteeing that all elements (city objects, surfaces, LoDs, attributes, etc.) necessary for tools to verify compliance with building permit regulations are present and correctly formatted.

Testing in the CHEK Project

To perform data requirement validations, a methodology was developed consisting of two different phases:

- Semantic uplift: input datasets are converted into Linked Data format (RDF).
- SHACL validation: datasets in RDF are validated against a set of rules (SHACL “shapes”). Collections of rules are bundled as “validation profiles” and published as OGC Building Blocks. Additionally, inheritance relationships can be established between profiles, meaning that a given profile can automatically and recursively import rules from other profiles and focus on specialising specific requirements.

A validator can then leverage the semantic uplift transformations defined for its input data, along with a set of data requirements profiles, and apply the validation rules contained in the latter to the former, thus guaranteeing that the input datasets are suitable for use in checking compliance with building permit regulations in each specific case.

Semantic Uplift

In order to apply semantic validation rules, input city data, in various formats, is first converted into a standardised semantic format and merged into a single KG. This is a process called “semantic uplift”, which entails targeting relevant elements of the source data, converting to a simplified JSON format, and using JSON-LD to semantically “annotate” the resources to build the necessary relationships (triples).

Semantic uplift, though multi-step, offers a flexible, standards-based alternative to custom code, even enabling validation across multiple datasets.

The OGC has developed a software library that can parse declarative semantic uplift definitions (simple data transforms, JSON-LD context embedding, etc.) and apply them to input data. In the CHEK case, a semantic uplift definition was used to convert input CityGML/CityJSON data into CityRDF format, enabling validation shapes to be written against the CityRDF data structure.

Defining Profiles as OGC Building Blocks

The OGC Building Blocks are reusable pieces which simplify the implementation and maintenance of data standards by breaking down complex specifications into smaller, modular parts. Validation assets, including SHACL shape collections, are among the many resource types they support. Because Building Blocks can declare dependencies, validation profiles can inherit rules from others, enabling a flexible, hierarchical structure where each profile focuses on specific requirements while reusing shared logic (Figure 15.1).

The Validator Application

Based on this methodology, a requirements validator was implemented (Noardo et al., 2024). It is offered as a web application, compliant with the

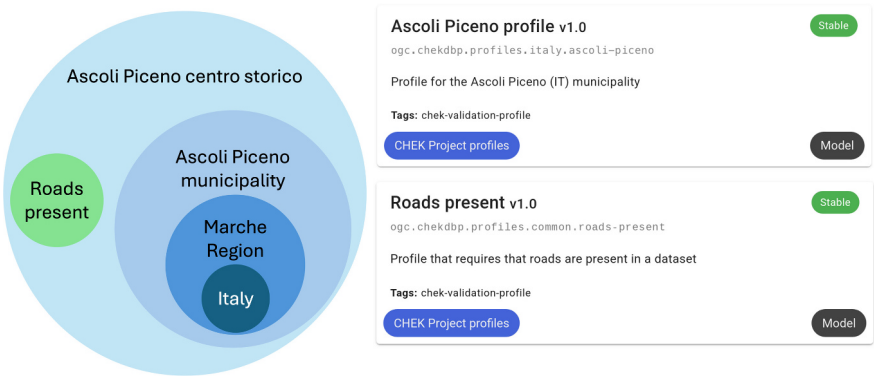


Figure 15.1 Example of a profile for a neighbourhood (“Ascoli Piceno centro storico”) (graphical representation of profiles composition on the left) importing rules from other profiles stored as OGC Building Blocks (right). The resulting rule set is the sum of all the profile rules.

CHEK Data Completeness validator

Backend service

Service URL
https://defs-dev.opengis.net/chek-validator/

VALIDATOR UPLIFT RULE GENERATOR

Validation data

Load rules from

☒ Existing profile

☐ Manual input

Select a profile for validation
Ascoli Piceno profile for CHEK ogc.chekdbp.profiles.italy.ascoli-piceno

General profile for the city of Ascoli Piceno

File to validate
buildings-lod012.json

File to validate

Parameters

buildingOfInterest *
ID_04030100_619

Identifier for the building of interest

▶ VALIDATE

Figure 15.2 CHEK data requirements validator user interface.

OGC API-Processes¹³ standard, facilitating its integration with other components and services.

The application includes a CityRDF semantic uplift definition to convert CityGML/JSON into RDF.

Validation jobs can be triggered either by directly querying the OGC API-Processes-compatible endpoint, or by using the sample, easy-to-use web interface embedded within the application (Figure 15.2).

The results of each validation job can be retrieved as a JSON document, which includes a full SHACL report, in JSON-LD format, with all the rule violations detected and elements triggering them, as well as informative error messages and other metadata.

Rule Templates

One of the limitations of our Linked Data-based approach is that writing even simple rules for the validation profiles requires knowledge of:

- Linked Data and RDF in general.
- The target RDF model for the semantic uplift (CityRDF, in our case).
- SHACL (and, potentially, SPARQL).
- Translating regulations into requirements.

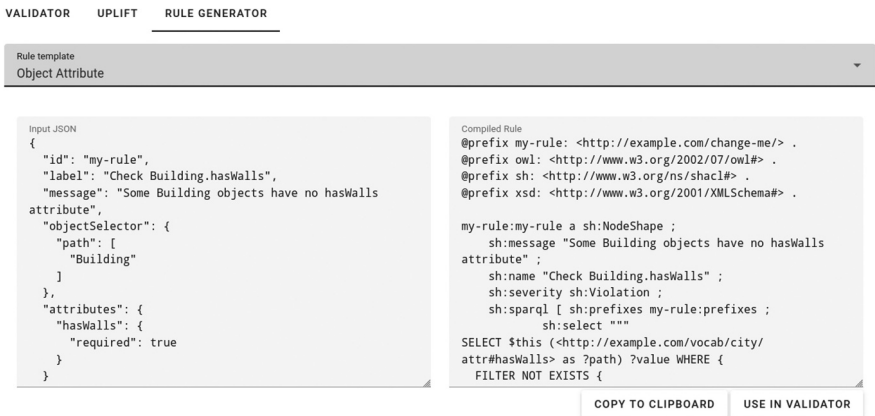


Figure 15.3 Example of rule generation from templates in the CHEK validator.

Rule templates can be defined as OGC Building Blocks, allowing common validation patterns to be expressed in formats like JSON or CSV and automatically uplifted into SHACL shapes. These templates may include a JSON schema and semantic uplift steps, enabling applications to generate “proto-profiles” and apply them to input data. Users with minimal Linked Data or CityRDF experience can use these templates to create simple rules or build more complex validations. The CHEK validator includes a built-in template parsing engine to support this process (Figure 15.3).

Semantic Web-Based Regulations Checking

The proof-of-concept use of CityRDF within the ACCORD project showcases the possibility of deploying it in real-world business scenarios wherever heterogeneous models need to be made interoperable and any of their aspects related for some purpose.

Testing in the ACCORD Use Case

CityRDF was used within the scope of the ACCORD project as a target ontology for BIM data. The main goal of the use case was to check whether buildings and their surrounding elements of the case study, i.e., the former Berlin Tegel airport, are compliant with regulations described in the XPlanung standard. Relevant building data was provided as a georeferences BIM model in IFC.

OWL/RDF Schema descriptive stack was chosen to get the BIM+urban development plans data integrated into a KG. The overall ETL process is depicted in Figure 15.4.

Available IFC semantic uplift processes, such as ifcOWL (Pauwels & Terkaj, 2015) and IFCtoLBD (Oraskari et al., 2018), while preserving all the information from the initial BIM models, generate overcomplicated OWL/RDF,

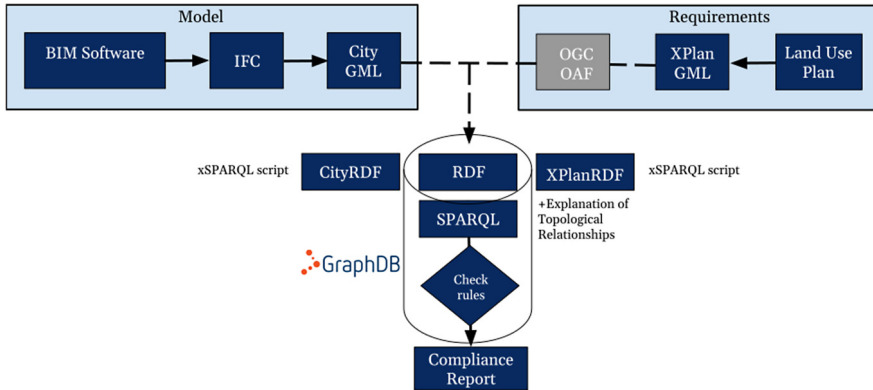


Figure 15.4 ETL workflow combining IFC data and XPlan urban development plans into an RDF knowledge graph, as input to compliance checking.

leading to almost a ten times increase in the file size. Simplification of ifcOWL files, as it is proposed in Pauwels and Roxin (2016), although reducing the resulting file size, still requires obtaining a fully converted ifcOWL file which leads to longer time to get final OWL/RDF file. Also, OWL/RDF files obtained that way do not employ CityGML structure of classes, which leads to ambiguity and decreases the interoperability of the resulting models. That is why CityRDF was chosen as a target language for IFC-to-RDF conversion. To perform compliance checking in this scenario, the building data for the project was converted into CityRDF in a two-step process: from IFC to CityGML and from CityGML to CityRDF.

The IFC models were converted into CityGML using a custom FME workflow.¹⁴ The pragmatics influencing the workflow were the practical usefulness of certain IFC classes in regulation checks. It also included a coordinate system transformation from the local BIM model coordinates (EPSG:3068–Soldner Berlin) to XPlan coordinates (EPSG:25833–ETRS89/UTM zone 33N). IFC objects’ geometries were written in CityGML as `gml:lod4MultiSurface`, with unique IFC IDs mapped to `gml:id`. Several key elements — such as Room UsageDIN277, Level, Floor Height, and Room Area — were successfully transferred, though some others could not be preserved. Representing `bldg:BuildingInstallation` and `bldg:BuildingFurniture` in a full LOD4 geometry led to large file sizes (~600MB), while converting all elements to `gml:lod4MultiSurface` reduced this to approximately 140MB. The coordinate transformation ensured correct georeferencing but introduced minor positional inaccuracies. A fragment of the resulting CityGML is shown in Figure 15.5.

Semantic uplift of CityGML to CityRDF was implemented with a custom script in xSPARQL¹⁵ which is a query language combining XQuery and SPARQL for transformations between RDF and XML. For the purposes of

```

▼<core:CityModel xmlns:core="http://www.opengis.net/citygml/2.0" xmlns:gml="http://www.opengis.net/gml" xmlns:
  <gml:name>LandUseCase</gml:name>
  ▼<gml:boundedBy>
    ▼<gml:Envelope srsName="EPSG:25833" srsDimension="3">
      <gml:lowerCorner>x_lower y_lower 28.42999999999998</gml:lowerCorner>
      <gml:upperCorner>x_upper y_upper 75.37999999999997</gml:upperCorner>
    </gml:Envelope>
  </gml:boundedBy>
  ▼<core:cityObjectMember>
    ▼<bldg:Building gml:id="Building">
      ▼<bldg:interiorBuildingInstallation>
        <bldg:InteriorBuildingInstallation gml:id="0mDZIkZeHEyBRKEmNliVpZ_422013"> </bldg:InteriorBuildingInstallation>
        ▼<bldg:boundedBy>
          <bldg:WallSurface gml:id="1fayqkKjvBseAs00ktN32Q_606459"> </bldg:WallSurface>
        </bldg:boundedBy>
        ▼<bldg:interiorRoom>
          ▼<bldg:Room gml:id="02cCmzzZvA2P21mwP3Yk9e_26652">
            ▶<gen:stringAttribute gml:id="03d92a03-1aac-42ba-b67c-0ca22716222e">
              ...
            </gen:stringAttribute>
            ▼<gen:stringAttribute gml:id="0aad0dee-0858-430b-a583-196b204a2e1e">
              <gen:value>Markthalle</gen:value>
              <gen:name>LongName</gen:name>
            </gen:stringAttribute>
            ▼<gen:intAttribute gml:id="1a7b060f-092b-4fbd-a7b6-dd4c7d9d9314">
              <gen:value>4.019999999999998</gen:value>
              <gen:name>FloorHeight</gen:name>
            </gen:intAttribute>
            ▼<gen:intAttribute gml:id="20f4e0cc-b41c-40f5-9dfd-7ef0f8e83503">
              <gen:value>74.11868931999763</gen:value>
              <gen:name>RoomArea</gen:name>
            </gen:intAttribute>
            ▼<gen:stringAttribute gml:id="e8702d14-5ef8-445b-83af-claef225bc42">
              <gen:value>NUF_2_Büroarbeit</gen:value>
              <gen:name>RoomUsageDIN277</gen:name>
            </gen:stringAttribute>
            ▼<bldg:lod4MultiSurface>
              ▼<gml:MultiSurface srsName="EPSG:25833" srsDimension="3">
                ▶<gml:surfaceMember>
                  ...
                </gml:surfaceMember>
              </gml:MultiSurface>
            </bldg:lod4MultiSurface>
          </bldg:Room>
        </bldg:interiorRoom>
      </bldg:interiorBuildingInstallation>
    </bldg:Building>
  </core:cityObjectMember>
</core:CityModel>

```

Figure 15.5 A CityGML file structure obtained from the IFC file.

ACCORD, only several elements from CityGML class hierarchy were transformed, including *InteriorBuildingInstallation*, *Room*, *WallSurface*, *Door*, *Window*, *BuildingFurniture*, *Building*, and *CityModel*. The resulting CityRDF graph is illustrated in Figure 15.6.

Spatial and logical reasoning over land parcels and buildings for compliance checking requires a joint spatial model, allowing to find building parts to which regulations apply based on their topological relationships to each other. Default model georeferencing methods for IFC do not allow for the finding of the location of individual model parts without additional transformation steps. At best, such georeferencing methods consist of setting the *IfcMap* Conversion values with the offset between the project coordinate system and the global origin of a projected coordinate reference system stored within the attributes *Eastings*, *Northings*, and *OrthogonalHeight* for global elevation. The rotation for the XY-plane can be stored using the attributes *XAxisAbscissa* and *XAxisOrdinate* (Clemen & Görne, 2018). Conversion of the IFC to RDF with explicit geometries in a uniform coordinate reference system, on the other hand, allows the reuse of existing and well-tested software to establish such

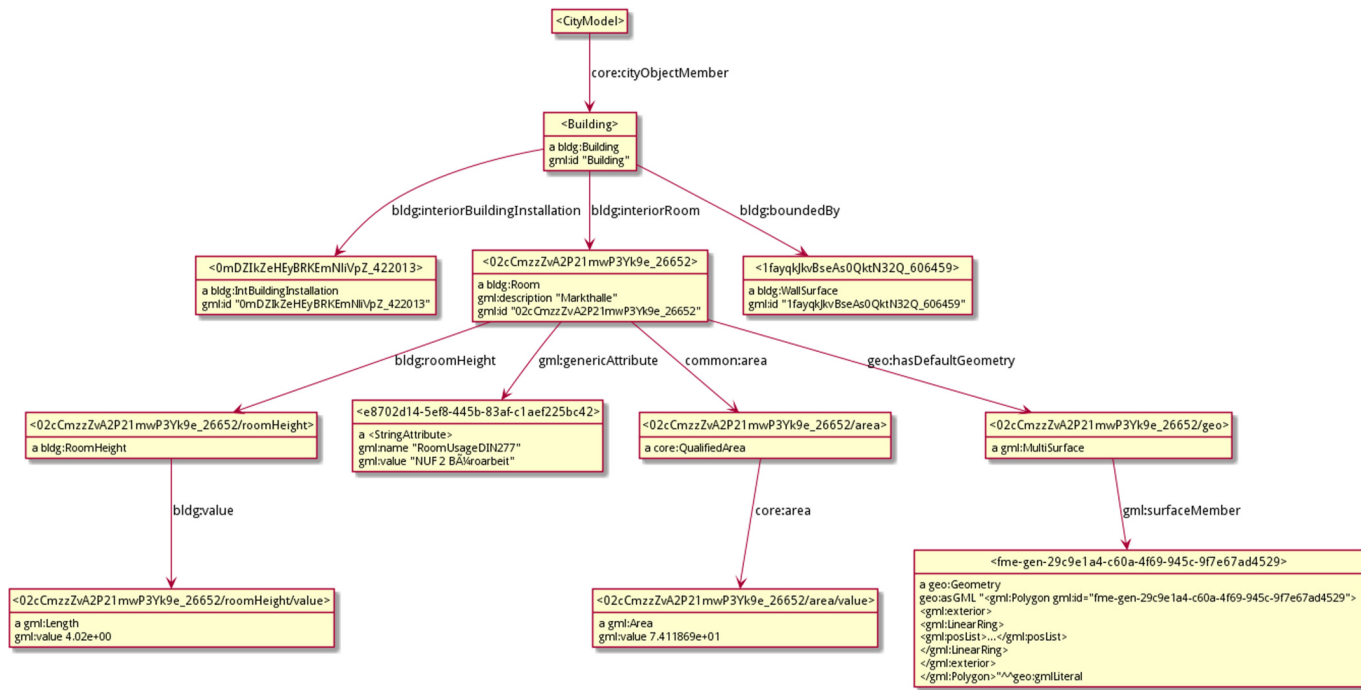


Figure 15.6 CityRDF excerpt for the CityGML file from Figure 15.5 (produced using rdf2rml: <https://github.com/VladimirAlexiev/rdf2rml>).

relationships between parts of both models as well as use other existing query and logical reasoning methods already built into Semantic Web technologies.

Topology relationships between land use parcel geometries and building geometries were described using GeoSPARQL ontology and materialised as subject–predicate–object statements. The resulting joined model allows for spatial reasoning and answering questions about whether parts of the building comply with the regulations applicable to land use parcels containing them or intersecting them, etc.

Unlike the CHEK project, which used reusable SHACL validation profiles defined as OGC Building Blocks, the ACCORD use case implemented compliance checks using custom SPARQL queries and spatial reasoning over a combined RDF model. For example, one of the compliance checks was whether the building is completely inside a land parcel with the allowed usage type. In a SPARQL query (Figure 15.7), it is possible to detect spatial relationships (`geo:sfContains`) and select the necessary usage type (`RoomUsageDIN277 "NUF1"`).

Apart from that, GeoSPARQL also contains corresponding functions allowing us to assess topology relationships on demand in case of less complex or more dynamic models. Materialisation of topology relations as well as various calculations (area, distance from the boundary lines, etc.) were implemented with the help of the Open Source Geospatial Foundation’s GDAL library (Rouault et al., 2025) wrapped in Python scripts.¹⁶

For example, a compliance check “whether the majority (greater than 90%) of the 2D footprint was inside a permitted land parcel” required additional calculation of the 2D footprint area, as the sum of room areas precalculated during IFC-to-CityGML conversion is not equal to the area of the 2D footprint.

First, land use plans as well as concrete city models can be assessed regarding consistency with axioms expressed in the theoretical part (TBox). In addition, it is possible to reason about the interconnected models and assess if building parts are conformant to the planned land use (e.g. percentage of commercial use does not exceed a certain threshold in the residential sector).

```
--base <https://graphdb.apache.org/resource/>/v/v
PREFIX rdf: <http://www.w3.org/1999/02/22/rdf-syntax-ns#>
prefix geo: <http://www.opengis.net/en/geosparql#>
prefix gml: <http://www.opengis.net/gml/#>
prefix xpr: <http://graphdb.apache.org/project/en/resource/xplanung->
select ((?numObj) as ?Result) where {
    select (COUNT(?obj)) as ?numObj) {
        graph Trigraph
        {
            ?g a geo:Geometry . #retrieves all geometries and objects they belong to
            ?parent gml:surfaceMember ?g .
            ?obj geom:hasDefaultGeometry ?parent .
            FILTER (?geom!=TURTLE) . POLYGON(??\|\|([0-1].[8])\\.\|[0-1].[8])\\.\|[0-1].[8])\\.\|[0-1].[8])\\.\|[0-1].[14]\|\|\")} #removes invalid points not detected as within by GML
MINUS { #excludes elements that are known as outside the building but included in the model by error.
    ?obj gml:geometryContribute ?G .
    ?g gml:value ?v .
    FILTER(?v in ("Systemelement:FaeEL_GLA_0025_Versatz000_Aufsatzkonstruktion", "Systemelement:FaeEL_GLA_0025_Versatz000_Aufsatzkonstruktion:7693233", "?BptdHmY4oEayowzu0w?", "IbmkiYrWx"))
MINUS {
    ?pc rdf:type xp:PermissibleLotCoverage .
    ?pc geom:hasDefaultGeometry ?pg .
    ?pg geo:sfcontains ?g . #Subtracts geometries contained in xp:PermissibleLotCoverage geometries
    FILTER(contains(str(?Graph), "12-50ba/rfc"))
```

Figure 15.7 SPARQL query to access specific items from a comprehensive knowledge graph.

In this particular use case, such a combined model allowed to answer, for example, the following questions:

- Whether the building design is contained within a land development plan.
- Whether all parts of the building are contained within permissible lot coverage.
- Whether the residential use of all building rooms does not exceed 5%.
- Whether office use of all building rooms is at least 60%.
- Whether building floor space index does not exceed planned floor space index in land development plan.
- Whether building height falls within the thresholds prescribed by land development plan.
- Whether the building is within heritage protection area.
- Whether the building fits within the planned boundary.
- Whether the majority (at least 90%) of the 2D footprint of the building lays inside the allowed building subarea.

Discussion

The developed semantic uplift, associated to the profile definition and validation, is a data-driven process, where semantic uplift definitions and validation profiles can be “swapped out” with others, making it applicable to many different use cases.

Moreover, CityRDF has effectively provided significant aid in supporting the automation of checking in digital building permits or in other use cases. The need for conversion could therefore be reduced, with consequent reduction of possible generated inaccuracies. CityGML rendition in OWL/RDF ties BIM data with linked urban data, creating highly customisable KGs capable of querying and logical reasoning on the data they store. KG engine providers, such as GraphDB,¹⁷ show practical applicability of the Semantic Web solution for integrating BIM and GIS data, and open the road to deeper adoption.

Some limitations are still present and should be considered for future improvements. xSPARQL is customisable and manually updatable; therefore, if other IFC classes will be used, xSPARQL should be edited, as well as the used FME workflows. The solution obtained in this study was rather tailored to the case study needs, and a generalisation should be applied in the next developments. However, a huge effort was done to bridge the traditional UML/XML model to an optimal semantic model, which can be avoided in future by publishing the results as a canonical implementation standard. Other applications will be able to reuse our results with a fraction of the effort involved. In the OGC Building Blocks, semantic uplift is now limited to SHACL. However, it can be developed programmatically (Python), or with other tools (e.g. xSPARQL, YARRRML,¹⁸ R2RML¹⁹) when XML-to-RDF is necessary. Finally, since uplift definitions and validation profiles are hard to write, shape templates can help in this regard.

Conclusions

Linked Data technologies were effectively used in two critical steps of the building permit digitalisation: First, they supported the semantic validation of data, enhancing trust in the reliability of the following analysis and checks, which is relevant for a legal point of view as well. Second, they facilitated integrated data analysis for the regulations checking.

It is recommended, for future developments, to reuse the existing ontologies as much as possible, with the described method, as well as relying on standard mechanisms for profiles definitions (i.e., no custom software libraries).

The work on the next version of the GeoSPARQL standard (v1.3) is ongoing, to provide better support for typical business operations within domains that make use of geospatial data. The GeoSPARQL working group has identified over 40 use cases from a diverse group of stakeholders. Many of those use cases would require the next version of the standard to provide vocabularies and function definitions specific to 3D geometries and their relationships. This will bring the language closer to enabling BIM/GIS interoperability. Currently, the lack of such functions and vocabularies makes it challenging to provide interoperability without using converters between different formats, which in turn makes typical workflows more cumbersome. Another part of the challenge is that most BIM geometries are not explicit but rather parametric, making interoperability with other representations difficult. Some of the most generic functions identified after collecting the abovementioned use cases, and still expecting geospatial literals as arguments, are already been added to GeoSPARQL1.3 specification.

In future work, the validator application will be generalised and the uplift process will be improved, as well as the support for multiple input types and the validation report display.

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Data Availability

<https://github.com/ogcincubator/cityrdf> CityRDF source and resulting files, workflows for reproducibility, examples of conversion.

<https://github.com/Accord-Project/Tegel-scripts> Python and xSPARQL scripts used in the workflow for ACCORD use case.

Notes

- 1 <https://www.buildingsmart.org/standards/bsi-standards/information-delivery-specification-ids/> Accessed 26/05/2025
- 2 <https://www.w3.org/RDF/> Accessed 05/06/2025
- 3 <https://www.w3.org/TR/shacl/> Accessed 05/06/2025
- 4 <https://www.w3.org/OWL/> Accessed 05/06/2025
- 5 <https://www.w3.org/TR/sparql11-query/>
- 6 <https://www.ogc.org/publications/standard/geosparql/> Accessed 05/06/2025
- 7 <https://blocks.ogc.org> Accessed 05/06/2025
- 8 <https://www.ogc.org/standards/citygml/> Accessed 05/06/2025
- 9 https://xleistle.de/xplanung/ueber_xplanung Accessed 05/06/2025
- 10 <https://accordproject.eu/> Accessed 05/06/2025
- 11 <https://chekdbp.eu> Accessed 05/06/2025
- 12 <https://schema.org/> Accessed 05/06/2025
- 13 <https://ogcapi.ogc.org/processes/> Accessed 05/06/2025
- 14 https://github.com/Accord-Project/Tegel-scripts/blob/main/fme/IFCtoCityGML-lod4city_ACCORD.fmw
- 15 <https://www.w3.org/submissions/xsparql-language-specification/>
- 16 <https://github.com/Accord-Project/Tegel-scripts>
- 17 <https://graphdb.ontotext.com/>
- 18 <https://rml.io/yarrml/>
- 19 <https://www.w3.org/TR/r2rml/>

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16 AI for Building Permitting

Balancing Speed, Flexibility, and Trust

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Introduction

Building permitting is a critical regulatory process designed to ensure that construction projects adhere to all relevant standards, including zoning, safety, and accessibility. Despite its importance, the process is often time-consuming, resource-intensive, and prone to inconsistencies due to the subjective nature of human decision-making (Fauth et al., 2023). Recent advances in Artificial Intelligence (AI) have revolutionized the Architecture, Engineering, and Construction (AEC) industry by enabling faster, data-driven decision-making in design, construction, and maintenance (Zabin et al., 2022). Naturally, this raises the question of how AI can contribute to the building permitting process as well.

In the broadest sense, AI refers to the replication of human intelligence in machines, enabling them to perform tasks that typically require human reasoning. Over time, the focus shifted to a specific category of AI, referred to as “weak AI”, which focuses on performing specific tasks within a limited context (Searle, 1980). This is the practical and applicable side of AI that powers many of today’s technologies and decision support tools, at the heart of which are Machine Learning (ML) algorithms.

The building permitting process involves many decisions made by different stakeholders at different stages. These decisions are not merely technical but demand the balancing of zoning laws, safety codes, and often broader societal goals such as environmental sustainability or politically initiated urban development strategies. What makes it particularly difficult is the complex interplay between codified regulations and the need for interpretation and human judgment. Adding to the challenge is the iterative involvement of a wide array of stakeholders, including applicants, legal advisors, architects, engineers, specialist consultants, planning committees, external technical reviewers, and occasionally the general public, whose differing interests and inputs can reshape project trajectories mid-review.

This characteristic resists full standardisation and automation and contributes to both the subjectivity and unpredictability of outcomes. While AI

promises to streamline aspects of the process, the fundamental complexity lies in these qualitative judgments, interdependencies, and project-specific nuances that are deeply embedded in the regulatory requirements and institutional culture of permitting authorities.

The adoption of AI in building permitting is gaining momentum, with various platforms offering support both to the applicants and to the approving bodies. For the applicants, platforms like permio (permio, 2025) and Govstream.ai (Govstream.ai, 2025) can guide users through the application process, provide instant responses to inquiries, helping applicants navigate complex regulations, and even analyze building plans against zoning laws and building codes before official submission. For the approving bodies, cloud-based building permit management systems such as CivitPERMIT can analyze 2D and 3D plans to detect non-compliance and report to the reviewer (SoftTech Global, 2025). While different platforms are being developed and tested, we have not yet seen widespread implementations of such tools.

Recent literature reviews reveal that most of the efforts in the domain of digital building permit transformation are focused on the integration of Building Information Modeling (BIM) in the process and rule-based systems for automated code compliance checking (Ataide et al., 2023). However, as stated in Bloch and Fauth (2023), the potential of transforming other phases of the permitting process is mostly overlooked. The permitting process involves a broad spectrum of data sources, including application forms, protocols, codes and regulations, etc., most of which are usually presented in an unstructured format like natural language. In addition, much of the geometric information is still provided in the form of images and 2D drawings. Despite AI's ability for processing diverse information types, its applicability to the permitting process remains underexplored. One notable exception is code compliance checking, which has gained significant attention over the years (Alnuzha & Bloch, 2025; Amor & Dimyadi, 2021).

In this chapter, we focus on the activities within the building permitting authorities. Therefore, we consider the building permitting process to begin with the pre-consultation and request application submitted to the respective building permitting authorities (e.g., municipalities, cities, administrative offices) and to end with a decision displayed in an issuance letter of the accepted or rejected building permit (Fauth et al., 2024). Our goal is to highlight the emerging opportunities and the critical challenges of integrating AI into the permitting process to encourage readers to rethink existing workflows in light of the recent technological advancements. We will map the main steps of the building permitting process, identify the key decisions that need to be made at each step, and analyze the data inputs that inform those decisions. By breaking down the process into components, we aim to understand the nature of each decision and the type of information required to support it. This will allow us to explore and propose AI-based tools that could assist (in varying degrees) decision-making.

From Expert Systems to Large Language Models (LLMs) – The Evolution of ML Applications in AEC

AI has evolved from rule-based expert systems starting from the 1960s (Tan et al., 2016) to sophisticated statistical models and deep learning models (LeCun et al., 2015). Each stage has brought new capabilities and applications, culminating in the current stage of pretrained transformer models, such as LLMs.

Among the first successful AI applications were expert systems, which simulated human decision-making using a knowledge base and an inference engine. Driven by the need to improve productivity and efficiency, AI has found its way into the AEC sector as well. In fact, permitting and Automated Compliance Checking (ACC) were among the earliest applications explored (Fenves, 1966). These early systems, usually rule-based expert systems, encoded regulatory requirements into machine-interpretable rules, enabling automated compliance verification. This is still the backbone of the most advanced existing applications for ACC today. A good example is Singapore's CORENET system for permitting, (CORENET X, 2024) although currently rule-based, it is now under further development, aiming to fully streamline the building permit process by utilizing cutting-edge technologies (CORENET X, 2024).

As computational power grew, ML methods emerged, enabling models to learn patterns from data rather than relying on hard-coded human-defined rules. ML usually involves text analysis, image recognition, and predictive analytics. Various ML approaches have been extensively investigated across different phases within the AEC domain, including design, construction, and operation and maintenance (Zabin et al., 2022).

Text analysis derives insights from unstructured text by means such as text classification, information extraction and retrieval, and summarization. In the AEC context, text analysis applications include generating and summarizing bridge reports (Liu & El-Gohary, 2016), classifying problematic statements in construction contracts (Al Qady & Kandil, 2015), retrieving relevant regulations for a specific building type (Lv & El-Gohary, 2016), and converting regulatory requirements into machine-executable formats (Jang et al., 2025; Lv & El-Gohary, 2016).

Computer vision applies ML techniques to visual data, performing tasks such as image classification, object detection, and image segmentation. As described in Paneru and Jeelani (2021), in the AEC domain, such models have been explored for different objectives, including site hazard detection, construction progress monitoring, and structural health monitoring. To give more specific examples, image-based models have been used for automatic identification of construction workers' activities on construction sites (Li et al., 2024) and for detecting defects in concrete (Koch et al., 2015).

Predictive analytics involves forecasting future outcomes based on historical data, encompassing techniques like time series analysis and applying ML models to tabular data. Typical applications in the AEC sector include energy

performance evaluation (Ekici & Aksoy, 2009), cost estimation (Castro Miranda et al., 2022), and many aspects of ACC (Alnuzha & Bloch, 2025).

The interest in Artificial Neural Networks, first introduced in the 1950s, resurged due to improvements in computational power and the availability of large datasets, leading to the rise of deep learning algorithms. With the advent of transformer models (Vaswani et al., 2017), the inherent parallelization capability of the self-attention mechanism allowed for large-scale pre-training of language and vision models using self-supervised training objectives. This pre-training equips models with general domain knowledge without the need for expensive manual labeling, enabling them to perform novel tasks given no, or only a few, examples, which is referred to as zero- and few-shot learning (Brown et al., 2020).

Furthermore, self-supervised training has prompted a paradigm shift from classification-centered approaches toward generative modeling (Raffel et al., 2020). These advances have enabled sophisticated natural language interfaces for interacting with structured data, such as retrieving BIM elements (Zheng & Fischer, 2023), and for autonomously performing complex tasks, such as compliance checking (Ying & Sacks, 2024). Despite the advances described, there are significant knowledge gaps in the application of AI to building permitting.

Envisioned AI-Based Building Permitting

Three potential AI-based solutions that could be envisioned for transforming the permitting process are: the phased approach, the one-shot approach, and the hybrid approach.

Phased Approach

The building permitting process can be divided into key steps, and by understanding the abilities of recent AI developments, we can envision ML solutions integrated into each of the steps. In this approach, AI would be deployed sequentially across the stages of the process. Each stage would focus on narrow and specific tasks, such as checking if the application is complete, assigning the application to a responsible checker, checking if the proposed building fits into the zoning requirements, identifying regulatory issues, etc. At each stage, the user would have the opportunity to interact with the system. This approach ensures transparency, allowing stakeholder involvement throughout the process.

User involvement helps to maintain flexibility within the process. For instance, if the system classifies an application as one that requires exceptions from the development plan, the user could be given the freedom to decide whether to grant the exception or not. Afterward, the application could continue seamlessly to the next step within the system. This approach allows the user to retain control over critical decisions while still benefiting from the system's ability to handle routine cases.

Table 16.1 presents the main process steps within the building permitting process, as identified in the work of Fauth et al. (2024) and further described in

Table 16.1 Main Process Steps Matched with Possible AI Solutions

<i>Process Steps</i>	<i>Decision</i>	<i>Data</i>	<i>AI Solutions</i>
Pre-consultation	Whether the project concept is viable and aligns with preliminary regulations.	Text descriptions, sketches	A system based on LLM/Vision Language Models (VLM). This could be a chatbot or a question-answer system to engage with applicants. The system would provide insights into zoning requirements, initial suggestions for involved agencies, what type of permitting procedure is relevant, the building class, planning requirements, heritage considerations, etc.
Submission and Administrative check	Whether the submission is complete and formatted correctly.	Application forms, documents, and design (2D or 3D)	A system based on supervised ML, NLP, and computer vision (in the case of a 2D-based submission) for information extraction and classification tasks. The system could be used for pre-filling application forms (applicant information, plot information, building information, etc.), validating the completeness of the application, checking that the application is classified into the correct type of procedure (permitting track).
Assignment	Assign the application to the relevant authority, department, or officer for review.	Project information, jurisdictional boundaries, department specializations, staff workload/capacity data	Recommender system or classification algorithms. Evaluating the experience of personnel relevant to the application, classifying application complexity, and scheduling (based on workload).
Participation of other agencies	Determine which of the public agencies should be involved.	Design documents (2D or 3D), regulations, reports	Classification system, LLM. Provide a list of relevant agencies based on project information. Identify previous similar cases to suggest a list of involved agencies.
Participation of the public	Decide if design changes are needed based on public feedback.	Letters, meeting transcripts, petitions, simplified design (2D or 3D)	Classification system, LLM. For the publication stage, the system could help identify the individuals who might be affected by the proposed design. For example, a chatbot to facilitate communication with the public. The system would help individuals understand how the proposed design might impact the built environment and ultimately help individuals decide if they want to submit objections. It could also assist in drafting and submitting the objections.

(Continued)

Table 16.1 (Continued)

<i>Process Steps</i>	<i>Decision</i>	<i>Data</i>	<i>AI Solutions</i>
Content check	Determine if the design complies with zoning, planning, and technical regulations.	Design documents (2D or 3D), regulations, reports	Supervised learning, NLP, LLM. At the core of this stage is the code compliance checking process which could be assisted by ML implementations, for example for performance-based regulations and ambiguous regulations. Additionally, for dealing with exceptions, the system could identify similar cases where exceptions were requested and the conditions for granting them.
Issuing a notification	A collective decision of all previous decisions.	Application documents, checking results, plans, images, laws, and regulations	Report generation with a multimodal LLM (MLLM). This system would collect all results from previous stages, summarize them, and generate a final report. The system would also provide references to the laws and regulations relevant to decision-making.

Fauth et al. (2025), and suggests possible AI solutions for every step. In all the proposed solutions, the system would support the applicants on one side and free many of the authorities' resources on the other.

Beyond the reduction of the required manual effort and processing time (compared to the conventional manual workflows), one of the benefits of an AI-based system is that it can increase consistency in decision-making. Once the decisions are made automatically, based on the system's recommendation, subjective evaluation of the applications is removed.

One-shot Approach

The one-shot solution would aim to simplify and fully automate the building permitting process by handling all data in a single step, providing a final decision in a single output: approved, rejected, or flagged for further review. This means that the AI ingests all application materials, such as forms, plans, 3D models, and any relevant contextual information, such as the planning and building law, in one go. One of the main difficulties in such a scenario is that this holistic AI agent would have to handle a variety of data types, including text data, images, geospatial data, building information, etc. In other words, it would have to handle both structured and unstructured data.

In practical terms, such a scenario could be achieved using expert systems or multimodal LLMs (MLLMs). However, due to the limited context length of transformer models and the extensive size of the relevant information, substantial data compression would be required during the embedding process, which can inadvertently lead to the loss of crucial detail and thereby impair the accuracy of the MLLM's outputs.

To mitigate this, hierarchical information processing could be envisioned. In this approach, distinct aspects of the scenario would be encoded as specific tokens at various granularities. For example, dedicated tokens could represent different views of a site, the overall building structure, individual storeys, and discrete administrative or technical requirements. Within the MLLM's transformer layers, these requirement tokens would then be able to attend to tokens representing design models, building views, and other relevant application data. This interaction would allow the system to determine the compliance status for each requirement, forming the basis to make the final decision, ideally accompanied by a trustworthy reasoning trace.

While this hierarchical methodology appears conceptually sound, its practical and effective implementation hinges on significant future technological advancements.

The key difference between this approach and the phased approach is that there is a single output that is received after processing all the relevant data. While this has the potential to drastically reduce the processing time and the manual labor for applications, the main drawback is the lack of transparency, which is expected to affect the level of trust of the stakeholders in the systems.

That also means that the individual steps are not transparent to the user, and the participation of the public and other agencies becomes difficult. Recent scientific literature highlights the growing importance of explainable AI across various domains (Saarela & Podgorelec, 2024). The National Institute of Standards and Technology (NIST) (Phillips et al., 2020) has defined four fundamental principles for explainable AI.

- 1 Explanation: A system delivers or contains accompanying evidence or reason(s) for outputs and/or processes.
- 2 Meaningful: A system provides explanations that are understandable to the intended consumer(s).
- 3 Explanation Accuracy: An explanation correctly reflects the reason for generating the output and/or accurately reflects the system's process.
- 4 Knowledge Limits: A system only operates under conditions for which it was designed and when it reaches sufficient confidence in its output.

These principles are designed to build trust and confidence in AI systems. While many researchers are investigating these issues in a variety of domains, recent reviews have not identified work on the subject in the AEC domain (Saarela & Podgorelec, 2024). While building trust in a system is difficult, losing trust is also an issue that has to be addressed. Research in the robot-human interaction field (Esterwood & Lionel, 2023) shows that trust is steadily eroded when violations occur. They studied a range of strategies to repair trust and determined that while most strategies helped repair trust in the system, none of the strategies rebuilt trust to the level before the violations occurred. In the expectation that similar results would hold in automated permitting systems, this argues for highly accurate systems from the outset, paired with in-built trust repair strategies for the times that the system produces incorrect outcomes.

Hybrid Approach

Rather than consuming all data at once, a hybrid human-AI collaboration could be more feasible. This could be achieved through a fully streamlined building permitting process where the human is involved at predefined points, potentially whenever a step is completed or when there is uncertainty in decisions or a complex case. Alternatively, one could imagine more loosely defined multi-agent frameworks where the AI system iteratively walks through the required process steps, retrieves the relevant information, and evaluates its completeness and correctness. The system could be free to seek human input only when it deems necessary. The full execution trace would be available and could eventually be summarized into a compliance report. This would meet at least two of the NIST principles, providing explanations that are also meaningful. However, there is the danger that the outputs become too long and overwhelm any attempts to contest them. Regarding the explanation accuracy, it is debatable how trustworthy reasoning traces from current-day LLMs actually are. For example, Stechly et al. (2025) showed that the correctness of reasoning traces does not necessarily

reflect the correctness of the final answer. Similarly, Lindsey et al. (2025) showed that the LLMs might produce unfaithful reasoning paths if biased to a certain outcome or if they resort to fabricating information due to knowledge gaps. If assistance is frequently requested for low-impact decisions, there is a growing risk of review blindness in the human expert. If too much trust is placed in the AI system, erroneous decisions may go undetected. This delicate balance between humans and AI is still to be investigated and defined.

Discussion and Conclusions

As AI tools become more sophisticated, their potential to improve efficiency, consistency, and speed in the building permitting process becomes widely recognized. However, the pace of AI adoption in the building permitting process seems to be lagging behind other applications. We see a wide range of AI-based tools already widely adopted across various stages of the construction lifecycle. This raises an important question: what makes the building permitting process so different?

For any type of decision support system (let alone a decision-making system), concerns around trust, privacy, safety, fairness, transparency, and explainability must be addressed. This is especially important in high-stakes contexts like permitting, where decisions have legal, financial, and societal impacts. As such, a human-in-the-loop strategy is preferred in order to allow oversight, accountability, and confidence in automated processes. Pursuing a “one-shot” implementation where AI is expected to take over the entire workflow in a single leap may speed up the process tremendously, but it introduces risks and may lead to a mistrust of the system. Developing and maintaining trust is a crucial aspect in this context. Higher levels of trust require the involvement of the user; therefore, envisioning an AI system for permitting involves a “human-machine” relationship, a collaboration that aims to leverage the strengths of both (see organizational decision-making, for example, Jarrahi, 2018). This type of collaboration has not yet been sufficiently explored in the AEC domain in general and in permitting processes in particular.

It's All About Trust

Based on Edwards et al. (2000), the role of AI in the decision-making process can be broadly categorized into two groups: supporting human decision-makers and replacing them. Trust plays a crucial role in the adoption of AI-powered tools in the industry. As reported in the work of Emaminejad et al. (2021), there are several factors that affect trust in AI. All of these factors are particularly important to consider in the context of AI-powered permitting:

- 1 Transparency and explainability – trust depends on users being able to understand how AI makes decisions. One of the greatest difficulties is the “black box” nature of many of the AI models. In the context of building permitting, we can assume that systems that are able to provide justifications for their decisions (or recommendations) are more likely to be trusted by users.

- 2 Privacy and security – the building permitting process involves the collection of data that includes design documents, personal information, and potentially financial details. Trust in an AI-based system means that mechanisms are in place to ensure data privacy and security.
- 3 Safety and reliability – although these concepts have been mostly referred to in research that involves human-robot interaction, safety issues must be addressed in the building permitting process as well.
- 4 Ethics and fairness – one major risk is that biases present in the training data can lead to unfair recommendations and decisions. This could lead, for example, to favoring specific developers over others. According to Bastidas et al. (2025), ethics and fairness are critical concerns in the digitalisation of processes in the planning and building authorities. Fairness demands that decisions remain understandable, inclusive, and free from discrimination, ensuring that all applicants are treated equitably.
- 5 Human-centered technology – there seems to be a perception in the industry that AI-based tools are designed to replace the existing workforce, or, in our case, to replace decision-makers. However, AI systems do not have to replace the decision-makers; they can be designed as decision support systems.
- 6 Benevolence and affect – some research in behavioral studies has reported that the level of trust can increase if the AI systems and humans can “bond”. It is driven by social elements and “human-system” interactions (Pitardi & Marriott, 2021). In a way, this is now becoming possible with the ability to interact with the systems through natural language. In this case, a user-friendly, transparent interface could make the difference.

While we recognize the importance of trust in AI-driven permitting and understand the parameters that enable it, these very parameters can sometimes counteract the efficiency gains that we seek to deliver through these AI-powered systems. For example, ensuring transparency and explainability means the system cannot function as a black-box “one-click approval” tool. Users must still be involved in verifying outputs and making final decisions, which slows down the process. There is a fundamental trade-off: greater automation enables faster processing but reduces human control, while increasing transparency and oversight fosters trust but complicates and slows decision-making. Striking the right balance requires designing AI systems that automate where possible but involve human oversight where necessary.

Outlook and Open Questions

AI contributes speed and data processing capabilities, and humans provide contextual understanding and creativity. The challenge is in finding the balance between human and AI decision-making. In the building permitting domain, we have not yet begun to explore what this relationship should look like. Of course, as a first step, it is important to understand what kind of tasks AI is capable of handling in this context. In this chapter, we outline the potential of

different AI-based support tools across the various steps of the permitting process, based on our knowledge and understanding. Each type of suggested application must be further investigated to understand its actual applicability, limitations, and the feasibility of providing the envisioned solution.

We believe that we should not strive to replace human oversight with AI but rather enhance human abilities. An AI system should act as a decision support tool rather than a decision-maker. As already mentioned, we do not yet have a clear understanding of how responsibilities should be shared between automated systems and human experts. This integration demands further exploration and understanding of the repetitive and data-intensive tasks that AI can handle, while humans address ambiguities and exceptions. Of course, some low-level decisions could be safely made, which leads to the need for a deep classification of the tasks themselves. A multi-dimensional classification system should address the complexity of the task, its dependencies on different data types, the legal or ethical considerations, the level of repetitiveness and risk. Such a classification framework could provide guidelines on what types of decisions may be delegated to AI, under what conditions, and with what levels of human supervision. Following this framework, different AI tools can be implemented and further evaluated. The evaluation process should be closely tied to the organizational and procedural context. It is not enough to evaluate simply the performance of these tools for specific tasks; we must also understand what evaluation metrics are expected by the experts.

While describing the envisioned AI-powered permitting system, additional key questions surfaced:

- When looking at current review results as performed by human experts, we may uncover human errors. How can AI systems build on that? Will the AI mimic the “bad decisions”?
- What is the level of trust needed by different stakeholders in order to adopt AI-powered systems in permitting? And can we measure that?
- What kind of organizational changes will be needed to adopt AI-based solutions in permitting? Will it require additional roles to be involved in the processes (specialist IT support for example)?
- The type of data in the process (BIM or CAD) has a tremendous effect on the types of AI systems to develop. Should we try to support the current practice of the countries lagging behind or forget the 2D format and focus only on recent advancements?
- Documents such as regulations often have gray areas that require interpretation by a human expert. As AI-based systems are often very bad at “knowing what they don’t know”, how will the system deal with that? How can we systematically decide when an issue must be resolved by a human expert?

To conclude, AI holds great promise for supporting the complex building permitting process. Potentially, AI implementations could speed the process, streamline and reduce repetitive tasks, enhance consistency, and support

decision-making in all steps. However, the success of such an application does not depend only on technological developments. It requires a clear strategy for balancing human judgment with machine assistance, including reevaluation of steps, roles, and responsibilities. Most importantly, automation for the sake of it should not be our priority. Instead, we should aim for a system that supports the human expert instead of replacing them.

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17 AI-Driven Interpretation of Regulatory Documents Using NLP & LLMs

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Introduction

Compliance checking is integral within the Architecture, Engineering, and Construction (AEC) sector to ensure the safety, stability, reliability, and usability of building designs. Conventionally, compliance checking relied on manual methods, which proved to be labour-intensive, time-consuming, expensive, and error prone (Fuchs & Amor, 2021). Thus, there has been a significant shift towards Automated Compliance Checking (ACC), which has been extensively studied over the past 50 years (Zhang, Ma, & Nisbet, 2023). The aim of ACC is to enhance the accuracy and productivity of compliance-checking processes while addressing the shortcomings of manual approaches and meeting the evolving demands of the industry.

Primarily, compliance checking is a twofold process. Initially, it requires identifying the relevant building codes or regulatory requirements applicable to a building design, followed by verifying compliance against these requirements. Comparatively, the second phase is less challenging for automation, given that modern building designs are typically generated using computer software, resulting in digital or machine-processable formats. However, a significant challenge arises from the fact that building codes are mainly written in textual documents intended for human consumption, such as domain experts. Natural languages are hard for computers to process automatically because of their unstructured nature and the complexities of human-centred design (Manning, Raghavan, & Schütze, 2008). These challenges are further amplified in the regulatory texts by their complex structures, ambiguities, and domain-specific characteristics. Thus, in enabling ACC, formalising or interpreting the information conveyed in regulatory text into machine-processable formats has emerged as a pivotal and complex phase (Zhou, Zheng, Lin, & Lu, 2022).

To address this critical need, previous research within AEC has proposed various approaches for rule formalisation from text. In early work, manual methods were popularly used for this task due to the complexities associated with text and domain-specific demands (Beach, Rezgui, Li, & Kasim, 2015; Hjelseth & Nisbet, 2011). However, the labour-intensive nature of manual approaches and their limitations in efficiently supporting ACC

promoted automating information extraction utilising Natural Language Processing (NLP) and Machine Learning (ML) techniques. Starting with the rule-based approaches (Zhang & El-Gohary, 2016; Zhou & El-Gohary, 2017), this shift has gradually evolved into adapting deep learning techniques, such as Bidirectional Long Short-Term Memory and Convolutional Neural Network architectures (Wang & El-Gohary, 2021; Wang & El-Gohary, 2023), over the past years.

Continuing this trend and leveraging recent advancements in NLP, an AI-powered rule formalisation suite was developed as part of the ACCORD project. Within the NLP domain, there has been a clear shift towards neural language modelling approaches, which employ advanced text encoding and decoding mechanisms and are successfully applied across a wide range of applications (Hettiarachchi, Adedoyin-Olowe, Bhogal, & Gaber, 2023; Plum, Ranasinghe, Jones, Orasan, & Mitkov, 2022). During this transformation, both Pre-trained Language Models (PLMs) and Large Language Models (LLMs) have gained significant attention due to their strong language understanding capabilities (Minaee et al., 2024). Building on these advancements, a range of language model-based approaches were explored in the development of ACCORD's rule formalisation suite. This chapter provides a comprehensive overview of these design and implementation approaches, together with the key findings and future insights.

Pre-trained Language Models for Rule Formalisation

We constructed our approach based on PLMs, focusing on two fundamental information types available in the text: (1) entities and (2) relations, which altogether shape the semantics in natural language (Jurafsky & Martin, 2009). An entity is a concept mentioned in the text that can be categorised or, simply anything that can be identified using a proper name. For example, “gradient” and “five per cent” represent entities in the sentence “The gradient should not exceed five per cent”. A relation is a semantic connection or association between entities in the text. In the same sentence mentioned above, there is a “less-equal” relation between “gradient” and “five per cent”. Jointly, these entities and relations capture the rule(s) expressed in the text.

We also observed that entities and relations fall well within the strengths of PLMs, which have demonstrated superior performance in text classification, including general named entity recognition and relation extraction, often achieving state-of-the-art performance (Plum et al., 2022; Shen et al., 2023). Moreover, entities and relations can be organised into a knowledge graph, representing rules expressed in text, streamlining ACC. Although knowledge graphs are intermediate representations between natural language and formal rule languages (e.g., SPARQL), they are intuitive, being ideal for human-in-the-loop reviews and resolving text ambiguities, facilitating automatic conversion into structured rules.

Methodology

Overall, our approach follows a four-step pipeline, as illustrated in Figure 17.1. It takes a regulatory sentence as input and generates an entity-relation graph as the final output. It also generates intermediate outputs, such as entities and relation tuples, to improve transparency at each stage and enhance the overall explainability of the process. The entity and relation classifiers are ML models based on language model architectures, leveraging the knowledge embedded in pre-trained models. The entity pairer and graph builder are integrated as connecting components to transform data formats between stages to enable smooth data flow within the pipeline.

Entity Classifier: We adapted the transformer-based sequence labelling architecture, shown in Figure 17.2, for entity classification, following its remarkable results (Devlin, Chang, Lee, & Toutanova, 2019; Hettiarachchi et al., 2023). To align with this architecture, we framed entity classification as a sequence labelling problem. We used the popular BIO (Beginning, Inside, Outside) format, which is considered the standard for information extraction, (Ramshaw & Marcus, 1995) to format labelled data (or model output) while using raw text as model input. An example of this data format is shown in Figure 17.3.

Relation Classifier: We adapted the architecture shown in Figure 17.4 for relation classification, building on recent advancements in the NLP field (Baldini Soares, FitzGerald, Ling, & Kwiatkowski, 2019; Plum et al., 2022). Following the aim to identify the semantic connection between an entity pair, we incorporated four special tokens into the input: <e1> and </e1> to mark the start and end of the first entity, and <e2> and </e2> for the second entity, as illustrated in Figure 17.5. From the output layer, embeddings of <e1> and <e2> were extracted as linguistic representations of the two entities to facilitate the relation classification.

Dataset

We evaluated the proposed approach using the CODE-ACCORD dataset (Hettiarachchi et al., 2025). It contains 862 regulatory sentences sourced from building regulations in England and Finland. Each sentence is annotated with entities and their relations, enabling the construction of corresponding graph representations.

The dataset includes four entity categories (listed in Table 17.1) and ten relation categories (listed in Table 17.2), following a simple structure to support generalisability and versatile information capture across different regulatory subdomains.

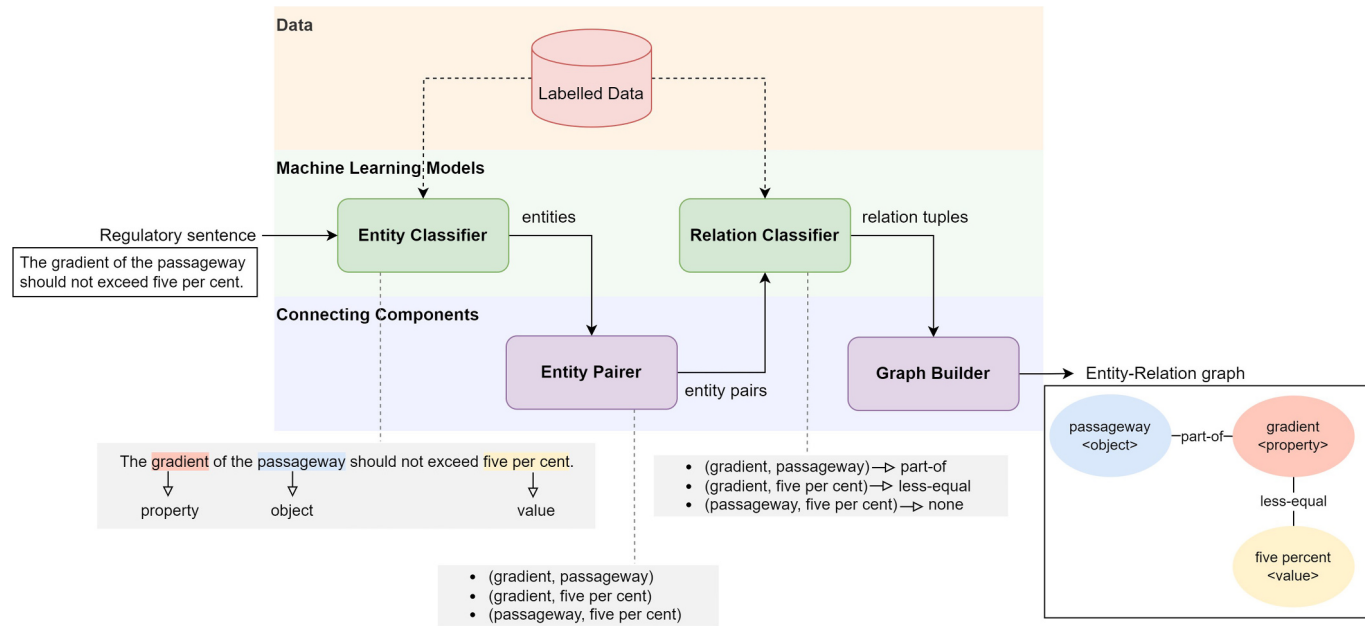


Figure 17.1 Overview of language model-based approach.

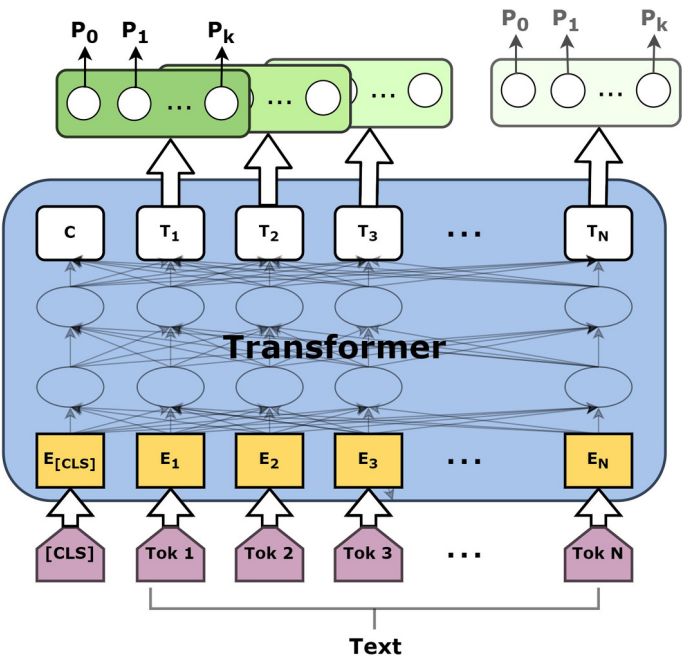


Figure 17.2 Entity classification architecture.

Output/Labelled sentence	O	B-object	I-object	O	O	B-quality	O	B-quality	O
Input/Raw sentence	A	fire	door	must	be	self-closing	and	self-bolting	.

Figure 17.3 Entity-labelled regulatory sentence in BIO format.

Table 17.3 presents a few annotated sentences from the CODE-ACCORD dataset. We used the entity-annotated data to fine-tune the entity classifier and the relation-annotated data to fine-tune the relation classifier, targeting each model’s respective task. The data distributions across different entity and relation categories are visualised in Figures 17.6 and 17.7, respectively. Altogether, CODE-ACCORD comprises 4,297 annotated entities and 3,329 relations across all the categories (Table 17.3).

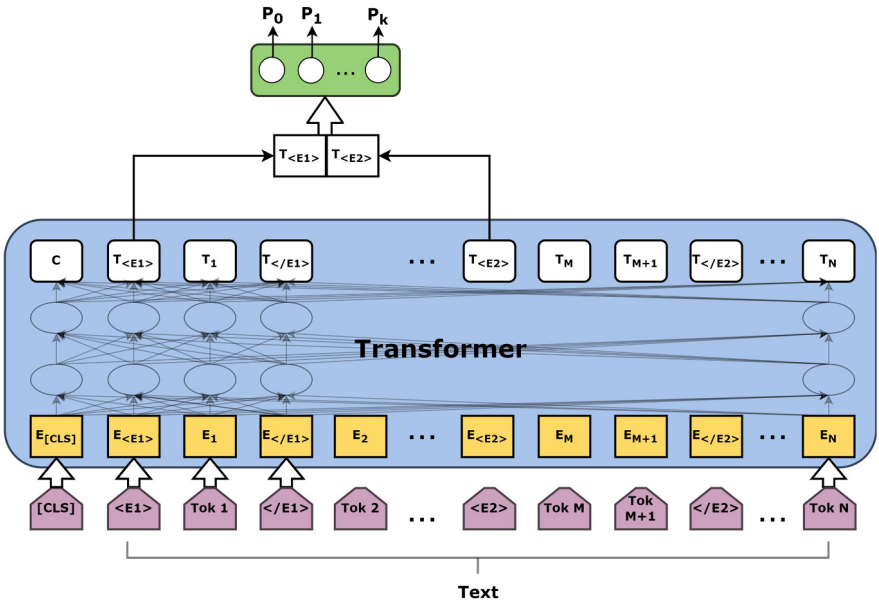


Figure 17.4 Relation classification architecture.

The $\langle e1 \rangle$ fire door $\langle /e1 \rangle$ must be $\langle e2 \rangle$ self-closing $\langle /e2 \rangle$ and self-bolting.

Figure 17.5 Sentence with entity markers provided as input to the relation classifier.

Table 17.1 Entity Categories. A Colour Theme is Used to Enhance the Clarity of Annotation Samples Given Below

Category	Description
Object	An ontological concept which represents a thing that is subject to a particular requirement (e.g., window, fire door)
Property	Property of an object (e.g., width, height)
Quality	Quality or uncountable characteristic of an object/property (e.g., horizontal, self-closing)
Value	A standard or a numerical value that defines a quantity (e.g., 1,500 millimetres, five per cent)

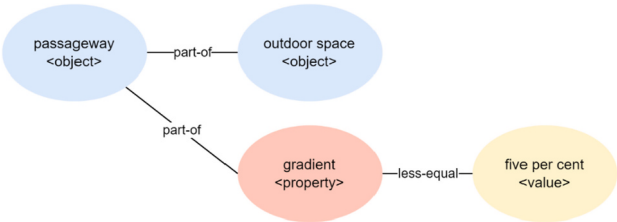
Table 17.2 Relation Categories

Category	Description
selection	A limit to the scope of an object/property based on another object, a quality or a user
necessity	A qualitative/subjective or existential necessity of an object/property (e.g., should, should have, shall be, etc.)
part-of	Being a part of an object/property
not-part-of	Not being a part of an object/property
greater	A value that should be greater than to
greater-equal	A value that should be greater than or equal to
equal	A value that should be equal to
less-equal	A value that should be less than or equal to
less	A value that should be less than to
none	No relation

Table 17.3 Annotation Samples from CODE-ACCORD Dataset

Original Sentence	Entity Pairs	Relation
The gradient of the passageway located in an outdoor space may not exceed five per cent.	The <property>gradient</property> of the <object>passageway</object> located in an outdoor space may not exceed five per cent.	part-of
	The gradient of the <object>passageway</object> located in an <object>outdoor space</object> may not exceed five per cent.	Part-of
	The <property>gradient</property> of the passageway located in an outdoor space may not exceed <value>five per cent</value>.	less-equal

Entity-relation Representation



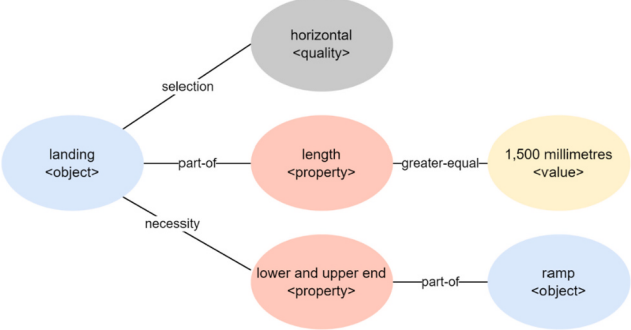
There shall be a horizontal landing with a length of at least 1,500 millimetres at the lower and upper end of the ramp.	There shall be a <quality>horizontal</quality> <object>landing</object> with a length of at least 1,500 millimetres at the lower and upper end of the ramp.	selection
	There shall be a horizontal <object>landing</object> with a <property>length</property> of at least 1,500 millimetres at the lower and upper end of the ramp.	part-of

(Continued)

Table 17.3 (Continued)

Original Sentence	Entity Pairs	Relation
There shall be a horizontal landing with a <property>length</property> of at least <value>1,500 millimetres</value> at the lower and upper end of the ramp. There shall be a horizontal <object>landing</ object> with a length of at least 1,500 millimetres at the <property>lower and upper end</property> of the ramp. There shall be a horizontal landing with a length of at least 1,500 millimetres at the <property>lower and upper end</ property> of the <object>ramp</object>.	horizontal <quality>	greater- equal
	length <property>	necessity
	lower and upper end <property>	part-of

Entity-relation Representation



Results and Discussion

We involved four PLMs: BERT-Large (bert-large-cased) (Devlin et al., 2019), RoBERTa-Large (roberta-large) (Liu et al., 2019), ALBERT-Large (albert-large-v2) (Lan et al., 2020), and ELECTRA-Large (electra-large-discriminator) (Clark, Luong, Le, & Manning, 2020), pre-trained on English text for our experiments. These models are popular within the NLP community and showcase distinct characteristics following their different pre-training settings. RoBERTa is an optimised variant of BERT designed for improved performance, while ALBERT offers a lighter, more efficient version with reduced model size. ELECTRA uses a token discrimination-based approach for more efficient training. We obtained all the models from Hugging Face’s model repository (Wolf et al., 2020).

All model architectures were fine-tuned for the targeted classification task using the same hyper-parameter setting to ensure a fair comparison and

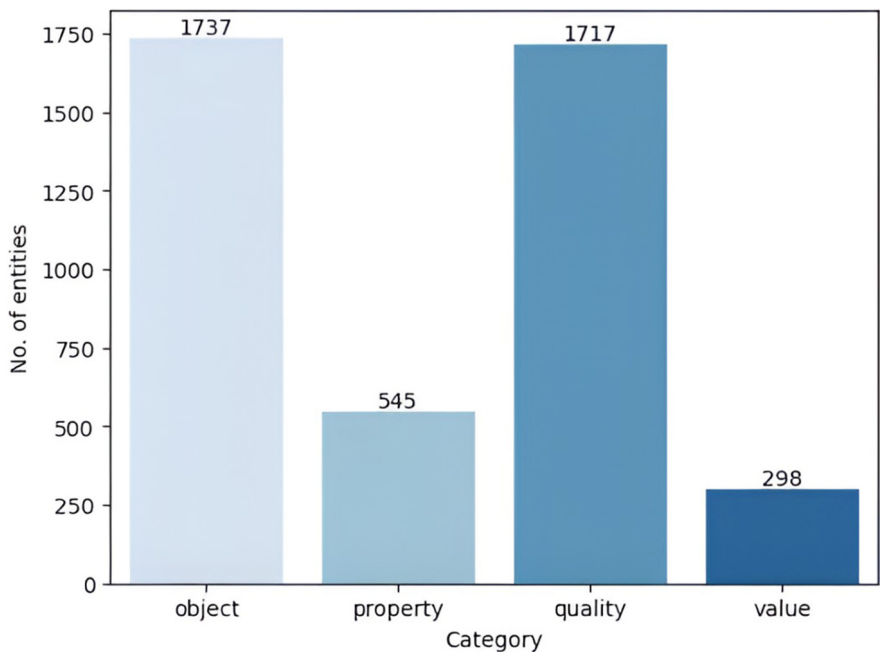


Figure 17.6 Distribution of entity categories in the CODE-ACCORD dataset.

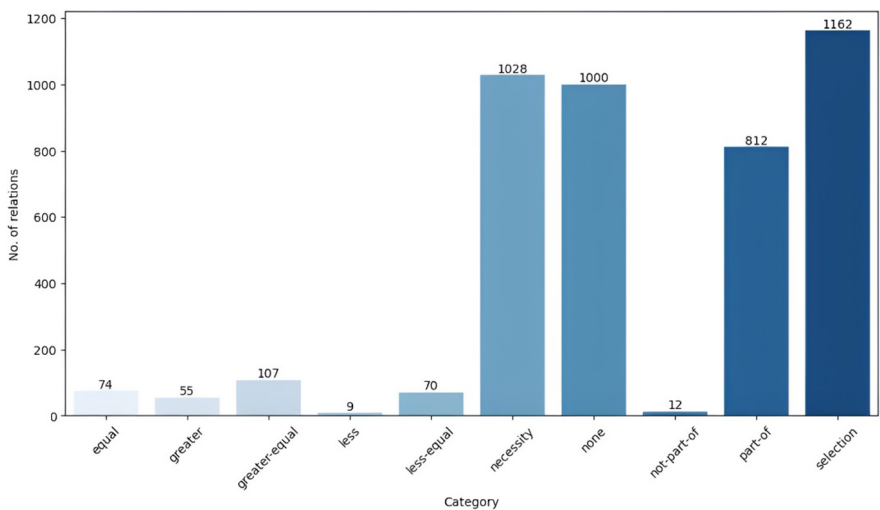


Figure 17.7 Distribution of relation categories in the CODE-ACCORD dataset.

establish a consistent baseline for the experiments. Each model was trained on five epochs with a batch size of 16. We used the Adam optimiser with a learning rate of $1e^{-5}$. During fine-tuning, each model was validated on 10% of the training data, while the remaining 90% was used for training. We allowed 5–15 evaluations per epoch depending on the training data availability. To ensure efficient use of computational resources, early stopping was applied with a patience of ten evaluation steps.

We mainly used precision, recall, and F1, the standard metrics for classification tasks, to evaluate the model performance. For entity evaluation, we used the seqeval framework with strict mode on BIO format to compare the entity spans (Nakayama, 2018). All metrics were macro-averaged across categories, reflecting the equal importance of each category.

Entity Classifier’s Performance: The performance of the entity classifier across four PLMs is summarised in Table 17.4. The validation F1 scores ranged from 57% to 64%, whereas the test F1 scores showed a slight decrease, ranging from 47% to 62%. Since the model is fine-tuned based on validation results, it is expected to perform better on the validation set than on unseen test data. Among the PLMs, RoBERTa-Large achieved the best overall performance. On average, it outperformed the other models by approximately 4% in validation F1 and 8% in test F1, indicating its stronger capability to capture entity-related patterns.

Relation Classifier’s Performance: The performance of the relation classifier across three PLMs is summarised in Table 17.5. We excluded ELECTRA-Large from these experiments, following its low performance in entity classification. Overall, the F1 scores for both the validation and test sets ranged from 51 to 59% and 51 to 55%, respectively. Similar to the trend observed in entity classifier results, the validation results are slightly more accurate than the test results, reflecting the effect of model tuning based on validation performance.

Discussion: The PLM-based architectures mentioned above have consistently achieved over 75% F1 scores in general named entity recognition and relation extraction tasks (Hettiarachchi et al., 2023; Plum et al., 2022).

Table 17.4 Performance Evaluation of the Entity Classifier Using Various PLMs

<i>PLM</i>	<i>Validation</i>			<i>Test</i>		
	<i>P</i>	<i>R</i>	<i>F1</i>	<i>P</i>	<i>R</i>	<i>F1</i>
BERT-Large	0.6182	0.5448	0.5686	0.6288	0.5446	0.5694
ELECTRA-Large	0.6838	0.5486	0.5964	0.5633	0.4468	0.4740
ALBERT-Large	0.6708	0.5841	0.6219	0.6270	0.5354	0.5703
RoBERTa-Large	0.6352	0.6427	0.6379	0.6281	0.6197	0.6212

The best F1 score is marked in bold.

Table 17.5 Performance Evaluation of the Relation Classifier Using Various PLMs

PLM	Validation			Test		
	P	R	F1	P	R	F1
BERT-Large	0.6129	0.4887	0.5144	0.5714	0.5029	0.5243
ALBERT-Large	0.6332	0.5393	0.5590	0.5592	0.4978	0.5122
RoBERTa-Large	0.6099	0.5895	0.5903	0.5577	0.5481	0.5498

The best F1 score is marked in bold.

Additionally, similar entity classifiers applied within the AEC domain, particularly in focused subdomains such as fire protection, have demonstrated stronger performance, often exceeding a 70% F1 score (Zhou et al., 2022). However, our experiments received comparatively lower results.

This performance gap can be mainly attributed to two factors. First, although general-purpose PLMs can understand general contexts well, they struggle to capture domain-specific nuances relevant to AEC regulations. Second, the data we experimented with were designed to be broader, spanning multiple subdomains in AEC, adding complexity to the classification process. It is essential to focus on a wider scope rather than targeting a single well-defined subdomain to assess the general applicability and practical aspects of the models.

Our results indicate the potential of language models for rule formalisation, especially considering the general pre-trained knowledge of the experimented models and the limited annotated data used for training. They mainly suggest that it is essential to either incorporate domain-specific knowledge into language models through additional pre-training on relevant corpora or to provide the model with a larger volume of annotated data for more effective learning, in order to improve model performance and meet the practical needs of ACC.

Large Language Models for Rule Formalisation

We adapted more complex input and output formats with our LLM-based approach, following LLM’s advanced capabilities. Instead of continuing with the pipelined approach used in our above experiments, which involved language models fine-tuned for narrowed-down downstream tasks, we chose to explore the emergent capabilities of LLMs in addressing the practical challenges of rule formalisation.

We aimed to automate the RASE annotation process using LLMs. RASE is a widely recognised approach in AEC to capture regulatory information from text blocks together with their underlying logic and causal structures (Hjelseth & Nisbet, 2011). It converts regulatory text into well-defined logical rules, capturing their structure and semantics to support ACC. However, RASE was commonly used as a manual annotation approach by domain

experts, considering its complex nature and requirements to resolve linguistic ambiguities related to AEC regulations (Beach et al., 2015).

Methodology

Our approach included a single step which directly transforms regulatory text into RASE annotations, as shown in Figure 17.8. Free text in the chapters or sections of the approved documents was passed as input to automatically generate a structured YAML format with annotations named Building Compliance Rule Language (BCRL).

BCRL format was proposed as a part of the ACCORD project, building on RASE annotations (Dridi et al., 2023). It mainly encapsulates the document structure and regulatory information. The document structure is represented by elements, such as titles, sections, paragraphs, and bullet points, which are organised in a nested YAML format, reflecting their hierarchical structure in the document. Each of these elements is annotated with appropriate RASE annotations, covering four primary operators: R-requirement, A-applicability, S-selection, and E-exception, along with their metadata, object, target/property, comparator, value, and unit. Altogether, BCRL provides a comprehensive structure that can be directly converted into logical rules. A sample input text and its corresponding BCRL-formatted content are shown in Figures 17.9 and 17.10.

As the LLM, we chose OpenAI’s GPT-4o model considering its advanced nature (OpenAI, 2023). Also, our initial experiments indicated that GPT-4o outperforms other LLMs, including open-source models, further supporting our model selection. We tested GPT-4o’s capabilities following two popular avenues: few-shot learning and fine-tuning. Few-shot learning assesses the

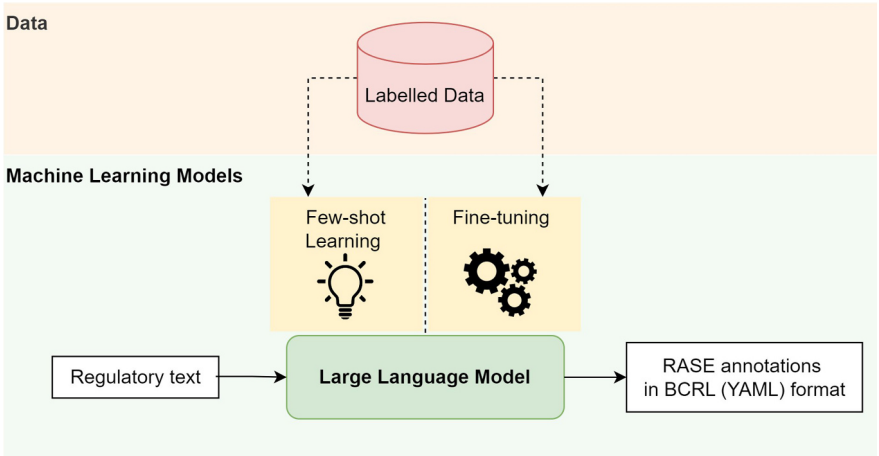


Figure 17.8 Overview of large language model-based approach. Sample input regulatory text and output RASE annotations are illustrated in Figures 17.9 and 17.10.

Provisions

1.13 A 'level approach' (from the boundary of the site and from car parking spaces designated for disabled people to the principal entrance, to a staff entrance or to an alternative accessible entrance) will satisfy Requirement M1 or M2 if:

- a. it has a surface width of at least 1.5m, with passing places, free of obstructions to a height of 2.1m;
- b. passing places at least 1.8m wide and at least 2m long are provided within sight of each other (the width of the passing place may be included in the width of the level approach), but in any case spaced at a distance no greater than 50m;

Figure 17.9 Text snippet from England's building regulation: Access to and use of buildings – Volume 2.

model's capacity to perform a task using its pre-trained knowledge and a few samples seen via the prompt. Contrarily, fine-tuning updates the model parameters to adapt it to the target task, utilising more computing resources.

Few-shot Learning: We carefully selected three shots (or data samples) with input-output pairs to include in the prompt to provide the model with a context for the task. Following the samples, we included the text input that needs to be converted into the BCRL format.

Fine-tuning: This approach allows the model to be customised for the targeted task, building on its available knowledge. We converted all the training samples into JSONL format, including system, user, and assistant roles. Being a closed-sourced model, OpenAI API provides fine-tuning as a service to its users. Following the given guidelines, we uploaded the correctly formatted dataset to their API and then initiated the fine-tuning job.

Additionally, we explored combining fine-tuning with progressive active learning.

Fine-tuning with Progressive Active Learning: Progressive active learning allows the model to refine itself through expert review. In this setup, the model's predictions were evaluated, and samples with high confidence were selected for expert review after the fine-tuning stage. The selected samples were then reviewed and, where necessary, corrected by experts to meet the required standards. Once validated, these reviewed samples were incorporated back into the training dataset and used to further fine-tune the model. This cycle was repeated across multiple iterations until all training samples had been reviewed and reintegrated into the training dataset. This iterative process allowed the model to learn from its errors and gradually improve its predictions.



Figure 17.10 RASE annotations and corresponding metadata in BCRL (YAML) format. The corresponding annotations are graphically illustrated in the diagram below.

Table 17.6 RASE Category Distribution over Approved Document Sections

Approved Document	Sections	R	A	S	E
M2: Access to and use of buildings other than dwellings	6	1,177	374	96	76
L2A: Conservation of fuel and power in new buildings other than dwellings	6	239	74	18	21
BB100: Fire safety design for schools	13	845	303	116	113
Total	25	2,261	751	230	210

Note: Columns R, A, S, and E represent the requirement, applicability, selection, and exception counts.

All the source code and results of these experiments are available and documented in this GitHub repository: [Natural Language Processing of Building Codes – ACCORD Project Documentation](#).

Dataset

For our experiments, we used 25 sections from three approved building regulation documents from England, each translated into the BCRL format by domain experts. This dataset, developed as part of the ACCORD project, is the initial and sole dataset available in BCRL format (Dridi et al., 2023).

Each data sample included free-text content extracted from the section and its corresponding BCRL-formatted version provided as a YAML file. The YAML files consisted of nested elements that represent the hierarchical structure of the document section, along with RASE annotations. We excluded all tables and figures, as we exclusively focused on textual content. Table 17.6 summarises the selected section counts from each document and their RASE-annotated tag distribution. Most tags represent requirements (R), while exceptions (E) appear less frequently, reflecting the typical structure and emphasis found in regulatory texts.

Results and Discussion

Due to the complexities associated with the focused output format, we adapted two novel measures, structural similarity and text similarity (Al-Turki et al., 2024), to compare the model-generated outputs against the ground truth. Structural similarity evaluates the graph-based or hierarchical similarities in the YAML files. It converts the YAML formats into graph representations and computes the similarity between graphs using the SimGNN model (Bai et al., 2019). Alternatively, text similarity compares the generated and actual textual contents in the YAML files. It computes the proportion of overlapping words between two texts while penalising for discrepancies. Both metrics return scores

Table 17.7 Performance Evaluation with Few-Shot Learning

<i>Metric</i>	<i>Min.</i>	<i>Max.</i>	<i>Std.</i>	<i>Average</i>
Structural Similarity	0.57	0.79	0.07	0.69
Text Similarity	0.68	0.85	0.05	0.76

within the range of 0–1, where values closer to 1 indicate a higher degree of similarity.

Few-shot Learning Performance: We evaluated the few-shot learning approach across 22 data samples (or sections), excluding the three samples used to provide a contextual understanding of the task to the model during prompting. Table 17.7 summarises the structural and textual similarities between the model-generated and actual outputs. The average structural similarity score was 0.69, with text similarity of 0.76, indicating GPT-4o’s capacity to understand and perform a complex task by only seeing a few samples in a resource-efficient manner.

Fine-tuning Performance: Due to the limited data availability, we constrained the fine-tuning experiments to a test set with five samples. From the total of 25 samples, 15 were used for training and 5 for validation. Although the test set is small, each sample represents an entire section from an approved document, capturing all its complexities and nuances. Therefore, the test set still offers fair insights into model performance. Table 17.8 summarises the results of fine-tuning experiments.

Fine-tuning returned better average similarity scores of 0.74 for structure and 0.81 for text. Incorporation of progressive active learning led to further enhancements, increasing structural similarity by 9% and text similarity by 6%.

Discussion: There is a growing trend in using LLMs for a wide range of NLP and information extraction tasks (Minaee et al., 2024). Their adaptability and flexibility make them well-suited for any task that can be framed as text generation. However, due to the novelty of the BCRL format and the specific evaluation metric used in our study, currently, there exists no directly comparable work or results to benchmark our findings with.

Overall, our experiments show that LLMs are capable of handling complex tasks, such as converting free text into the BCRL format, with promising results. The GPT-4o model produced satisfactory outputs using the few-shot learning approach, only seeing three data samples with inputs and outputs. Its performance improved notably through fine-tuning and progressive active learning, even when training on a limited amount of data. Overall, our findings suggest that LLMs have strong potential to facilitate rule formalisation effectively.

Table 17.8 Performance Evaluation with Fine-Tuning

Metric	Min.	Max.	Std.	Average
Structural Similarity	0.67	0.78	0.05	0.74
Text Similarity	0.78	0.84	0.02	0.81
<i>Fine-tuning with progressive active learning</i>				
Structural Similarity	0.74	0.88	0.03	0.83
Text Similarity	0.77	0.93	0.05	0.87

Conclusions

Language models, particularly PLMs and LLMs, have revolutionised the landscape of NLP. PLMs introduced advancements in capturing contextual meaning within the text, while LLMs have extended these capabilities through their emergent features, such as instruction following and in-context learning, marking a significant shift from traditional NLP methods. These models have achieved state-of-the-art results across a wide range of NLP tasks, reinforcing their potential and versatility. However, their application in regulatory document interpretation or rule formalisation within the AEC section remains underexplored. Given that building regulations are primarily available in written form, processing text to extract relevant information and convert them into structured, machine-processable format is a crucial step towards ACC, which can be effectively handled by language models.

We explored a range of language model-based architectures and learning techniques to evaluate their potential for rule formalisation, building on recent advancements in NLP. Being ML models, both PLMs and LLMs required annotated data for training. However, we observed some notable changes in the complexity of tasks these models can handle and their data requirements between PLMs and LLMs.

Comparatively, LLMs present a more convenient alternative to PLM-based models, as they eliminate the extensive requirements on domain-specific knowledge integration and task-specific learning required by PLMs. LLMs’ in-built knowledge allows them to tackle complex tasks by only seeing a few examples in the prompt (in-context learning) or through fine-tuning on relatively small datasets, reducing the data requirements that PLMs usually need. Moreover, with PLMs, complex tasks often need to be broken down into smaller, well-defined subtasks to match their capacities. Such a breakdown also demands building and maintaining multiple models within a pipeline, which not only increases system complexity but also introduces a risk of error propagation across stages.

In contrast, LLMs can often perform complex tasks, such as converting a section in an approved document written in free text into a more structured machine-processable format in a single step. However, most LLMs are closed-sourced and operate with limited transparency. Unlike pipelined models, each performs a smaller subtask, generating intermediate outputs and providing

insights into how results are generated; LLMs typically do not reveal their internal processing or reasoning. As a result, it becomes difficult to diagnose and correct errors in outputs generated by LLMs.

It is also crucial to consider computing requirements and ethical implications when developing tools for interpreting building codes. Generally, LLMs require more computational resources than PLMs due to their scale. Moreover, some LLMs are only accessible via paid APIs, raising concerns about data privacy and compliance, particularly when regulatory information must be sent to external cloud servers for processing.

In conclusion, language models, including both PLMs and LLMs, offer promising avenues for automatically interpreting regulatory documents for advancing ACC. While their advanced NLP capabilities enable sophisticated information extraction and rule formalisation, they also come with limitations, including challenges in integrating domain-specific knowledge and a lack of transparency in their decision-making process, as we discussed above. Addressing these limitations will be key to developing more effective and trustworthy tools in future to support ACC in the built environment.

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Part III

Implementing Digital Building Permits

International Experiences and
Case Studies



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18 Finland's Digital Leap in Building Permits

Journey through Hands-on BIM-Piloting and Cross-sectoral Collaboration

Rita Lavikka, Anna-Riitta Kallinen, Antero Hirvensalo, Tomi Henttinen, and Tiina Talvitie

Introduction

Finland is a forerunner in digitalising building permit processes, having set a benchmark for efficiency and sustainability in the built environment (Fauth et al., 2024; Lavikka, Beach, et al., 2024). Most Finnish municipalities utilise a cloud-based building permit system, allowing the submission of building design data in a machine-readable format, city three-dimensional (3D) reviews, online neighbour hearings, and official Industry Foundation Classes (IFC) archival. Finland's two building permit services facilitate communication between the building permit applicant and various permit authorities. When the permit applicant submits the building project data in IFC format, the permit service can automatically read the data, incorporate it into the application, and store it in a national Built Environment Information System. This reduces manual data entry, minimising human error in the process. The cloud-based building permit service checks the validity of the submitted IFC file. If the file is valid, the applicant and the permit officer can select which compliance checks, such as accessibility or operational safety-related, are required for the building type in question. The service then automatically conducts the chosen compliance checks and returns a report with the results.

Finland's new Building Act (Rakentamislaki 751/2023, 2023) will require applying for a building permit with an IFC file if the building project has been modelled using Building Information Modelling (BIM). This will take effect at the beginning of 2026. However, the design can be submitted as a PDF if the project is not modelled. This can be the case in small projects (less than 30 m²) or renovation projects where no significant changes are made to the structure or the building's designated use.

The digitalisation of building permit processes began in 2001 with the development of a data transfer schema to facilitate data exchange between municipalities' technical and environmental service systems. Since then, several national research and development projects from 2016 to 2023 have focused on developing and demonstrating technological solutions for digitalising building

permit processes (Lavikka & Kallinen, 2024). National research and development funding bodies, like Business Finland and the Finnish Ministry of the Environment, have financially supported these projects. A key factor in the success of digitalisation has been the involvement of diverse user groups, including designers, building control, software providers, consultants, construction companies, associations, and property owners, which has facilitated the adoption of the new BIM-based building permit process.

In 2016, municipalities were permitted to use digital archiving for their official long-term archives, eliminating the need for paper documents. Since 2025, the new Building Act has allowed the archiving of IFCs in the new Built Environment Information System. Alongside technological advancements and digital archiving, the national BIM requirements established in 2012, as well as municipalities' BIM modelling guidelines, have improved modelling quality, thereby advancing digital building permit processes. BIM education has also played a crucial role, with the Finnish Ministry of Environment financially supporting the BIM coordinator educational programme from 2021 to 2022, educating BIM experts.

In 2022, the City of Järvenpää issued the first residential BIM-based building permit (Sova3D, 2021). The submitted IFC file encompassed details about the building's structure, materials, facilities, and overall areas and volumes. The architecture adhered to the national common BIM requirements and the municipality's building control BIM guidelines (Kaaretkoski & Vastamäki, 2022). The cityscape and location reviews of the building within its environment were conducted using a 3D service of the City of Järvenpää. Regulatory compliance was manually verified using the Solibri Model Checker program. Since the issuance of the first BIM-based building permit, additional digital building permits have been issued. In the future, Finnish municipalities will archive building data in the forthcoming national Built Environment Information System, supporting more effective and sustainable planning and decision-making regarding the built environment (Finnish Ministry of the Environment, 2024). Next, the chapter will present how Finland has achieved its maturity level of BIM-based building permit processes, including experimental piloting with public-private partnerships. Following this, the real-life implementation of the City of Helsinki, along with other municipalities, is presented. Finally, the chapter presents conclusions for different stakeholders.

Finland's Journey to Digital Building Permit Processes

This paragraph presents the importance of BIM-based building permit services and data standardisation for digital permits. It will also explore the collaborative efforts between municipalities, software companies, and government bodies that have driven digital transformation, emphasising the role of research and piloting.

The Essence of BIM-Based Building Permit Services and Data Standardisation

BIM-based building permits in Finland could not exist without BIM-based building permit services. The development of these services began in the early 2010s. By 2015, two services – Cloudpermit and Trimble ePermit – had introduced electronic building permitting. Approximately 90% of all building permit applications went through one of these services in 2018. During the same time, buildingSMART Finland, the Ministry of the Environment, a group of municipalities, and the National Archives of Finland started discussing the IFC as the submission format for a digital building permit. IFC is an open BIM standard published by ISO (ISO 16739-1), the standard format for sharing BIM model data between software. The first pilots using IFC in the permitting were also carried out in 2018.

By the beginning of 2020, almost all building permit applications in Finland had already been handled electronically in PDF. Simultaneously, BIM, especially IFC, was used in most professional projects. Therefore, the technical basis for introducing IFC into the building permit process was excellent. At the same time, the Ministry of the Environment was preparing to reform the Building Act. An essential objective of the updated legislation was the requirement for machine-readable information and interoperability. In the autumn of 2022, the National Archives approved IFC 4 as an official file format for permanent archiving. The decision made it possible to use IFC as the machine-readable data format required by the revised Building Act.

However, although IFC, an international standard, establishes a standard data structure, it does not standardise the information stored in this structure. Before IFC can be used in automated review processes, the information in each project must be in the same form. This requires local definitions and standardisation, which have been implemented in various national development projects, such as RAVA2 (Kallinen, 2021) and RAVA3Pro (Henttinen & Nisbet, 2023; Kallinen, 2023).

In Finland, building permits are granted based on plans drawn up by architects. All other plans provided by different design disciplines in the project are submitted to the building control authority, but they are not part of the approved application. Nevertheless, the information in each set of plans must be standardised to be usable in the process.

The basic principle is that plans used for building permitting must contain information to determine whether the building will be healthy and safe for use. Regulations do not specify how this is presented in practice. The level of detail in drawings used in the building permit process has a long tradition. There are also many specifications relating to drawings, but these cannot be used as such in BIM-based designs. Thus, before using IFC in building permits, the level of detail and data requirements for different model components must be established. This can be a significant task, especially when considering the diverse range of project types. In any case, it is necessary to do this to

enable machine-readable results and automatic code-compliance checking. Finland is now working intensively on this issue.

In Finland, interoperability of built environment data refers to a commonly agreed-upon set of concept definitions, code lists, and data structures that serve as logical data models. Since 2019, the Ministry of the Environment has been leading an ongoing initiative to enhance the interoperability of built environment data (Ministry of the Environment, 2024). While the project does not directly offer methods or guidelines for BIM-based interoperability, it focuses on developing high-level data models and vocabularies that can support BIM-based data exchange. All data definitions produced by the project are published online as public digital data dictionaries, aiming to enhance semantic interoperability across the sector. In the first development phase, the automatic review process focuses on the model delivered by the architect. One of the challenges is that the native modelling software services that architects use in their work do not have these local standards built in. Therefore, each architect must manually define the correct information fields in their model. This can lead to inconsistent information that the automatic review process has not approved. To avoid problems, the required information must be logical. In addition, the required information should only consist of what is necessary for the various authorities to maintain the amount of information to a minimum.

Experimental Piloting with Public-Private Partnerships

The transformation to digital building permit processes and a more interoperable data environment has required mutual adaptation of people, processes, technology, and legislation. An important means for supporting this process in Finland has been experimental piloting. The model of experimental piloting is based on bringing together building projects and their stakeholders and experimenting with gradually evolving ways of using digital tools in the project, from design to building control. This effort has involved actors from different sectors. The model of experimental piloting is depicted from the perspective of innovation management, including the elements of management, multilateral interaction, cyclical learning, and motivation (Figure 18.1). Next, these elements are described in more detail.

Management

Managing such industry-wide and nationwide development requires an ecosystem management approach, where the aim is to lead the entire ecosystem rather than promoting individual organisations. Consultants for the pilot projects played a key role in creating an ecosystem designed to foster trust and a cooperative spirit among the various stakeholders.

In the RAVA3Pro project, pilots were guided by a core group that included the project manager, city officials, and consultants. The core group mapped out building projects where digital data and software tools could be tried for permitting.

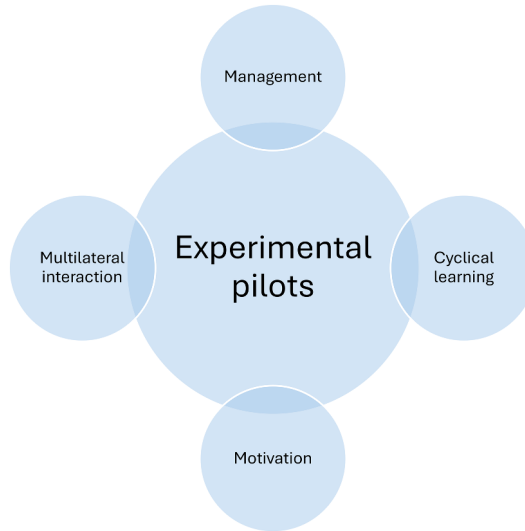


Figure 18.1 The model of experimental piloting.

Then they connected the designers, building controls, and software developers so that they could communicate and develop in collaboration.

In the individual experiments, project managers organised the actual production of the features to be experimented with and the subsequent reflection sessions. They also handled the public procurement processes for acquiring extra resources, as the pilots included various work packages involving technology experts and software manufacturers.

Multilateral Interaction

Central to the piloting process was the cross-sector interaction among the actors and their diverse viewpoints. The pilots combined people with expertise in BIM-based design, building controls, legislation, standards, and software, as well as hands-on experiments (Figure 18.2). This enabled an exchange of ideas from different professional views.

The requirements set for designers and design software depend on regulations and standards, and vice versa, which is why interactivity has been essential for their development. This interactive approach has enabled the gathering of solutions that work in practice and have been incorporated into the development of national requirements.

The experiments initially included a limited amount of permit data, such as the building area and location, prepared by consultants. These data requirements were given to the building projects' designers, who had to write the data into their design models in a format that enabled machine readability. The automatic checking and receipt of data were tested in the cloud-based services of building controls.

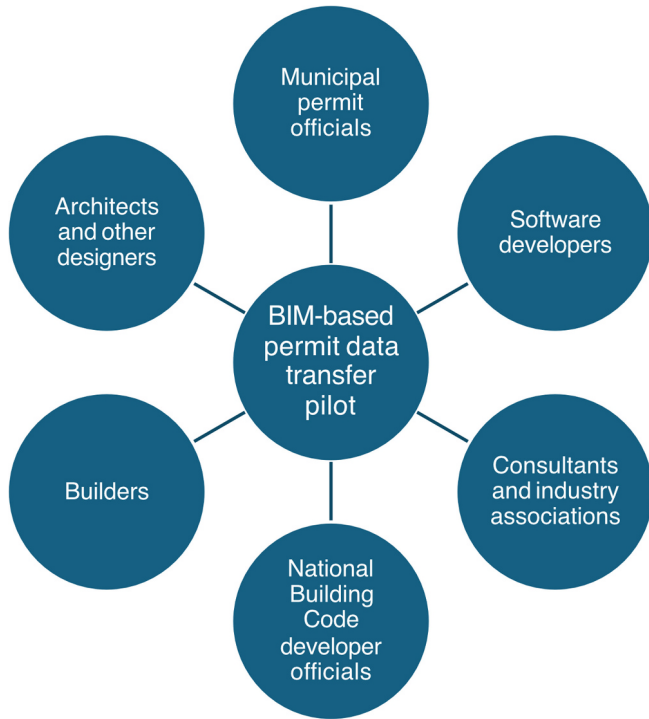


Figure 18.2 Participants of the pilots. (Adapted from Hirvensalo (2024)).

On a practical level, the consultants provided instructions and hands-on guidance to the architects of the pilot projects to incorporate the permit data into the BIM design. Then, the participants gathered for demo meetings to examine how the BIM model and data would be transferred to the building controls. Observations were made regarding issues with information writing formats and coordinates.

Notably, pioneering software companies were also involved in developing the data transfer processes and the necessary software, and they invested their resources in their development. This attitude reflects the spirit required for effective multilateral cooperation.

During the pilots, it became evident that software firms need a better understanding of the data being transferred to building controls to interpret it correctly in their software. For this, the firms need better cooperation with architectural designers. To put it bluntly, architects and building inspectors often lack the necessary coding skills, and software firms are unfamiliar with the work of architects and building inspectors. Piloting was needed to fill this gap.

National requirements and legislation for model-based permitting were validated through public comment rounds. Experts from various design fields

defined use cases and properties for model-based permitting. The validation process became a shared task nationally, as anyone could comment on the presented materials.

Cyclical Learning

The starting point for piloting is cyclical learning, where knowledge gained from one project is applied to the next. Finland has undertaken numerous national development projects, with each cycle building on the experiences gained from previous initiatives. At the core is the ability to plan projects in accordance with the current development possibilities in the industry and municipalities.

At the beginning of the pilot, the starting point was to determine how the law-making would support information models and machine-readable content for building permits. Secondly, the data for piloting automation in building permit processes was taken from the current level of know-how. The pilots focused on the use cases from the perspective of building controls, and the usability of using IFC data transfer was assessed. The results were fed back for further testing and refinement.

Cyclical learning was found necessary for the municipalities, as they cannot automate all their processes and services at once. They must develop new ways in parallel, as the statutory permit operations must always be running. Therefore, one step at a time is a good progression, as new things can be gradually introduced alongside daily operations. The same principle applies to the software firms' development steps.

Motivation

Although the legislation will bring about some changes, a crucial factor is people's enthusiasm and willingness to innovate. Finland has a strong tradition of proving things in practice, and the maturity of people in utilising building information models is already high. They seek a detailed understanding of how using IFC models is intended to function in the permitting process.

Success in adopting digital processes has motivated continuing experimentation and piloting, and the municipalities have assumed a growing role. The more advanced municipalities have been at the forefront of development, and the results have been shared nationally among other municipalities.

The motivation and reluctance of people to engage in development efforts have been discussed since the early stages of the Finnish pilot projects. By focusing on a limited amount of data in the experiments, changes have been partially achieved in practice; however, the industry has not been able to easily change its operating models. This is due to partial opt-in: the actors cannot easily see the benefits of automation, but ask why they should do something useful for the benefit of someone else.

This is especially relevant for the designers. Transitioning to fully machine-readable data and automated code compliance would likely require additional effort from designers. However, if the benefits primarily accrue to building control authorities, designers' motivation for development might diminish.

The key motivating factor has been the belief that digitalising permit processes is achievable and that, ultimately, automation brings benefits that can produce a significant digital leap in the permit processes. Confidence in the project's results has been essential, and progress would have stalled if we had focused solely on potential failures. In the future, change management should consider the socio-economic drivers and obstacles that affect the implementation of automation in permit processes. New business models for sharing economic benefits are also necessary.

While this has been mostly a Finnish enterprise, international connections were also emphasised during piloting. The Nordic Council of Ministers' LCA development project was significant as it created guidelines for reliable BIM-based material inventory (bill of materials) and specifications for information needed for modelled building components (Lavikka, Kouhia, et al., 2024). Finland's experiences have been shared with the EU BIM task group. These results can be valuable for replicating national development projects elsewhere, with the following materials available for transfer (RAVA3Pro, 2025):

- Native and IFC model examples for piloting
- Description of use cases, property sets, and assisting templates for data transfer
- Legislative principles for enabling model-based permitting
- Requirements for the cloud-based building permit service for machine-readability
- Management model of multilateral piloting

Practical Implementations of Digital Building Permits

This paragraph highlights the City of Helsinki as a leader in digital transformation in urban planning and building permit processes. In collaboration with other municipalities, Helsinki has been a leader in implementing automated code-compliance checks, streamlining the building permit process, reducing waiting times, and enhancing transparency. The paragraph discusses the pioneering use of IFC files within the 3D city model for a more visual neighbour consultation process and leveraging geospatial data and digital twins to enhance urban planning and building design.

Practical Implementation of BIM-Based Building Permitting and Automatic Code-Compliance Checking in Municipalities

Following the RAVA3Pro project, the City of Helsinki initiated the KympR3 project at the start of 2024 (Talvitie, 2025). Before the start of the KympR3

project, a pre-study called R3HaSu was conducted. This pre-study included workshops and interviews with key personnel from the Urban Environment Division's services. The pre-study aimed to identify and ensure the necessary development areas. Based on this study, the project plan was defined. Four key focus areas for implementing the RAVA3Pro and BIM-based process in the City of Helsinki were identified via the pre-study: (1) standardising guidelines and updating the requirement documents, (2) managing process changes and supporting change management, (3) enhancing technical capabilities, and (4) providing training and learning opportunities, including piloting initiatives. The Kympr3 project aimed to ensure the successful implementation of the RAVA3Pro project results within the Urban Environment Division, in preparation for the new Building Act. The project also focused on implementing machine readability and integrating automated checking in the handling of BIM models within the building permit process. The goal was to establish a streamlined and unified BIM workflow for the Urban Environment Division's services and units throughout the entire construction lifecycle. As part of the project, national-level development will be monitored, and participation in these initiatives will be planned.

Automatic Code-Compliance Checks for Transparency, Time Reduction, and Simplicity

The collaborative model, involving multiple municipalities and stakeholders, has proven highly useful in implementing automatic code-compliance checks. The City of Helsinki has been the leading municipality in the RAVA3Pro development, and this collaboration has continued beyond the project. For instance, the City of Helsinki, together with the cities of Vantaa, Järvenpää, Hyvinkää, and Tuusula, launched a joint development project to implement automatic code-compliance checks as part of the building permit approval process (Kallinen, 2025). Automation will simplify the application process, reduce waiting times, and increase transparency. The code-compliance checks are based on building regulations and RAVA3Pro use cases. Additionally, designers can perform the same checks using their Solibri Desktop licenses before submitting their IFC files to the building permit process. The implementation of automatic code-compliance checks is also part of the Kympr3 project's roadmap in the City of Helsinki.

The implementation of code-compliance checks occurred within Cloudpermit's Software-as-a-Service (SaaS)-based building permit platform. This involved testing and piloting the IFC checking module using IFC files created explicitly for this purpose. Cloudpermit and Solibri have collaboratively developed IFC-based code-compliance checking via a SaaS-based REST API data exchange under the EU project ACCORD (ACCORD, 2025). The REST API is an Application Programming Interface (API) that follows the principles of Representational State Transfer, a software architectural style that guides the design and use of web APIs for communication between client and server

applications. In practice, designers upload their IFC files to the Cloudpermit service, which performs an initial check of the IFC information structure, for example using Information Delivery Specification (buildingSMART International, 2025). If the IFC file conforms to the required information structure, Solibri will perform automatic code-compliance checks. Solibri performs the automatic code-compliance checks in the background within the SaaS environment. The results of the Solibri check are then returned to the Cloudpermit report on the user interface. In this process, no one manually handles the IFC file. A visual viewer is also available to display the check results, allowing users to explore the 3D building model and the issues found during the compliance checking.

Visual Neighbour Consultation Process

The City of Helsinki is developing and exploring the use of IFC models in digital twins. The IFC model of a new building is embedded into the 3D city model, allowing neighbours visually see what the building would look like once constructed. It shows how the building fits into the cityscape and surrounding nature, and whether it casts shadows on other buildings. The model can be used to observe changes in lightning conditions at different times of the day. Many construction projects involve notifying and consulting neighbours. In this process, the neighbours are presented with the project's plans, including any deviations and their justifications. The neighbours need to sign a form to confirm they have been informed and allowed to express their views. During the consultation, neighbours can submit reasoned opinions about the project. The premise is that a visual neighbour consultation process would be easier and more understandable for neighbours.

Continuous Development in Leveraging IFC Models to Streamline Urban Environment Workflows

Cities can play a key role in developing BIM-based use cases for designing an even better-built environment. As cities vary in size, larger cities typically develop new digital workflows and guidance, while smaller cities mainly adopt the guidance created by others. The City of Helsinki, Finland's largest city, has been actively involved in developing use cases for BIM-based processes and city digital twins. In addition, ongoing development focuses on how IFC files can be utilised in city surveying and how spatial data and coordinates can be provided to designers as initial IFC-based information for building design and spatial modelling. The City of Helsinki is piloting the use of IFC files in city survey measurements and Digital Twin platforms for various use cases. Figure 18.3 illustrates the accuracy and relevance of using 3D models for urban planning and architectural visualisation. It demonstrates how 3D models can effectively represent real-world environments, aiding design and planning processes by providing a clear and detailed visual reference.



Figure 18.3 The structural view of an IFC model in the Solibri software (left side) and the same IFC model used as visualisation material, combined with city model views that display the actual buildings and the surrounding environment (right side).

Photo courtesy of ARCO Architecture Company, Mr Tero Pulkkinen and Mr Mikko Lahti.

The Helsinki City Survey Services is developing city digital twins to support the data-driven decision-making needs of users in the Urban Environment Division by integrating data from multiple sources and visualising it in the 3D city model. The data in the City of Helsinki's 3D city model is automatically and regularly updated (City of Helsinki, 2025). The Proof-of-Concept videos demonstrating the digital twins are published on the Helsinki channel (Helsinki Channel, 2025). In addition, aerial 4D city model scheduling pilots for various use cases are also a key focus of development in 2025 (LEAN 4D, 2024).

The City of Helsinki is also participating in several other development projects, including the latest national RAVA3.5 project, which focuses on updating secondary regulatory information related to the Building Act, such as IFC property sets, codes, descriptions, and pilot models, to meet the new requirements of the Building Act. The RAVA3.5 is led by the City of Järvenpää and funded by the Finnish Ministry of the Environment.

Conclusions

Finland's building permit process stakeholders –including software companies, building authorities, and construction sector stakeholders – have actively and successfully participated in the development and piloting of digital building permit processes, for example, through the RAVA projects. However, both builders and designers have expressed concerns about the additional workload and the distribution of benefits. There is a clear need for better statistical evidence on the realised benefits of digitalisation. Digital processes, including digital data on buildings, products, and materials, as well as the machine-readable BIM model and its associated data, provide opportunities for more advanced analytics; however, issues such as paywalls and data accessibility still need to be addressed. While there are high expectations for the new digital building permit process, some of these are diluted by the current legislation. Historically, change processes towards digitalisation in Finland have been marked by confusion and

debate; however, once all stakeholders commit, progress accelerates, and in retrospect, the process appears straightforward. It is worth noting that such a flexible and collaborative approach is rare in other countries; the adaptability of the Finnish construction sector and the national mentality have enabled this unique development.

However, a lot remains to be done. Researchers should continue to explore the integration of digital building permit processes with emerging technologies such as artificial intelligence. Investigating the potential of new technologies to enhance automated code-compliance checks and improve data accuracy will be crucial. Additionally, longitudinal studies on the impact of digital building permits on the construction industry's efficiency and sustainability can provide valuable insights for further advancements.

Practitioners, including architects, engineers, and construction managers, should actively engage in the adoption and implementation of digital building permit processes. Embracing BIM and ensuring that all project data is machine-readable will streamline the permitting process and reduce errors. Continuous professional development and training in digital tools and technologies will be essential to stay updated with the latest advancements and best practices.

Policymakers should focus on creating a supportive regulatory framework that encourages the adoption of digital building permit processes. This includes updating legislation to mandate machine-readable data formats and automated code-compliance checks. Additionally, fostering public-private partnerships and providing funding for pilot projects and research initiatives will accelerate the construction industry's digital transformation. Ensuring all stakeholders, including municipalities, industry professionals, and technology providers, are involved in the decision-making process will enhance collaboration and drive successful implementation.

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Data Availability

Data sharing does not apply to this chapter as no new data were created or analysed.

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19 BIM-Based Building Permit

Semi-automated Code-Compliance Checks in Estonia

*Christopher-Robin Raitviir, Pille-Riin Peet,
Irene Lill, and Raido Puust*

Introduction

The building permitting process is a foundational mechanism of regulatory governance in the built environment. Beyond its function in ensuring legal compliance, permitting mediates how planning objectives and design intentions are translated into constructed form, directly impacting spatial, social, and environmental outcomes. Across Europe, however, permitting systems are under intensifying pressure. Policymakers face growing demands for faster and more predictable approvals while simultaneously advancing complex policy objectives, including carbon emission reductions, the delivery of affordable housing, and the digital transformation of public services. These multidimensional pressures have exposed longstanding structural deficiencies in conventional permitting workflows—particularly fragmented documentation practices; dependence on non-machine-readable formats; and persistent information loss across the planning, design, and construction phases (Raitviir & Lill, 2024).

In response to these systemic challenges, governments and research communities have increasingly adopted digitalisation strategies aimed at improving the efficiency, transparency, and accountability of permitting processes. Among the most transformative of these innovations is the implementation of Building Information Modelling (BIM), which enables the creation of digital, structured, and interoperable representations of built assets. BIM facilitates new forms of regulatory review, including automated and semi-automated code compliance checking based on codified, machine-readable rules (Fauth et al., 2025; Ullah et al., 2020). At the European level, BIM-based permitting supports a range of strategic initiatives, such as the Renovation Wave and the Affordable Housing Initiative, which identify digital transformation as essential for achieving goals related to sustainability, resource efficiency, and housing provision (European Commission, 2020).

BIM-based permitting offers not only the potential to accelerate project delivery and streamline administrative review but also to establish synchronised data environments that improve the continuity and integrity of information across the building lifecycle. The use of semi-automated compliance checking, in particular, can reduce administrative burdens, enhance regulatory

oversight, improve data quality, and mitigate the risks associated with manual interpretation and fragmented decision-making (Raitviir & Lill, 2024). Supporting these capabilities are emerging technical frameworks such as Industry Foundation Classes (IFC), CityGML, and the ISO standard *level of information need* (ISO 7817-1:2024), which formalise the use of structured digital models as both design artefacts and instruments of regulatory compliance (Noardo, Wu, et al., 2022; Ullah et al., 2020). These developments point to a paradigmatic shift in the role of permitting: from a static legal checkpoint to a dynamic, data-driven platform for coordinating spatial, technical, and regulatory decision-making.

Among European countries, Estonia has emerged as one of the most ambitious and advanced implementers of digital permitting reform. Through its national e-construction platform, the Estonian government is embedding BIM directly into the permitting process by linking digital building models with the Estonian Building Registry (EHR). The resulting system supports semi-automated compliance checking based on IFC-format models and open rule-checking engines, currently covering approximately 47 regulatory constraints, including housing requirements, accessibility, and fire safety (Pärn et al., 2022). The 47 checks account for only 10–15% of all potential permit checks, yet they address the majority of buildings and establish a solid foundation for the service as a minimum viable product. Estonia's approach represents a rare case of public-sector-led platformisation of permitting, a strategy characterised by modularity, interoperability, and extensibility through public APIs and open standards.

This chapter presents the first comprehensive academic analysis of Estonia's BIM-based permitting infrastructure. It examines the system's legal and institutional foundations, data requirements, rule-checking mechanisms, and governance model. Drawing on both primary documentation and implementation data, the chapter explores how Estonia's approach contributes to the evolving discourse on digital permitting, advancing not only technical innovation but also institutional alignment between regulation, digital registries, and open data standards. As such, this case offers a potential model for scaling digital permitting beyond isolated pilot projects into integrated elements of national infrastructure.

By positioning Estonia's experience as both a technical and institutional reference point, the chapter identifies the key preconditions for successful implementation. These include clearly defined BIM data requirements, harmonised planning legislation, and an agile approach to platform governance. The analysis also reflects on the broader socio-technical implications of digitising regulatory processes—particularly tensions between automation and legal interpretation, questions of accountability and liability, and challenges related to equitable access for smaller market actors. In doing so, the chapter contributes to a broader understanding of how digital permitting may evolve as a core component of future regulatory ecosystems across Europe.

This chapter is written from an embedded perspective. The author served as the conceptual lead and project manager for the design and implementation of

Estonia's BIM-based permitting system, overseeing its technical architecture, regulatory integration, and national rollout. This dual role, as both practitioner and researcher, affords privileged access to the internal workings of the project, including stakeholder negotiations and institutional decision-making. The resulting analysis is therefore both reflective and practice-informed, drawing on public documentation as well as first-hand experience in translating legal and technical frameworks into an operational digital permitting platform. This insider perspective enables a critical examination of the conditions, trade-offs, and institutional dynamics that shape the success or failure of such transformative public-sector initiatives.

Background Literature

The accelerating digitalisation of regulatory workflows has prompted a growing body of research into the challenges and opportunities associated with automating the building permit process. This emerging literature has produced a diverse array of conceptual models, rule-checking systems, and structured data protocols aimed at enhancing compliance assessments through digital means (Noardo, Wu, et al., 2022; Ullah et al., 2020). Collectively, these contributions reflect significant technical maturity and methodological breadth—particularly in the development of rule-based validation techniques, the formalisation of digital code interpretation, and the design of structured model submission frameworks. These advancements have laid a strong technological foundation, demonstrating that under specific conditions, digital models can encode legal requirements and facilitate more efficient permit review processes.

A particularly active line of research focuses on the formalisation of information requirements and the logic underlying model validation. Fischer et al. (2025) illustrate how conventional property lists can be translated into machine-readable formats using the Information Delivery Specification (IDS) framework, enabling customisable and verifiable submission criteria. Their earlier study (Fischer et al., 2024) extended these methods to encompass geometric and semantic rule types, thereby broadening the scope of automation. While technically innovative, these approaches are generally positioned as modular tools rather than components of full institutional implementations.

Parallel efforts have examined the embedding of specific regulatory constraints, particularly spatial rules, within software environments designed for early stage review. For instance, Fischer et al. (2023), working within the BRISE-Vienna initiative, proposed a hybrid compliance-checking model that combined algorithmic processing with mandatory human oversight. Their work exemplifies how complex spatial logics, such as escape route geometry, can be partially formalised and integrated into semi-automated regulatory workflows.

Despite significant progress in the development of individual tools and frameworks, comprehensive implementation within public authorities remains limited. BRISE-Vienna represents one of the most advanced initiatives to date. As documented by Urban et al. (2024), it incorporates a fully digital openBIM

submission pipeline, automated rule-checking, pre-assessment protocols, and even augmented reality-enabled stakeholder hearings. However, its scope remains largely municipal, deeply embedded within Austria's legal-administrative context, and reliant on proprietary infrastructure. As such, it serves more as a high-functioning prototype than a scalable national model.

Estonia's initiative, by contrast, moves beyond the prototype stage to address systematic implementation at a national level. Instead of piloting city-level solutions, Estonia has integrated BIM-based permitting directly into the EHR and broader e-construction platform. The system supports semi-automated compliance checks based on open standards (Pärn et al., 2022). Its architecture prioritises modularity, interoperability, and extensibility through public APIs, thereby enabling integration with third-party solutions and other national digital infrastructure, including Estonia's evolving Digital Twin. In doing so, Estonia begins to address what some scholars identify as the “missing middle” in the literature: the gap between component-level innovation and institutional-scale digital transformation.

More broadly, much of the existing literature adopts a software engineering or information modelling perspective. While these contributions are technically indispensable, they often rely on idealised assumptions of administrative coherence and digital readiness. Beach et al. (2020) caution that the effectiveness of rule-checking systems depends not only on computational logic but also on their ability to accommodate legal interpretation, inter-agency variability, and jurisdictional complexity. Similarly, Pärn et al. (2022) emphasise that platform governance, institutional buy-in, and stakeholder usability are critical determinants of long-term success.

A persistent adoption gap also exists in practice. Even where formalised information requirements are in place, the production of regulation-ready digital models remains resource-intensive—particularly for small firms lacking in-house BIM capacity. As Noardo, Guler, et al. (2022) warn, unless such systems clearly demonstrate value in terms of faster approvals, reduced compliance risk, or operational efficiency, their adoption may remain limited, unless there is top-down approach, i.e. BIM is required by law. This insight underscores the importance of articulating and demonstrating the systemic benefits of digital permitting—not only its technical feasibility.

In an effort to bring greater conceptual clarity to the field, Fauth et al. (2024) propose a multidimensional taxonomy for classifying digital permitting systems across legal, organisational, and technical dimensions. This framework supports the comparative analysis of initiatives, situates discrete technical tools within broader governance structures, and informs ontology development for future permit workflows.

What emerges from this literature is a nuanced yet incomplete picture. While the technical components for digital permitting are increasingly robust, their integration into operational, legally compliant, and institutionally scalable systems remains rare. Estonia's national initiative contributes to addressing this gap. It illustrates how platform openness, standardised data environments, and harmonised legislative frameworks can collectively support systemic digital

transformation within regulatory governance. As this chapter will argue, Estonia's model serves not merely as a technical case study, but as a broader example of how intersectoral coordination, public-sector innovation, and cross-domain interoperability can elevate digital permitting from experimental projects to critical national infrastructure.

Method

This chapter adopts an embedded case study approach (Yin, 2018), with the author serving as both participant and analyst in the development of Estonia's national BIM-based permitting system. This dual role provided direct access to institutional processes and decision-making typically inaccessible to external observers. The case is distinctive in the digital permitting literature as a rare example of a full-scale, public-sector deployment—initiated by the Estonian Ministry of Climate and integrated into the national permitting infrastructure—rather than a pilot or municipal-level initiative.

The author served as conceptual architect and project manager for the initiative, overseeing software architecture, rule-checking logic, stakeholder engagement, and regulatory alignment. This insider role enabled direct insight into policy negotiations, system design, and cross-agency coordination. The case study spans the full implementation lifecycle—from the 2019 proof-of-concept through technical specification, development, testing, and national rollout. The BIM-based permitting system was formally launched within the EHR on 14 February 2024, and by year's end, it had supported the issuance of its first two BIM-based permits.

The empirical materials were analysed using an interpretive, thematic approach, focusing on institutional design, governance logic, the translation of legal requirements into technical specifications, and stakeholder experience. Particular attention was given to how regulatory intent was encoded into digital form, and how open standards—such as IFC—enabled automation, extensibility, and interoperability in a public-sector context.

While the author's embedded role offers depth and contextual insight, it also introduces concerns around subjectivity. To mitigate bias, methodological triangulation was applied—cross-referencing findings with peer-reviewed literature, external evaluation reports, and international comparisons (e.g., BRISE-Vienna and EU-level working groups). The study is further situated within established frameworks of digital government and regulatory innovation to contextualise Estonia's experience in the broader European landscape.

Results

Digital Building Permitting within the Estonian Building Registry

The EHR, developed under the Ministry of Climate, is the central digital platform for managing the full lifecycle of construction-related procedures. More than a data repository, EHR is a workflow-driven system supporting

application, review, decision-making, and public communication in a legally binding and transparent manner.

Fully web-based, the EHR serves as the main interface for applicants and authorities—including local governments, developers, architects, engineers, and citizens—handling building permits, design conditions, occupancy certificates, and other authorisations. Each process is embedded with legal logic and metadata from Estonia's Building Code and Planning Act.

A key strength of the EHR is its modular microservice architecture, which enables integration with national registries such as the address system, cadastral registry, geospatial maps, and population data, as outlined in the official developer documentation (EHR, 2024). This allows automated validation of contextual information like location data and ownership without manual input. Although the cadastral registry is not yet three-dimensional, and the BIM-permitting system does not currently validate against cadastral restrictions, future development will address this, with a focus on zoning compliance. At present, the EHR queries cadastral data via X-Road to prevent duplication across registers.

User experience is prioritised through structured, form-based submissions that guide applicants with embedded validation and feedback at each stage of the permit process. As each field in the application form is linked to back-end rules and data validation mechanisms, it significantly reduces input errors and administrative delays. Authorities can issue clarifications or approvals within the same interface, and approved permits are automatically archived and shared as appropriate. Once approved, permits are automatically recorded and made available for public or professional access, depending on the level of sensitivity.

Importantly, EHR functions as a governance platform, not just a technical tool. Workflow and decision logic changes undergo formal design processes aligned with Estonia's public digital service principles. The platform is continuously updated in collaboration with ministries, municipalities, and users via an openly published agile roadmap.

Despite its strengths, the EHR faces challenges, including usability issues, as users frequently find the system unintuitive (Arrak et al., 2024), and a continued reliance on document-centric workflows (e.g., PDF submissions), which hampers automation, reduces transparency, and causes delays in the permitting process. Ongoing reforms seek to resolve these issues by adopting machine-readable formats like IFC to improve data quality, automation, and process visibility.

In summary, the EHR offers a centralised, legally grounded digital infrastructure for permitting, designed to support cross-agency interoperability, real-time validation against authoritative data, and continuous adaptation to evolving regulatory needs. This institutional and technical foundation has enabled the integration of model-based processes within an operational permitting system, rather than as a separate or experimental initiative.

Development of the BIM-Based Permitting Process

The development of Estonia's BIM-based permitting solution was driven by a clear policy mandate to improve regulatory transparency, reduce processing time, and support machine-readable permitting. Initiated by the Ministry of Climate, the project was designed not as a pilot but as a national-scale deployment fully embedded in the EHR. The aim was to create a legally equivalent, model-based permit application path that integrates with existing digital workflows. This required both a new IFC model submission interface and a fully integrated microservice architecture within the EHR. The resulting solution consists of a distinct BIM module that manages the intake, validation, and storage of IFC files, while maintaining synchronisation with the broader permitting workflow and administrative logic of the registry.

Following the initial 2019 proof-of-concept, several iterative phases were conducted, including use case mapping, feasibility studies, user interface (UI) prototyping, legal analysis, and stakeholder workshops. Developed using agile methods, the system incorporated feedback from municipalities, permitting officers, vendors, and policymakers to address regulatory, technical, and operational needs.

At its core, the process relies on a web-based interface allowing applicants to upload one or more IFC models linked to specific buildings in their permit application. Uploaded models are processed by BIM.works developed by BIM Base (<https://bimbase.nl/>), which performs validation, geometric analysis, and metadata extraction. Built-in visualisation tools let applicants and authorities inspect models, toggle rule-check results, and review comments anchored in the 3D geometry. Designers can check their models and see the results of automated rule checking, before submitting the application. There are no differences between the view of applicant and municipality regarding the BIM functionalities. Results are downloadable in BIM Collaboration Format.

Rule checks are a mandatory step before submission. Applicants must review all results, respond to failed checks using embedded commenting tools, and confirm that any unresolved issues are either addressed or acknowledged. This structured interaction between automation and human accountability ensures traceability and reduces legal ambiguity.

The BIM module integrates with multiple EHR components—file systems, notifications, commenting tools, and metadata services. Events are managed via asynchronous message queues, and all key actions—upload, check, log—are traceable via audit trails. Its modular architecture supports horizontal scaling and future extensions (e.g., new rules, third-party engines) without disrupting core infrastructure.

From a data governance standpoint, a key decision was to avoid rigid schema constraints. Instead of enforcing a uniform IFC structure, the system extracts regulatory-relevant properties using flexible mapping techniques. This reduces barriers for smaller firms and accommodates real-world variation in IFC authoring across platforms.

In sum, Estonia's BIM-based permitting system was built not as a prototype, but as an institutionalised digital pathway. Grounded in national regulation and integrated with state systems, it demonstrates how public-sector digital infrastructure can support model-based rule checking at scale—embedding machine-readable models, automated compliance logic, and legally binding workflows within a unified national permitting framework.

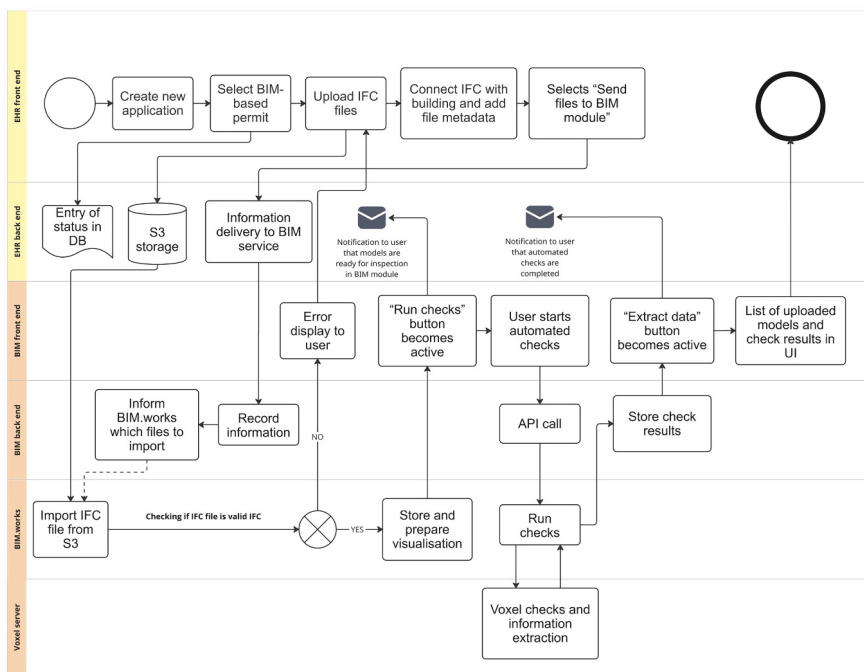


Figure 19.1 Technical flow diagram of the IFC model upload process.

Stakeholders and User Interface Considerations

A key principle in developing Estonia's BIM-based permitting system was accessibility—both technical and cognitive—for the diverse stakeholders involved. While applicants are typically design professionals using modelling (Revit, Archicad, etc.) and coordination tools (Solibri, BIMcollab, etc.), permit officials and municipal reviewers often lack BIM expertise and do not use high-performance computers capable of running desktop model viewers.

To avoid creating adoption barriers, the system was developed as a fully web-based application. Most public-sector users work on standard laptops with limited graphics capacity. Deploying GPU-intensive desktop software across municipalities would have required major investments in hardware and training. A browser-based solution allows immediate access for any authorised official without installation or setup.

UI design was equally critical. Many reviewers are experienced in 2D drawings and narratives. Introducing them to complex BIM viewers could cause confusion. The EHR-embedded BIM module was therefore designed with minimal functionality—a streamlined interface for uploading models, viewing them in 3D, and inspecting rule-check results linked to specific elements. Figure 19.2 shows an example UI with a negative check result and a commenting function.

This approach yields two main benefits. First, it lowers the threshold for permit officers to work with 3D models by reducing distractions and learning curves. Second, it preserves workflow continuity: applicants—typically BIM professionals—remain responsible for model authoring and compliance, while permit officers focus on decision-making, aided by simplified review tools. This ensures a clear division of labour and supports accountability.

Role-based commenting and simplified navigation allow feedback without requiring technical expertise. Rather than training all officials in BIM, the system adapts BIM logic to existing roles. Early feedback from municipal reviewers indicates that the streamlined interface has reduced onboarding time and

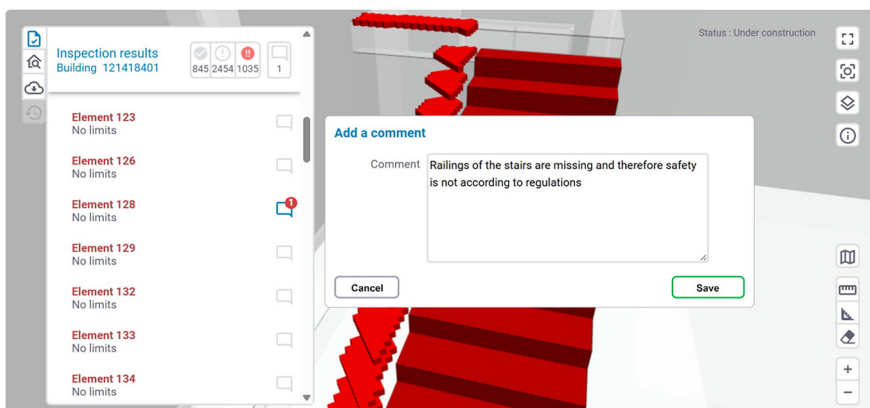


Figure 19.2 Example of UI with negative check result and commenting function.

enabled model-linked commenting, even with little to no prior BIM experience. This reflects a broader insight: successful adoption depends not just on technical capability, but on alignment with daily practices and digital capacity.

National BIM Requirements and Information Delivery

Automated compliance checking depends on structured, machine-readable data in submitted IFC models. To enable this, Estonia developed national BIM requirements known as ÜBN (Common BIM Requirements), including a dedicated annex specifying required building data content. These define the IFC entities and properties needed for rule checking, validation, and integration with the EHR.

While international standards like IDS are gaining momentum, Estonia's system predates its publication and currently relies on national specifications—property set definitions (Psets), IFC field naming, and backend validation logic. Migration to IDS is planned, with future support for importing IDS files to verify model consistency and readiness.

With these structured requirements in place, the rule engine can apply both basic validations and advanced compliance logic directly to the model.

Standardised IFC property content is essential—not just procedural—for automation. Without consistent naming, structure, and semantics, models can't be reliably checked. For example, if the fire safety class (fire-resistant, fire-retardant, or combustible) is not recorded correctly in the AR_Building (AR representing architectural discipline) property set, the system cannot apply appropriate rules for evacuation, resistance, or compartmentation. Similarly, mislabelled or missing room categories in AR_Space can cause key checks—like minimum area or accessibility—to fail. Table 19.1 shows examples of mandatory properties used in rule checks.

Many of these attributes were newly introduced into the ÜBN specifically for the BIM-based permitting system, with no precedent in earlier BIM mandates. This initiative has advanced both regulatory and modelling standards. Model authors are advised not to omit required attributes—even when no value applies—but to use placeholders like “-” to maintain validation continuity.

The ÜBN framework acts as both a data contract and a compliance interface, reducing interpretation ambiguity and ensuring uniform enforcement of national code requirements. Once aligned with IDS, it will also support broader interoperability, enabling standardised data exchange across systems and jurisdictions.

Automated Compliance Checking

A cornerstone of the system is its ability to perform automated compliance checks on digital building models using a hybrid logic engine integrated with the EHR and BIM.works backend. The aim is not to replace human

Table 19.1 Examples of User-Defined Property Sets and Their Purpose for Rule Checking

<i>IFC Entity</i>	<i>Property Set</i>	<i>Property</i>	<i>Purpose</i>
IfcBuilding	AR_Building	PurposeUseCode	To set requirements for fire safety checks depending on the purpose of use of the building. Five-digit code from a predetermined selection.
IfcSpace	AR_Space	Category	Room classification for area calculations and legal checks. Text from a predetermined selection.
IfcSlab	AR_Slab	LoadBearing	Identifies load-bearing elements for fire resistance analysis. Boolean value.
IfcZone	AR_Zone-FireSafety	EvacuationRoute	Marks the evacuation routes for safe exit path validation to calculate the proper exit route length. Boolean value.
IfcBuildingStorey	AR_Storey	LegalStorey	Determines legal storey status under national codes to extract correct data to the application and determine fire safety requirements. Boolean value.

decision-making but to pre-screen models for common code violations, highlight inconsistencies, and accelerate permitting.

The system currently supports 47 automated checks covering spatial requirements for housing, fire safety, accessibility, and legal definitions of building elements. These checks were selected from interviews with permit processors to maximise the impact in the process and minimise the effort for the applicants. Many are traditional rule-based validations—for example, verifying that bedroom and living room areas meet the national minimum (e.g., 8 m²), or that load-bearing walls meet fire resistance classes based on use. These rules are implemented as parameterised functions applied to model geometry and property sets.

Beyond basic rule matching, the system supports advanced compliance logic. A key innovation is the use of connectivity graph algorithms to verify accessibility. For instance, if an apartment is on the fourth floor or higher, the system traces the path from the entrance via elevators to ensure a barrier-free route. If none exists, it flags an error.

Another advanced technique uses voxel-based spatial analysis. For example, to determine stair safety, the system generates a 3D occupancy grid around stair geometries to assess fall zones, headroom clearance, and obstacle-free distances. This enables automatic detection of safety issues—such as unguarded edges or long escape routes—that are difficult to catch through 2D review. Figure 19.3 shows an example of voxel-based fire escape route validation.

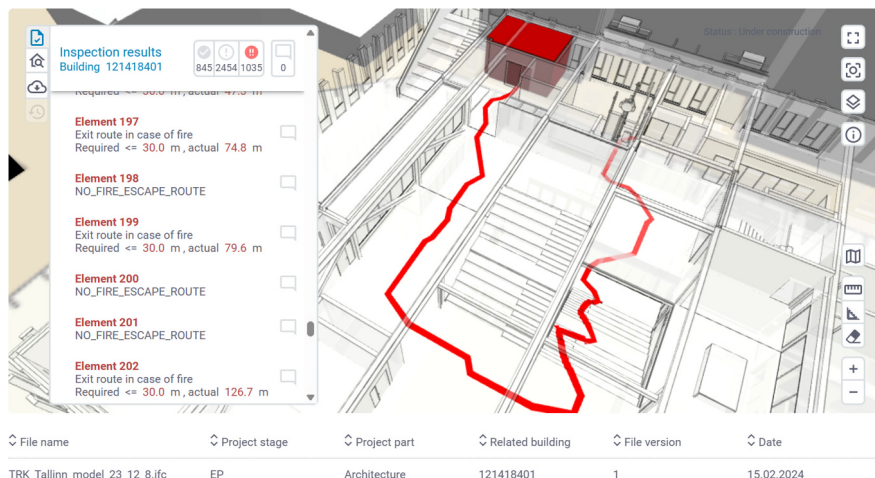


Figure 19.3 Voxel-based fire escape route calculation example in BIM module UI.

However, automation introduces not just speed but also risk. Two types of errors must be actively managed:

- **False negatives** occur when the system flags a non-existent error, often due to complex legislation with many exceptions and interpretive room. Eliminating these would require more granular data entry, which is often unjustified. Reviewers are trained to recognise and clear such false alarms without rejecting submissions.
- **False positives** are more problematic. These arise when the system misses actual violations due to missing or misclassified data. For example, an unlabelled room may bypass area checks and lead to non-compliance. To mitigate this, the BIM requirements enforce mandatory property population, with warnings triggered for absent classifications.

Rule updates are centrally managed by the EHR team in collaboration with domain experts to stay aligned with legislative changes and best practices.

To reduce the user burden, the system extracts structured data, such as building function, heated area, number of floors, and apartment counts, directly from IFC models. Traditionally, this took 1.5 to 2 hours for a multi-storey building; in the BIM-based process, it happens in seconds, cutting administrative effort and reducing error risk.

The rule-checking engine is modular, allowing checks to be added, updated, or deactivated without disrupting system stability. Each check includes structured metadata such as severity, feasibility, legal source, and classification (e.g., “fire safety”, “geometry”), with outputs exportable in both human- and machine-readable formats to support EU-level integration and multilingual access.

Together, these rule-checking and data standards form the technical core of Estonia's BIM-based permitting system, offering a replicable model for combining automation and transparency in regulatory decision-making.

Discussion

Estonia's BIM-based permitting initiative demonstrates that large-scale automation of regulatory processes is both technically feasible and institutionally achievable. Its success lies not in algorithms or IFC compliance alone, but in integrating legal mandates, user-centred design, and adaptable technical standards within a coherent governance model.

A core strength of Estonia's approach is its socio-technical alignment. By prioritising web-based access, reducing data entry in BIM models and application forms, and simplifying rule interactions, the system reflects real-world public-sector conditions. Rather than assuming widespread BIM fluency, it accommodates varied institutional capacities, enabling broader adoption and long-term sustainability. The use of modular architecture, national BIM requirements (ÜBN), and open APIs reflects strategic foresight. These elements support interoperability with other systems and provide a path towards standards-aligned evolution. For example, future adoption of IDS would support deeper assessment of data quality and model completeness—ensuring that automated checks operate on reliable inputs. This flexibility positions Estonia's infrastructure as a future-ready platform, not a one-off solution.

Nonetheless, challenges persist. The reliability of automated checks is limited by data quality and legal ambiguity. False positives and false negatives still occur, especially when models omit key classifications or rules that require contextual interpretation. Estonia addresses this with a hybrid model: applicants must respond to failed checks, while reviewers retain discretion—balancing automation with accountability. This hybrid approach offers a practical model for jurisdictions seeking to digitalise permitting without undermining legal due process. Court practice in Estonia has established that local municipalities are responsible for interpreting the building code in many cases—particularly zoning, architectural, and environmental matters. Therefore, building control must also verify the content of the design, not only whether all the required documents exist and all designers hold the appropriate professional qualifications, which makes the quality of rule checking an important issue.

Deeper obstacles are structural. Building regulations remain non-machine-readable, and no widely usable systematic method yet exists to determine which rules can be automated. As a result, rule development depends on expert interpretation and manual translation—demanding ongoing collaboration between legal and technical actors and sustained institutional capacity, as it was done in Estonian BIM-based permitting development. Ambiguities in regulatory language further complicate rule formalisation. The Estonian building code often includes vague or context-sensitive terms that resist translation into strict logic. Ontology-based methods show promise but require intensive modelling and

investment. Similarly, natural language processing tools are not yet capable of reliably parsing Estonian legal texts at the precision required for permitting and therefore, applications remain exploratory.

Still, Estonia's model offers actionable lessons. It proves that nationwide automation is viable when technical, legal, and institutional components are developed in tandem. Moreover, it contributes to broader European-led initiatives—like digital building logbook—by offering a tested reference point for national-scale implementation. Estonia's experience illustrates how domestic innovation can inform EU-wide regulatory harmonisation.

In sum, while Estonia's approach is shaped by its distinctive digital governance, it provides a strong model for designing scalable, user-oriented permitting systems. Future efforts may build on this foundation by advancing legal-technical integration, multilingual regulatory ontologies, and cross-border interoperability.

Conclusions

This case study underscores the critical importance of aligning digital permitting systems with broader legal, institutional, and organisational frameworks. Estonia's experience demonstrates that the effective deployment of BIM-based permitting is not primarily a technological challenge, but an institutional one—requiring regulatory clarity, governance alignment, and sustained stakeholder collaboration.

For researchers, the Estonian model highlights the need for further investigation into the interaction between automated rule-checking and discretionary decision-making. Future research should address how trust can be modelled, measured, and supported in semi-automated regulatory environments, particularly where legal interpretation remains necessary.

For practitioners, this case illustrates that automation in permitting should be understood not as a replacement for human expertise, but as a means to reduce friction, improve efficiency, and enhance procedural transparency. The design emphasis on user-centred interfaces and role-adapted functionality was essential to adoption and operational success, underscoring that usability is as important as technical correctness.

For policymakers, Estonia provides a compelling example that platform-based permitting is a viable and scalable pathway—provided it is grounded in national data standards, legal preparedness, and multi-stakeholder coordination. Institutional design choices—such as the use of open APIs, modular architecture, and public service co-creation—are foundational to long-term sustainability. Importantly, Estonia's model aligns with and informs emerging European efforts towards interoperable regulatory frameworks, including IDS, IFC, and cross-border digital permitting initiatives.

Looking forward, Estonia's experience suggests that the next frontier in digital permitting lies not in deeper automation per se, but in building the legal

and organisational capacity to govern these systems in a transparent, adaptive, and jurisdictionally interoperable manner. As digital permitting evolves into a core component of regulatory infrastructure, its future will be shaped as much by institutional governance as by software architecture.

Acknowledgements

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Data Availability

All the data used for the chapter is available and can be requested to the authors.

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20 Digital Building Permit Service at the Municipality of Rotterdam

Rolf Jonker and Wouter Streefkerk

Introduction

Building Information Modeling (BIM) have long supported design and construction processes and contain a lot of data that could significantly enhance municipal building permit checks. Despite its potential, BIM is rarely used in regulatory building permit check workflows. The Municipality of Rotterdam aims to change this through the Vergunning Controle Service (VCS), a digital building permit service integrating BIM, geospatial data (GIS), and machine-readable legislation to enable automated, transparent, and efficient checks. Developed in line with the Dutch Omgevingswet (Environment and Planning Act), the open-source VCS evolved through several innovation phases and now operates as a Minimum Viable Product (MVP). By applying open standards and linked data technologies, Rotterdam not only improves its internal compliance processes but also sets a national example for scalable, interoperable permitting systems.

Background

The municipality of Rotterdam investigated the opportunities and threats of digitization for the future of Rotterdam with its Digital City program, part of the overarching Digitalization Agenda of the municipality. Through this program, it supports and accelerates digital innovations within its organization and actively shares this knowledge, contributing to digital development both locally and nationally. One of the departments that received support in this regard was the department that handles building permits (department BWT—Bouw- en WoningToezicht). To reach the point of implementing the VCS, the municipality of Rotterdam has undergone several phases of innovation.

Digital Permit Service—Innovation Funnel Process

Since 2025 the department BWT has implemented the advanced permit-checking service VCS. This service integrates a digital BIM model based on open standards, an interconnected digital city, and open digital regulations to

facilitate better permit checks. Real estate developers can submit their BIM models digitally through the national portal for building permit applications called “Omgevingsloket.” The application is then processed in the municipality’s system for handling permit applications (PowerBrowser), where the BIM model serves as input for VCS. VCS then provides recommendations in an interactive report to the permit reviewer based on the submitted and available data.

The development process from idea to reality to reach this point was carried out through the innovation funnel process. At the end of 2020, a proof of concept was completed. The development of the proof of concept was a collaboration between the municipality of Rotterdam and TU Delft. The proof of concept demonstrated that digital permit control based on BIM, Geo, and digital regulations is feasible and justified further development. Based on the knowledge gained, a prototype was developed in 2022 in collaboration with the municipality of Rotterdam and software developer BuildingBits. The end user, the permit reviewer, was intensively involved in the development and testing of the prototype. The proof of concept and the prototype did not yet run in any production environment and therefore did not impact the critical processes. After the successful development of the prototype the Digital City program transferred ownership and responsibility for further development to the permit inspection department BWT. The department then developed the prototype into a minimal viable product in collaboration with the software developer Triply. This minimal viable product was put into production in 2025.

In addition to the development benefits, there are also associated costs. The municipality of Rotterdam applies general guidelines for innovation development costs, where a proof of concept is estimated at €30,000 or less, a prototype at €30,000–€150,000, and a minimal viable product at between €250,000 and €500,000.

Why a Digital Building Permit Service?

The municipality of Rotterdam has a number of goals that the digital building permit service contributes to, including short-term and long-term goals. The following are a short overview of the objectives that are expected to be achieved by VCS, which are also illustrated in Figure 20.1.

Short-Term Goals

The VCS contributes to these short-term goals set by the municipality of Rotterdam for the overall permit control process:

- **Process improvement:** Aligning processes within the organization to make use of digital models. This will enable the use of the VCS within the BWT process steps of the municipality of Rotterdam. The working methods should be made clear to colleagues. This can be achieved through workshops, manuals, or functional management. This supports the development of the municipality processes.

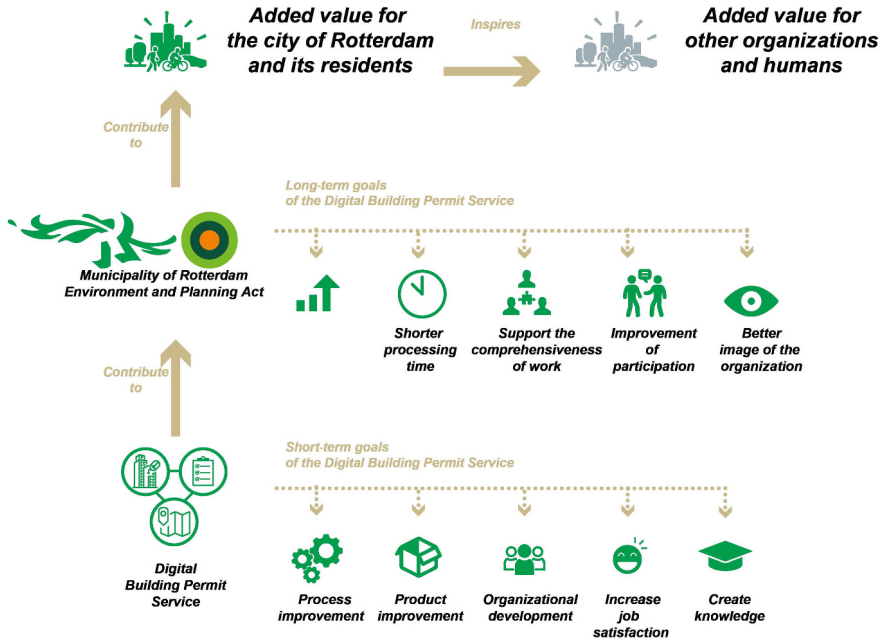


Figure 20.1 Goal Tree of objectives that are expected to be achieved by VCS. (Authors' own work).

- **Product improvement:** The VCS improves the permit control product by providing digital support for insight and completeness checks. Colleagues will get better insight into applications through 2D- and 3D-visualization. The completeness of the checks will be improved by making previously unavailable data accessible.
- **Organizational development:** The building permit department of the municipality of Rotterdam aims to be the best digital department in the Netherlands. The VCS helps Rotterdam stay ahead in terms of digital proficiency. The municipality of Rotterdam can serve as a national example for digital permitting, which the national digital system for the Environmental and Spatial Planning Act, in Dutch known as the *Digitaal Stelsel Omgevingswet* and a federated system for BIM information, in Dutch known as the *Digitaal Stelsel Gebouwde Omgeving*, can build upon. Colleagues are involved in development by assisting with testing and development. Additionally, training and manuals are provided, enhancing digital proficiency within the organization.
- **Job satisfaction:** Using the VCS should be enjoyable. The use of the service should provide more job satisfaction to colleagues.
- **Create knowledge:** Gaining knowledge about how to request a digital model of a design situation, ensuring the model is understandable by both humans and machines and serves as input for various processes. This enables the municipality to optimize its own processes and assist partners.

Long-Term Goals

The VCS contributes to the long-term goals set by the municipality of Rotterdam for the overall permit control process under the new law “Omgevingswet” (for further explanation on this law, see the next paragraph):

- Efficiency and shorter processing times: Digitally supported permit checks on various aspects make it possible to check permits more quickly. A pre-check by the applicant also improves the quality of submissions, speeding up the process and reducing the labor hours required for permit checks.
- Integration: Checking a model against multiple laws and aspects creates cohesion and coordination. Legislation is integrated into the tool, the script, which promotes cross-domain collaboration and effective support. This ultimately results in better quality developments.
- Reputation: By efficiently and qualitatively managing the permitting process, the municipality of Rotterdam gains a reputation advantage. Developing parties will form a positive impression of how the municipality works.
- Participation: Involving citizens and entrepreneurs in the development of the living environment as much as possible. New techniques, such as VR/AR, are used to enhance environmental awareness, which is important for the “reputation” goal.
- Knowledge creation: The process of digitally supported permit control is expected to lead to new knowledge within the municipality of Rotterdam. This knowledge can also benefit other processes.

These short- and long-term goals aim to offer added value to the city of Rotterdam and its residents. What is developed here serves as inspiration for other cities, is reusable, and thus provides added value for other organizations and individuals.

Environment and Planning Act, “de Omgevingswet”

Since January 2024, a new law has come into force in the Netherlands: The Environment and Planning Act, or in Dutch “de Omgevingswet.” This law consolidates 26 laws and many rules and regulations regarding our physical living environment into one single law. In addition to the changes in the law itself, a new digital system has been created for the environmental law. This is a single digital counter where everyone can quickly see what is allowed and what is not. Furthermore, it promotes a new form of collaboration in which participation and integrated working are the key pillars of the approach. The duration of the procedure time for reviewing permit checks has also been decreased. Applications that previously fell under the extended procedure of six months now fall under the shorter procedure of 8–12 weeks.

The VCS aligns with these changes in the law, the system, and the new collaborative approach. It supports the reduction of the procedural time required for permit checks.

Method

Three Realities of the Digital City in Permit Control

Within the Digital City program three different realities are distinguished (see Figure 20.2), based on the theory described by Santema and Brattinga (2018). The first reality is the “real” world, which we call the physical reality, governed by the laws of nature. People experience this as physical, real, and tangible. The second reality is the one where we make agreements with each other. This occurs in laws, regulations, norms, and standards. This is called the social reality or legal reality. The last reality is that of information systems, where everything is stored with data and applications. This is called the digital reality.

During the building permit assessment process, the compliance of these three realities is checked, which is why this concept was applied in the development of the VCS.

The physical reality: This is the tangible, observable world governed by the laws of nature. People experience this reality as concrete and perceptible things that can be seen, touched, and measured. Examples include buildings, roads, trees, or rivers. In the physical reality, events occur in line with natural laws, and it is where construction activities physically take place.

The social or juridical reality: This reality comprises all the rules, agreements, norms, and laws we create as a society. It includes legislation, regulations, oral agreements, and established standards. The social or juridical reality cannot be directly observed; it is abstract and based on shared understandings. For instance, an approval through a permit of a construction

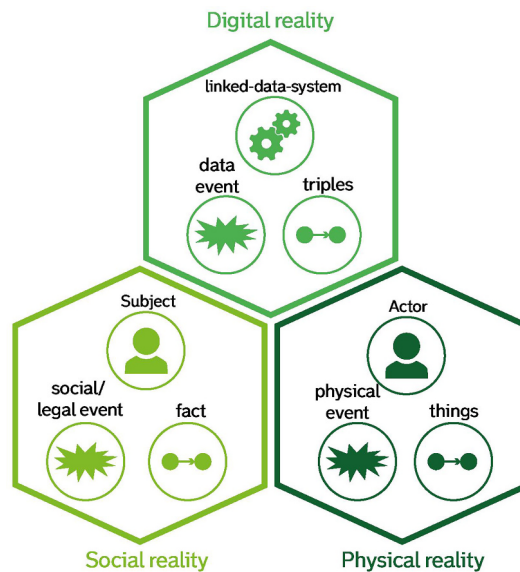


Figure 20.2 Social, digital, and physical reality.

project is not visible to the naked eye. Instead, it is represented through legal documentation and official records, which are vital for maintaining a just and orderly society.

The digital reality: This is the realm of information systems, where data, models, and applications exist. It includes the digital representation of physical objects and legal regulations. Data within this reality must be precise and accurately reflect both the physical and juridical realities to function effectively in decision-making and automation processes. For example, a digital model of a building must correspond accurately to the actual structure and adhere to the regulations that govern its construction.

Interplay between Realities

The three realities are deeply interconnected as shown in Figure 20.3. A physical event, such as the construction of a building, can trigger a juridical event, like the issuance of a permit. This juridical or legal event, in turn, must be correctly captured and represented in the digital systems used by the municipality. Recorded by an actor, and according to the agreed-upon process, this will lead to a data event. It is essential that the legal rules, conditions, and derivations correspond to what is done digitally, so that there exists a final state that is factually correct, both legally and digitally. The permit-checking service ensures alignment among these realities, verifying that digital representations

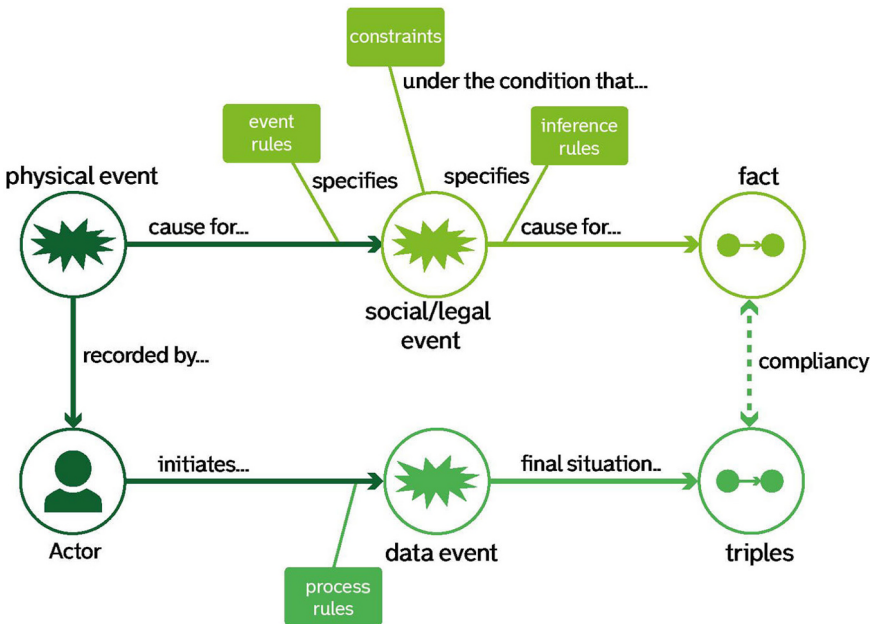


Figure 20.3 Interplay of the three realities.

(e.g., BIM and GEO models) comply with legal requirements and reflect the physical world accurately.

Compliance across Realities

Compliance and correspondence between the physical, legal, and digital worlds are of great importance. It is important that the data in the digital reality correspond with what is in the physical reality. When a “tree” is present in the database, one must be able to assume that the described “tree” will actually be found at the physical location. Also, one must be able to visualize what the data represents. A contractor should not cut down the wrong tree.

The legal facts must be based on the physical reality and actual objects. Legislation should not define concepts that do not exist in the physical reality. Otherwise, one encounters situations like having game rules for the wrong game. The legal fact should also correspond with changes in objects and understanding within the physical reality. Furthermore, the objects in reality must be situated according to the legislation. When a building application results in negative decision, the building should indeed not be constructed in physical reality.

Professionals are engaged in compliance with the realities. An inspector checks whether a builder complies with the permit, a data engineer verifies the quality of data, parliament repeals outdated laws, and linguist work on new concepts and words for real-world objects. The permit inspection service was developed in the context of these three realities.

How Does the VCS Work?

The aim of the VCS is digital support for the current building permit process. To do this, the service needs three key data components:

- 1 Data-driven meaningful 3D model of a building.
- 2 Data-driven meaningful 3D model of a city.
- 3 Data-driven meaningful legislation.

It needs all three components to function correctly. The idea is that a real estate developer provides a meaningful 3D model of a new building. This model contains all the necessary information about the building to check a permit. This includes information about usage, aesthetics, sustainability, construction, fire safety, etc. The building model is placed, geo-referenced, at a specific location in the digital twin city by the developer. The municipality ensures that this digital city is meaningfully available and contains all the digital elements of the city needed for the permit control. This includes information about the underground, spatial planning, and existing assets. As the third component, the legislator provides meaningful rules, including the application area. When combined, it will be clear to both humans and machines whether the combination of the

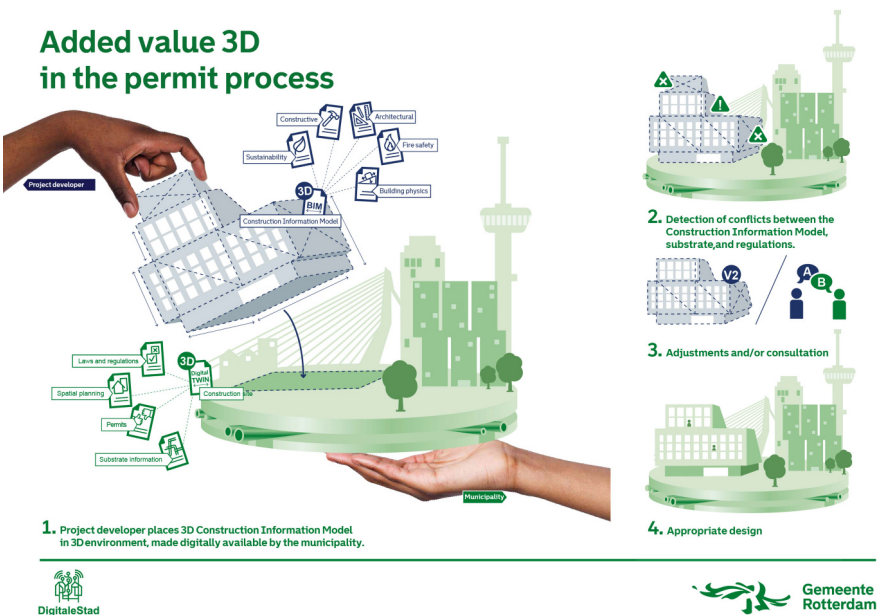


Figure 20.4 Infographic of the added value of 3D in the permit process. (Based on Rotterdam, 2024).

three sources leads to conflicts. Through adjustments and/or consultation with experts, a suitable design is eventually reached. Figure 20.4 shows an infographic concerning the added value of the 3D building permit process.

Information Delivery Specifications for the Digital Building Permit Service

To make the information available for the building permit service, proper information submission must be ensured. The current formats exchanged between parties are meaningful for humans but not for machines. To ensure that both humans and machines can meaningfully view the information, other data formats must be exchanged. A new design is submitted in IFC format, alongside or instead of PDF, and GEO standards such as CityJSON are used to exchange geo-information alongside or instead of maps. As a third element, rules are used in a rule-language such as SPARQL/SHACL instead of or alongside text (Figure 20.5).

Information Delivery Specification for BIM

BIM are an essential source for digitally supported permit controls. A prerequisite is that the BIM model provides essential information needed for the control. Since the IFC schema is used here, it can be understood by both humans and machines. Based on the use of the IFC standard, a specific Information Delivery Specification (IDS) has been created within the municipality of Rotterdam about which objects, attributes, properties, and values need to be

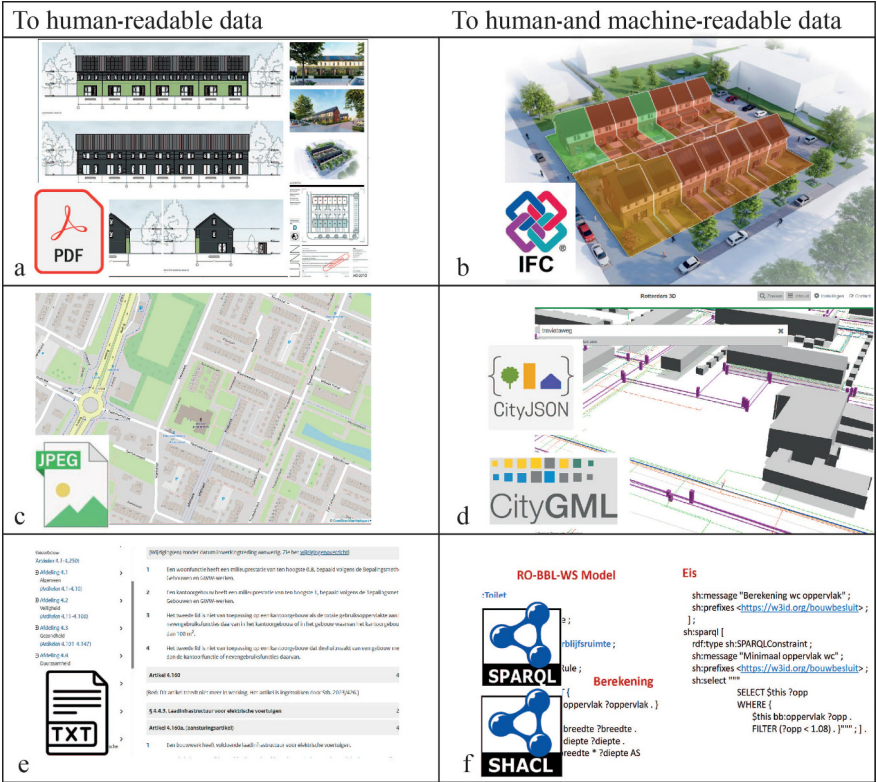


Figure 20.5 (a) PDF permit approval (LIJNN, 2023a), (b) IFC permit approval (LIJNN, 2023b), (c) BasisRegistratie Topografie (BRT) Map view, (d) Rotterdam 3D view, (e) Building Legislation on the web in text (Rijksoverheid, 2023), (f) Semantic rule-checking (Böhms-TNO, 2018).

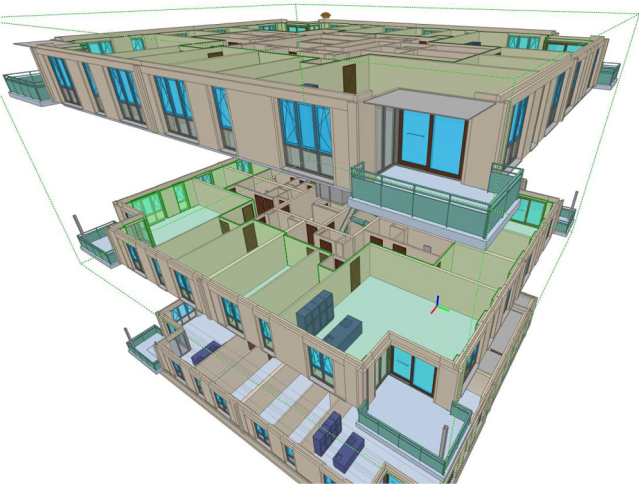
present in a BIM model when it is to be used for digital control. For instance, certain fire safety checks can only be conducted if the submitted BIM model includes information about the fire department entrance. The way the BIM model is georeferenced is also part of the submission requirements. These submission requirements are based on the IDS of Building Smart.

The specification of which information must be delivered, in Dutch Informatie Leverings Specificatie (ILS), builds upon Dutch national ILS standards such as the “BIM basis ILS” and the “ILS Ontwerp & Engineering.” Since these existing ILS do not yet sufficiently address the concept of “space,” Rotterdam has published an additional ILS on this aspect. Because the submission requirements for Rotterdam overlap significantly with the submission requirements of other governments, a generic ILS section has been developed and published by the national DigiGO program, which can be used by everyone (Jonker et al., 2025). The portal for application currently provides submission requirements to applicants. The next step is to offer the Rotterdam and national ILS in this portal (Figure 20.6).



ILS VOOR RUIMTEN IN DE OMGEVINGSWET

Indieningsvereisten van ruimte-modellering t.b.v.
vergunningsaanvraag OmgevingsPlanActiviteit (OPA) en
Technische Activiteit (WKB)



Van	Rolf Jonker, Abe Reurings, Wouter Streefkerk, Paul Strokap, Lex Ransijn, Menno Mekes, Juun Steen, Pepijn van der Vooren, Thomas Krijnen
Datum	Maart 2025
Versie	Definitief

Figure 20.6 Cover of the IDS standard for spaces in the “Omgevingswet” (Jonker et al., 2025).

A BIM Model That Is Compliant with the Information Delivery Specification

To investigate the feasibility of the IDS, a BIM model that complies with its own specifications was developed by the engineering office of the municipality of Rotterdam in collaboration with KuiperCompagnons.

It is possible to use this model for testing purposes. The rules in the VCS are based on the semantics of the ILS. This model can also serve as an example for other modelers (Figure 20.7).

Space Hierarchy Service

Many different types of spaces are required to be able to perform checks. Manually modeling these spaces is possible. However, to reduce the workload on the modeler, a space hierarchy service has been developed. Based on a minimal set of space-related information, additional information about other types of spaces can be created using logic.

This logic is part of the ILS for Spaces (or ILS Ruimten in de Omgevingswet in Dutch) (Jonker et al., 2025). The space hierarchy service uses an analysis of half-spaces to detect spaces and adjacent walls without the need for the BIM model to be perfect. Using voxelization techniques, the service checks whether a space in the model also contains a modeled space. The space hierarchy service was developed as a service alongside the VCS (Figure 20.8). It is not part of the service but can be effectively used in combination (Jonker et al., 2024).

Information Delivery Specification for GEO

Geographic information is a second essential source for digitally supported permit controls. There is still little software that checks rules requiring both geo- and BIM data. The initiative of the municipality of Rotterdam aims to accelerate development in this area. An example of a rule that requires both geo- and BIM data is the distance between a newly designed building, submitted in BIM, and the surrounding existing buildings, fire hydrants, cables and pipelines, or noise contours. This can only be checked digitally when a BIM model is submitted and geo-information is available and accessible. The VCS uses several geo-datasets for this. Most of them are open geo-datasets that are nationally available. Within the service, this is supplemented with Rotterdam specific datasets, which are in open data format but not nationally comprehensive. Figure 20.9 shows an overview of the data connections while Figure 20.10 shows the Rotterdam 3D map and the building registration database.

Digital Rules

The Digital System for the Environmental Act has provided an Information Model for data in the Environmental Act domain (IMOW). Part of this model is a model for rules. According to this structure, a rule can have a geographical

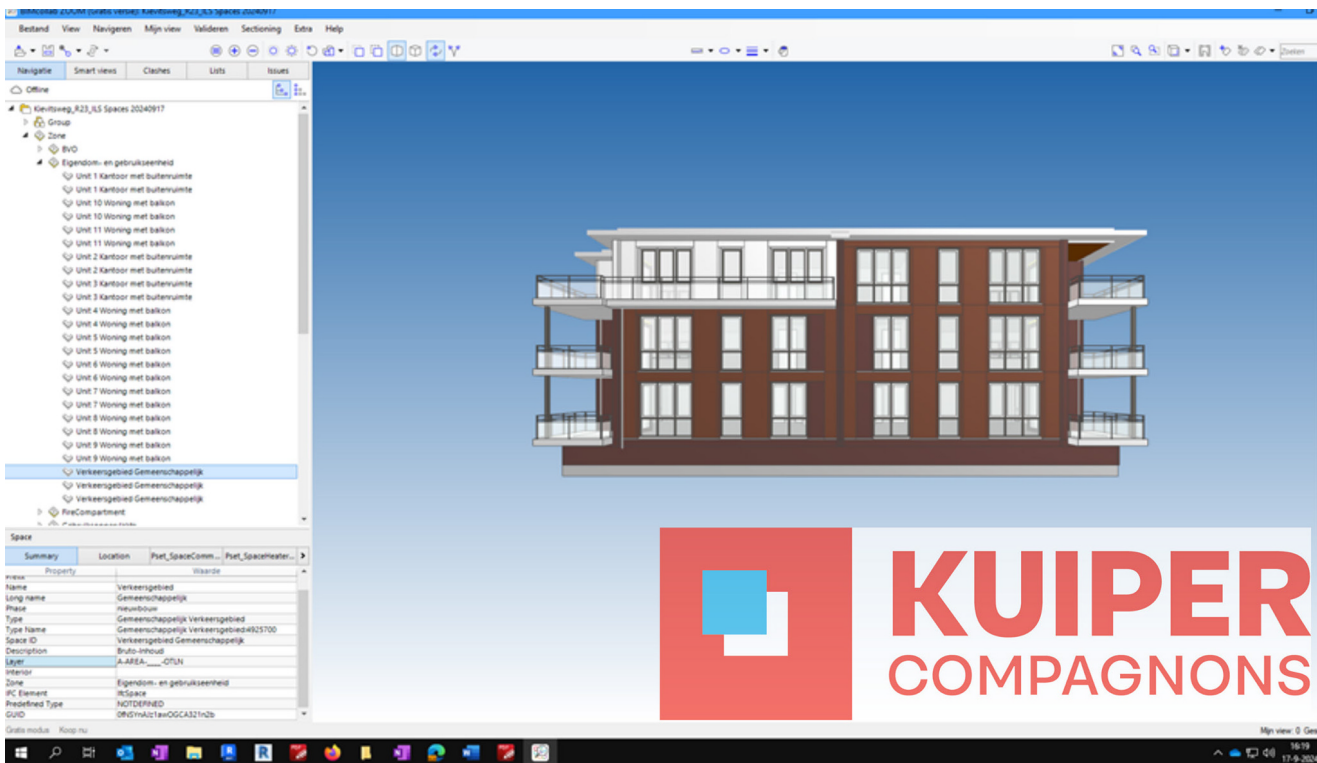


Figure 20.7 Image of a test model that is compliant with the Information Delivery Specification (KuiperCompagnons & Reurings, 2024).

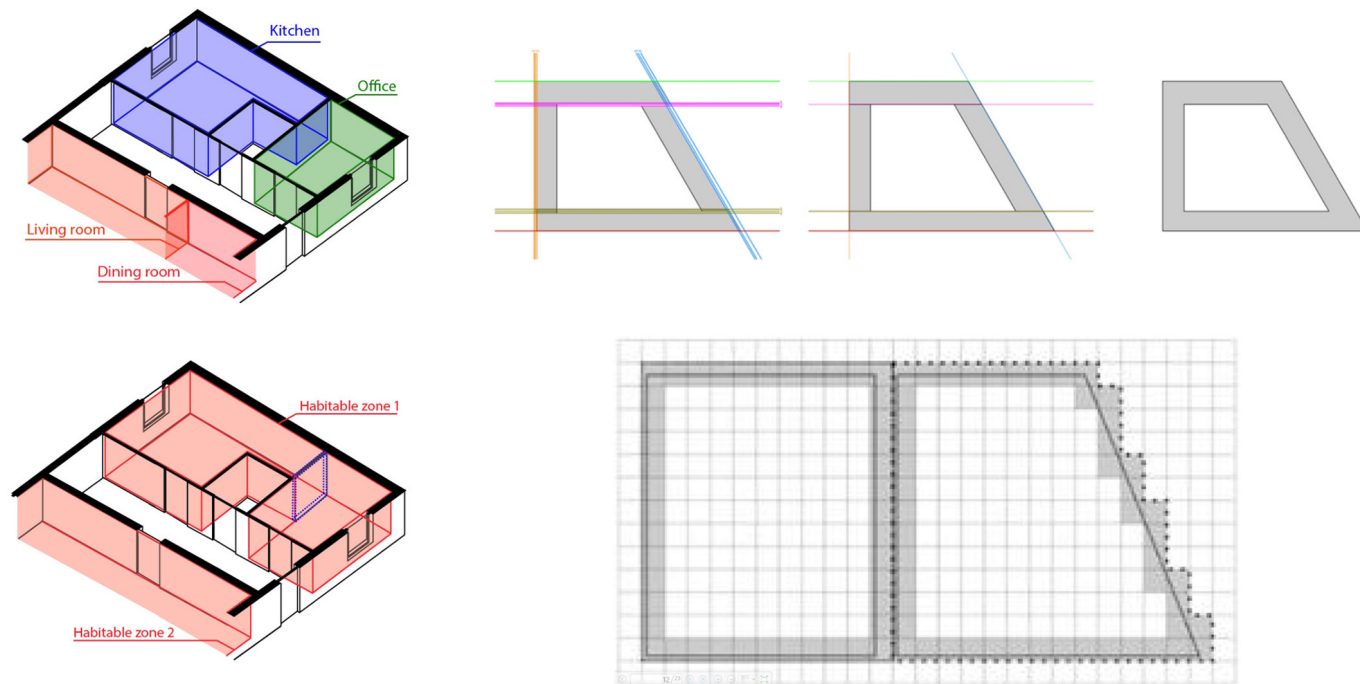


Figure 20.8 Method of extracting higher order spatial objects (Jonker et al., 2025).

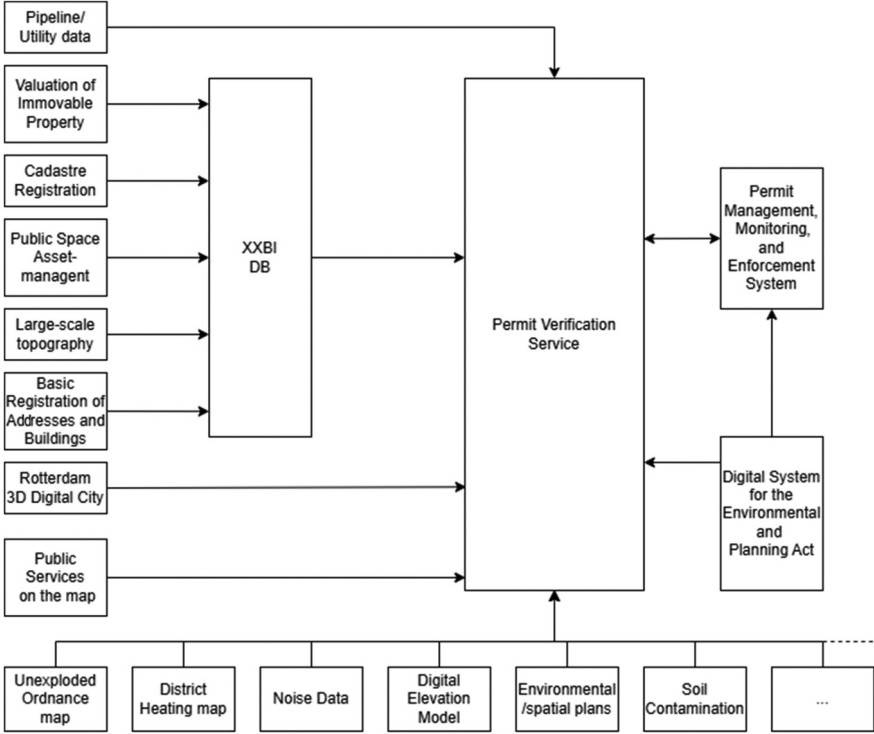


Figure 20.9 Overview of data connections.

reference and a location and can have an activity (e.g., building construction) to which the rule applies. This rule structure can be used by the digital building permit service, with the addition that, besides text, the rule is also available as a machine-readable rule. The VCS uses the open query language SPARQL and SHACL rules for this. Figure 20.11 shows an UML diagram for IMOW.

Below is an example of a rule where a BIM model is checked for its usage function. At the location where this rule applies, “Residential function” is allowed, and “Office function” is allowed only as a secondary use.

The rule is readable for both the machine and the human. This makes the process of permit control based on digital support transparent and traceable. Figure 20.12 shows a screenshot VCS.

Digital System for the Environmental Act

As a municipality, we connect our internal systems to the national provision to exchange information. For example, to publish environmental documents, register applicable rules, or receive permit applications and notifications. The VCS connects to the Permit Supervision and Enforcement (VTH) system and is a stand-alone service. When creating environmental plans, the information model Standard Official Publications, STandaard Officiële Publicaties (STOP) and the

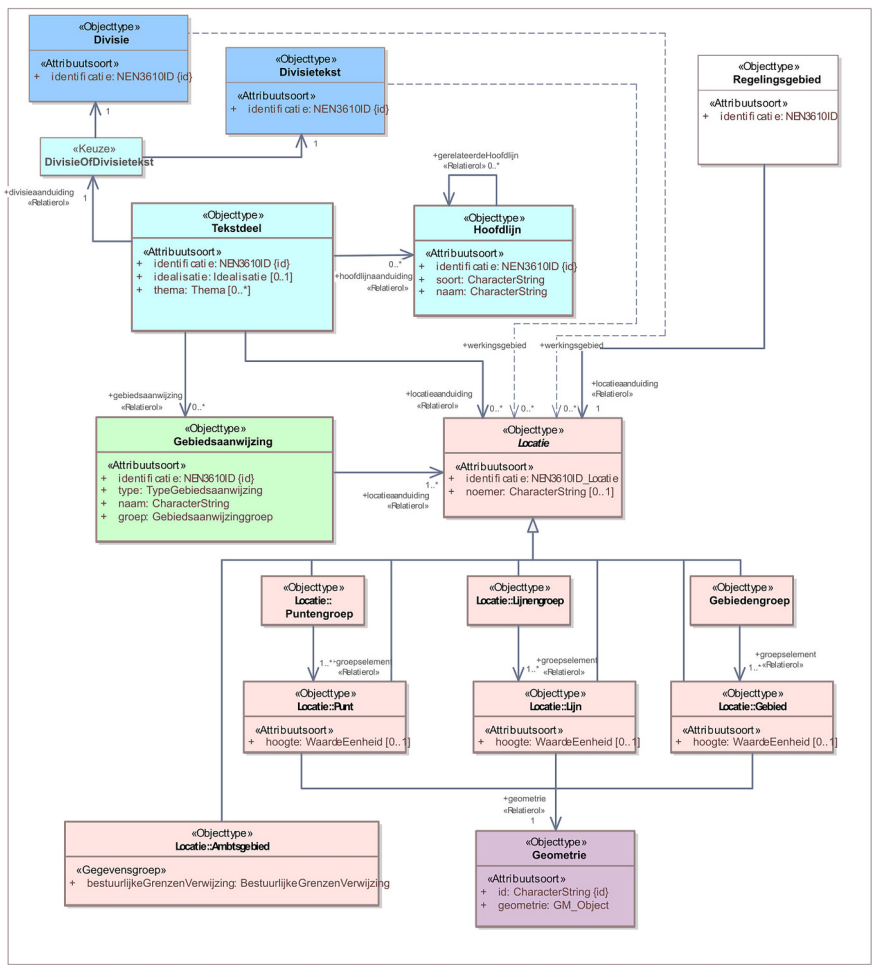


Figure 20.11 UML Informatie Model Omgevingswet (IMOW) (Geonovum, 2023).

Application Profile Environmental Documents (TPOD) are applicable. This data is stored in the National Facilities for Publication and Availability (LVBB). The Object-Oriented Provision of Environmental Documents (OZON) combines rules and locations so they can be viewed in a viewer. The rule is stored in the Registration of Applicable Rules (RTR). Information transfer for applicable rules is done according to the Standard Applicable Rules (STTR), and applications and notifications follow the Standard Application and Notifications (STAM). The Environmental Portal is the central place where this information can be viewed and used. Finally, there is a Cooperation Facility (SWV), which allows collaboration in permit applications. The MVP VCS uses these standards and information provisions (Figure 20.13).

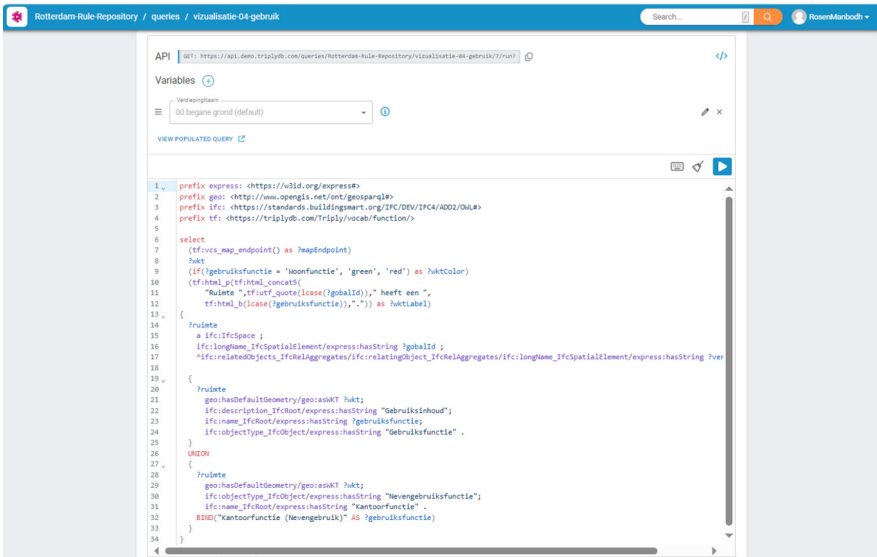


Figure 20.12 Screenshot of VCS showing digital regulation in SPARQL.

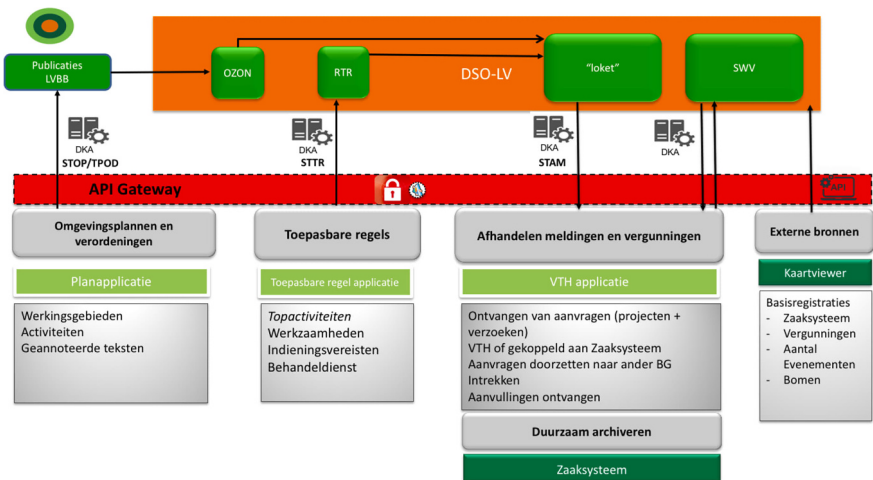


Figure 20.13 API Gateway of the digital system for the environmental act. (Based on VNG, 2020).

Combining and Querying Heterogeneous Datasets

The BIM data, Geo data, and rule data are different data sources from different registrations. The data is structured according to different information models with different vocabularies. The integration of this data is done by making it linked data and combining it in a triple store. This method allows the data to stay as close as possible to the original format without the need for conversion to another information model. Based on this data, various decision reports and exports can be generated (Figure 20.14).

To do this, it is essential to understand the vocabulary of IFC, CityGML, IMOW, and the rules.

For instance, a usage function from the law “Building Environment Regulations” can be found in the IFC model as `IfcSpatialZone` or `IfcZone` of object type “Usage Function.” The attribute “Name” gives the type of usage function, “Residential function.” In CityGML, this corresponds to a `BuildingUnit`, with the class “usage function” and function “Residential function,” and in the IMOW, the designation is “Residential.” The ability to relate concepts in BIM, GEO, and rules to each other is a major part of the task.

ICT at the Municipality of Rotterdam

To technically support the data processing process described above, adjustments have been made within the municipal infrastructure. High-level architecture diagrams, solution architecture diagrams, and detailed ICT schematics for

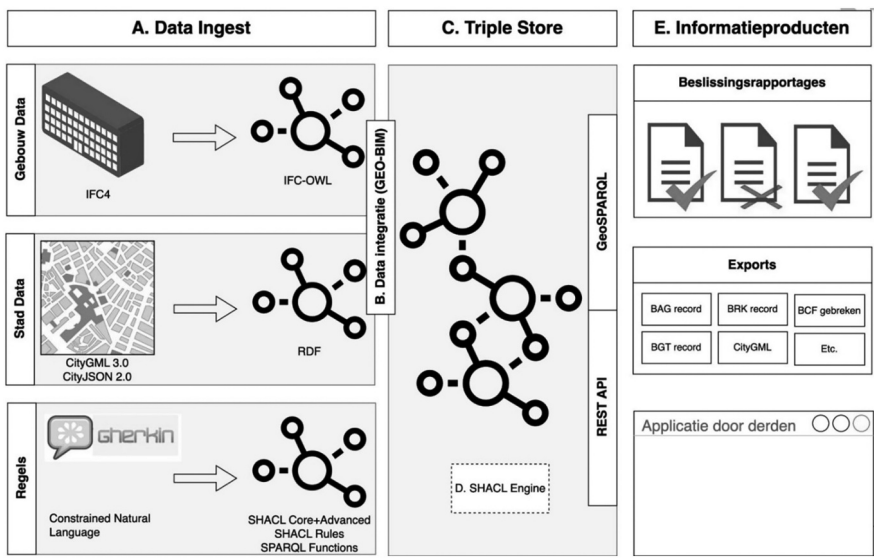


Figure 20.14 Data processing of the VCS (Triply, 2024).

integrations have been developed. Working with linked data in a triple store is new for the municipality of Rotterdam. A key part of the task was to correctly implement the service while ensuring privacy and security measures were upheld.

Result

The VCS in the BWT Process

The permit control process of the BWT department comprises three top-level processes: Exploring Initiatives, Processing Permit Applications, and Oversight and Enforcement. Currently, the VCS can be utilized in the permit application process, which consists of four parent processes, two of which are supported by the VCS. It supports the intake of permit applications, helping to determine if all necessary information is present. The submission requirements for BIM are outlined in the IDS standard of Building Smart International. The VCS generates an HTML report based on these IDS requirements. A BCF file is another output product that can be provided to applicants to show where the BIM model does not yet comply. This process step also verifies georeferencing by visualizing the BIM model in 3D alongside the 3D Geo-city.

Once approved, the VCS can also be utilized in the next process step—substantively reviewing the permit application. This includes verifying whether the intended use aligns with zoning, whether the building height meets the requirements, and whether the building form fits its surroundings. Technical requirements regarding construction, building physics, and fire safety have also been conceptually addressed. Figure 20.15 shows a building permit process map for the municipality of Rotterdam.

There are certainly opportunities for expanding the VCS for process steps outside the current scope. During the initiative exploration, potential projects can be quickly assessed, and in public notices, supervision, and enforcement, 3D models could provide better insight into what has been applied for. Once the process is complete, the registration as a building model for the land registry could be facilitated. These are potential areas for future development.

Digital Building Permit Control Service Container

The VCS is developed as an open-source product, with its code available on the Rotterdam's GitHub site.¹ Based on this code, an installation file can be created—a Docker image. When executed, this creates an instance of a digital building permit service in the relevant environment. The municipality of Rotterdam has implemented this, making the service available to permit control staff in the BWT department. The service is not offered by Rotterdam outside of the municipality, though anyone can set up the service in their own environment. The municipality is also in discussions to make the service available on a national platform for governments and market parties. Figure 20.16 shows the Digital Building Permit Container Service.

PROCESPLAAT BEHANDELEN VERGUNNING AANVRAAG voor gemeente Rotterdam

Toplevel

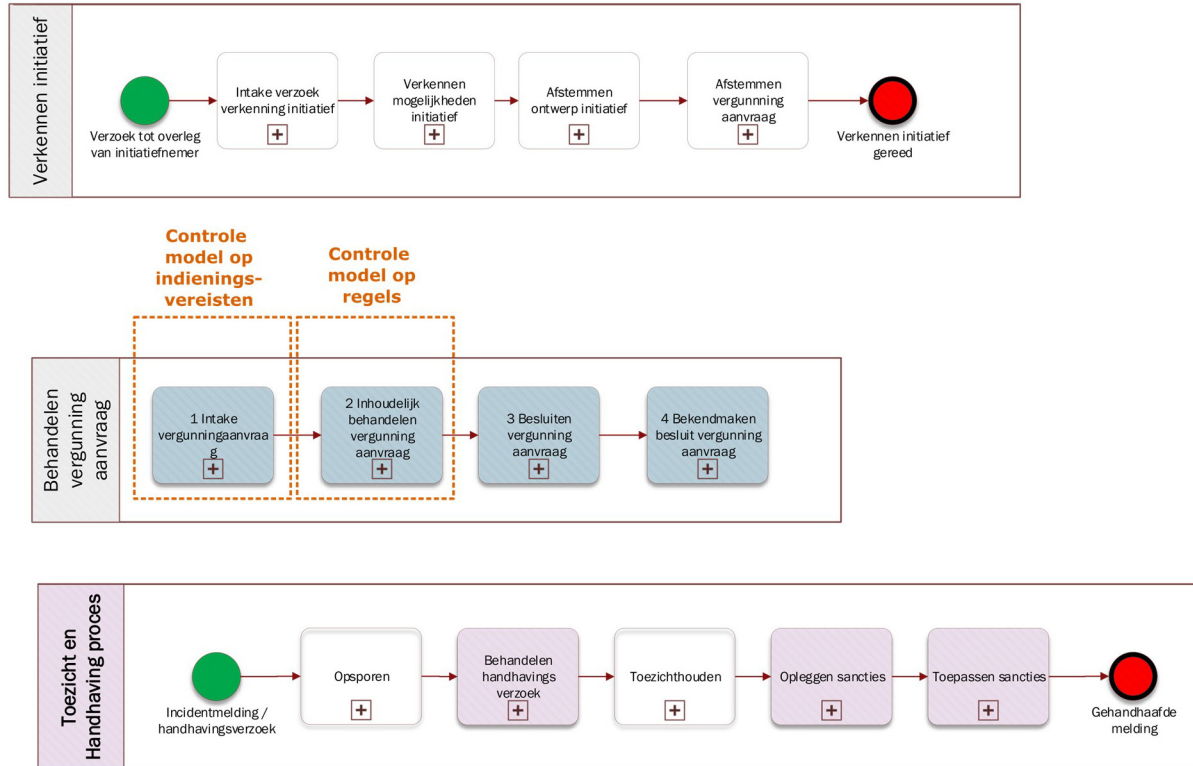


Figure 20.15 Business Process Model and Notation (BPMN) of the building permit process of the municipality of Rotterdam and usability of the VCS.

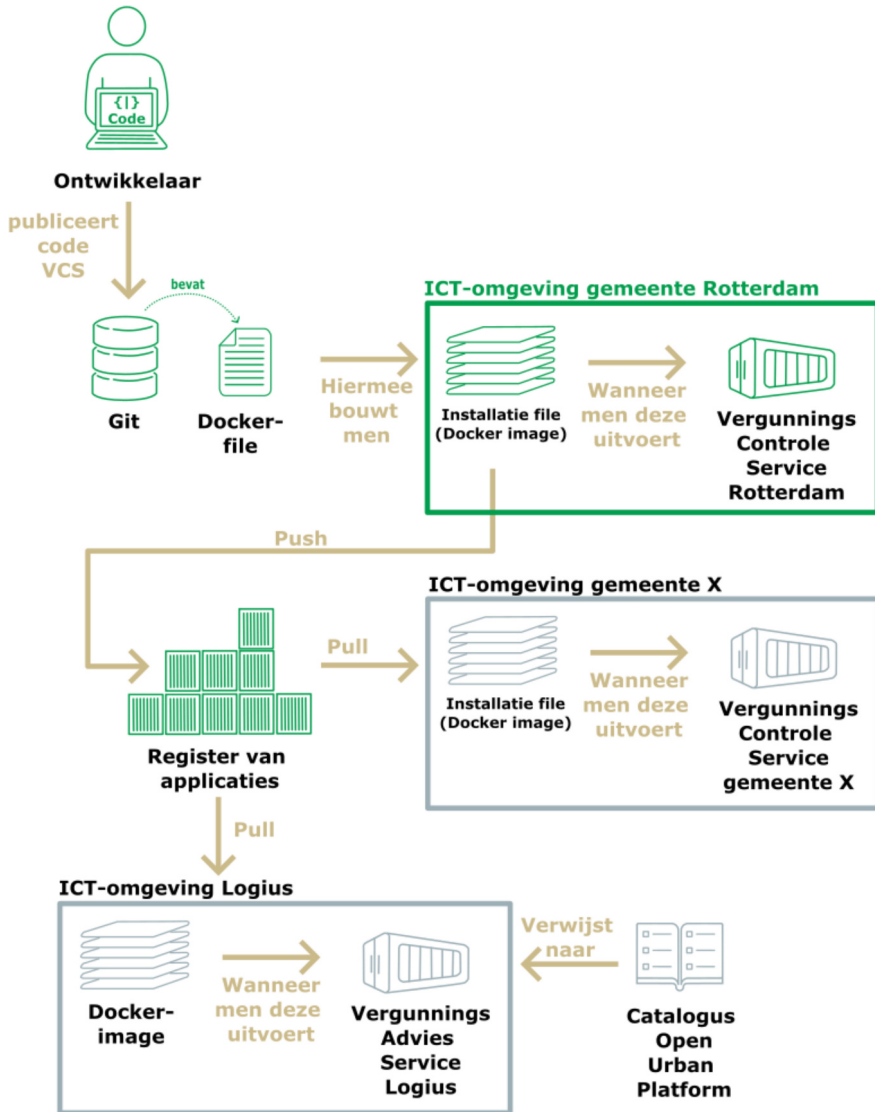


Figure 20.16 Digital building permit container service. (Authors' own work).

Maturity Level of the VCS and the Organization of Rotterdam

The High Level Construction Forum (HLCF) and the CHEK project offer maturity models for digital permit control. The municipality of Rotterdam has briefly examined both models. Based on the HLCF, the service and the organization can be assessed at Level 4, according to Figure 20.17. The VCS allows for integration of 3D BIM and 3D GIS (GeoBIM), and it is possible to apply

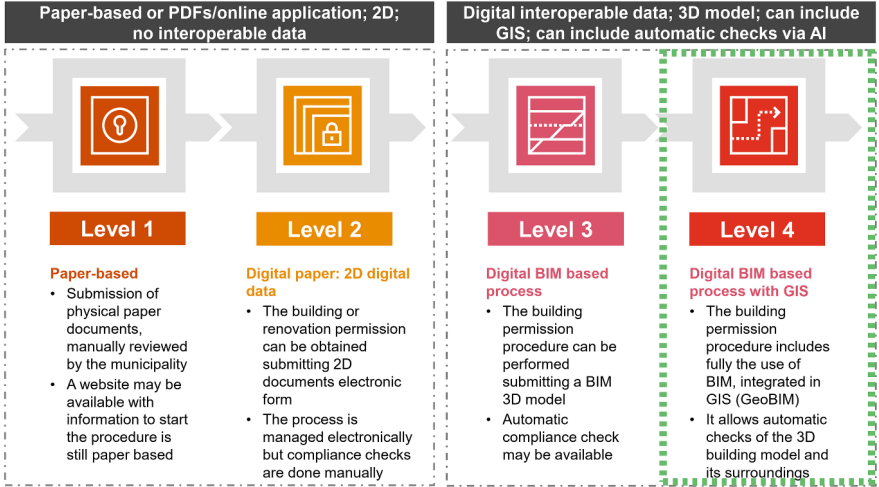


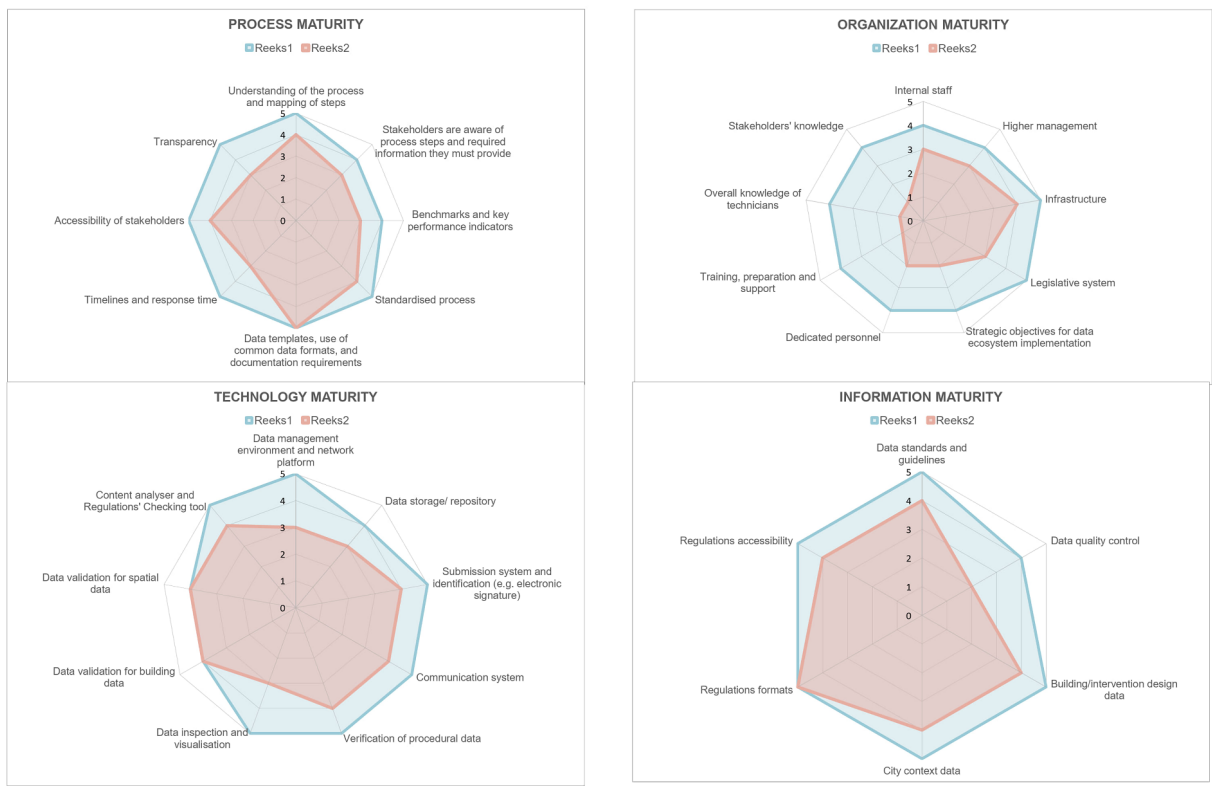
Figure 20.17 Four levels of digital maturity of building permits (Pwc, 2024).

machine-readable rules. A significant advantage of the chosen technology is that the control process is not a black box, unlike certain applications, such as large language models (LLMs).

The CHEK Maturity model shows in Figure 20.18 that the municipality of Rotterdam is reasonably mature in terms of technology and information. The greatest challenge for the future is to elevate the process and the organization to a higher level. As the VCS was delivered at the end of this year, the organization has not yet had time to become familiar with the developed technology. This will be a key focus moving forward.

User-Centered Approach

The end user has been central throughout the development of the digital building permit service. The service aims to assist people who review permit applications in their work. Since permit control does not yield a simple yes/no answer, the judgment of domain experts remains paramount. The VCS can be viewed as an advisory digital colleague rather than a controlling authority—a “computer says no.” To meet the end user’s needs, they were involved in the development process of the VCS. Feedback was provided on various iterations from different domains. This feedback was processed by the development team to ensure the delivered application aligns as closely as possible with the desired functionality. Users involved in preparing BIM models and establishing rules were also included in the service development process. Figure 20.19 shows photos of the digital building permit of the development and current situation of the Digital Building Permit solution in Rotterdam.



GRAPHICS

CDBPMM v1.1

1

Figure 20.18 Results of the CHEK Maturity model for the municipality of Rotterdam. (Based on CHEK, 2024).

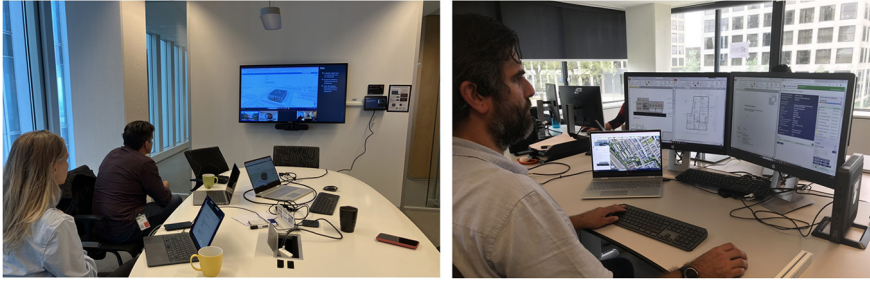


Figure 20.19 Photos of the development of Digital Building Permit (left) and current situation (right).

Current Status

Rotterdam currently (2026) has the VCS in the production environment. The internal service can be used when a BIM model is submitted as an attachment in an application on the national portal. For the current VCS the municipality has developed a number of rules, collected in a rule repository containing the rules for the GeoBIM domain. In the future, this repository could be expanded with other rules or complete rule sets. Another result is that the VCS code has been published on GitHub. In the Netherlands, the national “Common Ground” program brings municipalities together with a community of stakeholders to develop building blocks like software applications, technical components, or data exchange standards to realize the Common Ground vision. This vision assumes a flexible information provision using a shared data layer, enabling modern data exchange and smart data utilization. The VCS is included in the portfolio and has received a silver rating.

The VCS currently checks rules that apply within the borders of Rotterdam. An analysis shows that there are around 1,700 building regulations in the appearance policy, zoning plan, and technical regulations, in Dutch known as *Besluit Bouwwerken Leefomgeving*, that are being checked manually. The municipality of Rotterdam hopes to further develop this in collaboration with other parties on a national level.

National Coordination

The goal of the VCS is to be usable beyond Rotterdam. Additionally, it is beneficial for applicants if the permit submission requirements are consistent across various governmental bodies. To achieve this, national coordination took place regarding submission requirements. An initial small set of objects and attributes was agreed upon by governmental agencies, BIM modelers, and project developers. The specifications were published on the national DigiGO framework. They are accessible as an API, and software providers have demonstrated that this service can be integrated into applications.

A new national program is being developed to further refine permit control based on BIM. The municipality of Rotterdam is actively working to align with this program and to share the previously acquired knowledge.

Conclusions

The municipality of Rotterdam has been working for several years on digitally supporting the permitting process. This topic garners significant attention both nationally and internationally, with multiple initiatives aiming to address it. However, “digital permitting control” is an ambiguous concept. Often, a digital permitting control service boils down to validating a local BIM model using software such as Solibri, BIMcollab, Desite MD, or Bim.Permit, which typically focuses on local BIM models and a fixed set of requirements. On the other hand, a more comprehensive approach to digital permitting control incorporates Geo, BIM, and location-based rule data from various datasets. This method relies on a network of data, diverse vocabularies, and the integration of heterogeneous datasets.

A third approach to digital permitting control is the use of LLMs. This method is frequently showcased at conferences and workshops, yet it lacks the transparency and traceability essential for processes with legal implications, like that of Rotterdam. The permitting process here has a legal status, meaning it grants rights to applicants, requiring that all steps, information sources, and conclusions remain transparent and accountable. While LLMs may still be useful for translating natural language into constraint languages like SPARQL, full automation is not currently viable for legally binding decisions.

Digital cities, IDSs, and BIM models are emerging across various governments and market sectors. When these digital representations align in scope and content, the likelihood of a reusable permitting control service increases. To achieve this, IDSs should be as generic and universal as possible, while open standards—especially those provided by organizations like OGC, bSI, and W3C—should be prioritized.

Digital building permitting control based on GeoBIM and rule-based criteria requires coordination between the regulations in legal texts and terms in the Geo and BIM domains. For example, when a regulatory body refers to a “Building,” does it mean the concept of “IfcBuilding” in the IFC schema or a “CityGML Building” in the Geo vocabulary? In legislation, where semantics play a crucial role, clarity is key. It is essential to ensure that legal colleagues understand the vocabulary and definitions from the Geo and BIM worlds to confirm that these match the legal intent.

Despite efforts to make the rules accessible to all, creating a practical tool for generating SPARQL queries without requiring users to write in native SPARQL has not yet been successful. This limitation remains a barrier for new users and must be addressed to improve accessibility.

The permitting control service currently provides fast results—users receive output within seconds—but the role of human judgment remains essential for

final conclusions. Rotterdam does not endorse a fully automated system and instead actively counters the notion of a “computer says no” approach in discussions. User testing has also demonstrated that legislation is rarely applied in an overly rigid way; expert domain knowledge often allows for intentional deviations from strict regulatory interpretations.

The VCS is a flexible service that can be expanded with new requirements or adjusted to support aspects of the digital city model. Additional BIM data can also be specified in the IDS as necessary. Ideally, more organizations will join this development effort.

Building up from a proof of concept to a prototype, and then to an MVP, has proven to be an effective path for fostering digital innovation. The most challenging periods occur between these phases, as the risk of not advancing successful proofs of concept and prototypes is significant. Within Rotterdam, the Digital City program provided the support and belief in the value of innovation. Additionally, the management of the BWT department took a critical step by pushing for the service to go live. The support of BWT users has also been crucial to the success of this transition, helping foster the adoption of data-driven workflows and recognizing both the opportunities and limitations of this technology.

The VCS would not have succeeded without adherence to standards and the use of innovative tools. Aligning with standards, collaborating with knowledge institutions, and partnering with innovative organizations have been key to this project. By developing openly in line with the vision of Common Ground, we created VCS once and use it multiple times. This approach requires openness and collaboration, inviting others to share knowledge and build solutions together.

Note

- 1 <https://github.com/Municipality-of-Rotterdam/Vergunning-Controle-Service>

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21 Implementing Nationwide Public Service Software in Federal Systems

A Case Study of the ‘One for All’ Approach in Germany

Ronny Weinkauff and Christoph Vollmer

Introduction

A total of 215,900 flats were approved in Germany in 2024. Of these, 172,100 were new builds, divided into three categories: 37,900 single-family homes, 12,700 two-family homes, and 114,200 multi-family homes. The clients included 92,300 companies, 68,400 private individuals, and 8,800 public sector representatives (Destatis, 2025). In Germany, 934 lower building supervisory authorities are responsible for examining and issuing building permits. The Model Building Regulations confirm their responsibility for accepting, reviewing, and deciding on building applications. This includes managing the approval process, coordinating participation, and issuing notices (cf. Conference of Building Ministers, 2022).

The basic principles and framework conditions for building permits include the Building Code, the state building regulations, the technical building regulations, and the special building regulations. Technical building regulations, such as DIN standards, govern the technical aspects of construction. Fire protection, statics, accessibility, etc. are regulated in the respective state building codes or in special building regulations (see Federal Ministry of Justice, 2024).

The granting of building permits is a specific administrative service that is provided at municipal level in Germany’s federal system. In 2017, the ‘Onlinezugangsgesetz’ (Online Access Act, OZG) was passed in Germany, which had the ambitious scope of offering around 575 administrative services digitally for citizens and companies by the end of 2022 (Germany, 2017).

The OZG was the starting point for new activities in software development. New concepts were developed in OZG labs with a user-centred focus. The focus was on digital access to administrative services and less on the digitalisation of the entire administrative process (see Stasch & Steidle, 2020). An OZG laboratory was also carried out for the digital building application in the field of construction and housing. It was developed as a co-creative project between the federal state and local authorities. Based on the findings from the OZG lab, it was implemented as a software solution in the form of a ‘digital building permit’ reference implementation. A minimal viable product called Process

Room was then launched and rolled out in several federal states as ‘*Einer für Alle*’ (One for All, EfA) solution (Fiedler & Weinkauff, 2023).

In the Process Room, a collaborative application process was developed for applicants, incorporating decision support functionalities and creating model-driven opportunities (Weinkauff & Fauth, 2024). Additionally, the importance of spatial reference was recognised and analysed throughout the process, with the findings being conceptually taken into account (Weinkauff et al., 2022).

While the implementation of the OZG and EfA solutions in general is criticised from a municipal perspective, the EfA solution for digital building permits, Process Room, is highlighted as an exception, as can be seen in the interview with the municipal umbrella organisation (Berger, 2022).

The following research questions (RQ) will be examined in more detail for the digitalisation of the building permission process in Germany.

RQ 1: How was the EfA strategy implemented in Germany’s federal system?

RQ 2: What success factors and challenges can be identified in the nationwide implementation?

Background Literature

A survey of lower building supervisory authorities examined the situation regarding processes and digitalisation prior to the EfA solution rollout (Fauth et al., 2025). The main findings and requirements are incomplete and error-prone applications, a lack of transparency, heterogeneous processes and legal frameworks, limited digital adoption, insufficient staffing and technical resources, low Building Information Modelling (BIM) readiness, manual workload and inefficiencies, poor use of standards, limited cross-agency collaboration, resistance to change, and legal uncertainty.

The peculiarities of the governance of the German building permit procedure were investigated and systematised in Fauth (2021). The key findings are that there is no standardised process, so the procedure varies across authorities. Reviewers also have discretionary power for subjective decisions. It is still a process with limited digitalisation; for instance, BIM and digital tools are underutilised. Finally, there is a complex legal system where multiple laws and regulations complicate the process.

This is supported by the European country comparison of the building permit procedure (Fauth et al., 2024). The study examines the legislative system. The building permitting system is regulated by the building codes of the 16 states, plus one model building code as a recommendation for the states. Building codes provide a classification of buildings and define the requirements and conditions for each group of buildings. At the national level, the Planning Act covers regulations on spatial planning, while the Administrative Procedure Act regulates the management of discretion within a public

administrative process, for example. Additionally, there are standards such as XBau and XPlanung for process communication and data models.

Concepts for the use of spatial planning and approval procedures for the development of cooperative data infrastructures also offer considerable potential for digital approval procedures: all stakeholders have access to the same, up-to-date data; automated checks instead of manual, error-prone checks; joint action at the state and municipal levels in Germany, which is ultimately predicted to save time, provide legal certainty, and improve the quality of planning and approval processes (Brunzel, 2023).

The use of co-operative data infrastructures to support decision-making in the building permission process is elaborated in more detail from a technical perspective in Seder et al. (2000). In addition to specialised data, assessment knowledge is also required and processed in the building permit process.

On this technological basis, the administrative processes of the building permission procedure can be optimised, as proposed in Weinkauff (2001). During the planning application preparation phase, applicants can already obtain preliminary information by accessing geoinformation. In the approval process, there are generalised organisational structures for standard cases that process the majority of approval procedures without time-consuming participation steps. Decision-support systems enable approval processing by case managers or case teams without the time-consuming involvement of the relevant specialist bodies in the standard case for a specific building permission procedure.

To support the regulatory review, model-based inspection procedures were trialled and applied in Germany (e.g. in Ponnewitz, 2019; König et al., 2020). To ensure the inspection rules and conditions are met, Fuchs et al. (2024) propose developing formal representations of building regulations through a parallel drafting process. Parallel drafting means a simultaneous creation of legal (natural language) and formal (machine-readable) versions of building regulations.

Although the research question in Weinkauff and Fauth (2024) relates to collaborative application submission with decision support, it contains the architecture of the EfA solution in the form of a component diagram. The component diagram models how model-based checks for BIM models, the use of collaborative data infrastructures, and the use of artificial intelligence (AI) in the building approval process are technically enabled. The extension of the component view to include further optional systems of the lower building supervisory authorities, which can be connected via a message broker, can be found in Weinkauff et al. (2022).

Method

To address the two research questions, the case study method according to Yin (2018) is used in the case type of a single case study with embedded analysis units. Although single case studies are often criticised for being ‘too small’, Flyvbjerg (2006) demonstrates that their value lies in the knowledge they provide, their depth, and their exemplary nature. Four study propositions are

defined based on the two research questions concerning the implementation of the EfA solution and its success factors and challenges. Following Yin (2018), these assumptions should help to focus the study. Firstly, it is assumed that Germany's federal structure makes the standardised implementation of EfA solutions more difficult. Secondly, it is assumed that successful co-use depends largely on inter-organisational cooperation and inter-organisational funding. Thirdly, it is assumed that technical platform standards enable and promote nationwide rollout. Fourthly, it is assumed that user-centred software development and a high degree of digitalisation ensure the acceptance of the software solution and the digital administrative processes.

According to Yin (2018), the next step is to logically link the data to the propositions. How is empirical evidence used to either support or refute hypotheses? We analyse presentations, project reports, and media reports using qualitative content analysis. Document analysis includes OZG status reports, EfA software architectures from the Federal IT Cooperation (FITKO), draft resolutions from the IT Planning Council, XBau standard documents, and analysis of federal states regarding progress and implementation. As part of this case study, we will analyse 36 documents totalling 815 pages and 69,050 words.

As criteria for interpreting the findings, we define the effects of EfA implementation, the continuity of development, as well as inhibiting and promoting factors. For the qualitative data analysis, we then design a code system with four categories, which we derive deductively from the propositions (cf. Mayring, 2014). The start codes of the first category Outcomes and Effects are feedback from practice/administration and usage statistics/level of digitalisation. In the second category, Timeframe and Developments, there is one code per year for events/projects and activities. The name of the third code category is Barriers and contains codes for Financial Barriers, User-Related Barriers, Ineffective Standard Usage, Governance Weaknesses, Organisational Barriers, Technical Barriers, and Federal Structure. The fourth and final code category is Success Factor and contains the codes for User Orientation & Acceptance, Political Support, Digital Maturity of Public Administration, Organisational Success Factors, Technical and Structural Preconditions, and Inter-organisational Cooperation.

The analysis results are summarised, processed, and validated through expert interviews with the Digital Building Permit Department in Mecklenburg-Vorpommern (Mecklenburg-Western Pomerania). The final expert interview took place on 28 May 2025 as an online video conference and lasted 65 minutes. Following the expert interview, there was repeated communication with the department during the evaluation phase regarding additional questions of understanding and factual confirmations.

Results

After coding, a code cloud was generated by analysing the code frequency in Figure 21.1. The code cloud shows that a particularly large amount of information was coded on the topics of technical barriers, utilisation of standards, user orientation, and user acceptance.



Figure 21.1 Code cloud of qualitative data analysis.

From the perspective of this first formal evaluation, political support and inter-organisational cooperation also play a noteworthy role.

Outcomes and Effects

From a practical and administrative point of view, the EfA solution was awarded first place in the nationwide 21st eGovernment competition as the best OZG or register modernisation project in 2022 and, according to the Federal CIO Dr Markus Richter, is a great achievement in administrative digitisation. In an interview, architect Mr Polzer, for example, was also positive, giving the following reasons for using the system: it is a way to achieve a paperless office; project processing becomes more transparent; everything is faster; and the number of enquiries and projects is increasing, so they must be responded to with increased efficiency.

Table 21.1 Annual Development of Utilisation of the EfA Process Room

<i>Year</i>	<i>Utilising Federal States</i>	<i>Lower Building Supervisory Authorities Online</i>	<i>Building Applications Received</i>
2021	5	1	approx. 100
2022	8	3	approx. 250
2023	10	10	n.a.
2024	12	n.a.	3,956
2025 (as of August)	13	220	44,419

The district of Northwestmecklenburg had also previously won first place for its pilot project in the 18th eGovernment competition in 2019. The reputation at federal, municipal, and user level is therefore demonstrably positive.

Table 21.1 summarises the participating federal states and lower building supervisory authorities in live operation, as well as the building applications received, for the years 2021–2025, with regard to the effects and scaling.

Timeframe and Developments

The previous version of the EfA Solution Process Room was launched as part of the Northwestmecklenburg pilot project in January 2019. This online service formed part of the NWM online project, which involved developing and commissioning a variety of online administrative services as part of a multi-year plan. The IT solution was therefore designed to be agnostic, with the online building application and digitised building permit process implemented through no-code development.

In 2020, a reference implementation for digital building permits at the federal state level was developed for Mecklenburg-Vorpommern’s building regulations based on the Northwestmecklenburg district’s pilot scheme. This reference implementation was then made available to local authorities in Mecklenburg-Vorpommern and recommended for use by other federal states in accordance with the ‘one-for-all’ principle, even though initially, only a few administrative services were available digitally.

The first implementation of the EfA version, based on the reference implementation, took place in the district of Northwestmecklenburg on 1 January 2021, as a relaunch. Shortly afterwards, the first building applications were received. The first federal states joined the shared use alliance and prepared for the subsequent use of the EfA solution.

A special contractual construct was created in 2022 to regulate subsequent use. In order to offer the service to other federal states for subsequent use, the federal state implementing an EfA solution concludes a recruitment contract with Föderale IT-Kooperation (Federal IT Cooperation, FITKO). The subsequent federal state then concludes a subsequent utilisation contract

with FITKO. The IT service provider of the implementing federal state then makes the service available centrally to the subsequent federal state as a Software as a Service (SaaS) solution. Mecklenburg-Vorpommern was the federal state responsible for implementing the digital building permit, and the IT service providers were the DVZ Mecklenburg-Vorpommern GmbH in Schwerin and the software company brain-SCC GmbH in Merseburg. These providers also involved other subcontractors as required.

With regard to subsequent use, the advantages of the digital building permit solution were emphasised: the EfA solution's subsequent use was included in the reference implementation from the outset; it can be adapted to respective state building regulations through simple no-code configuration, not complex programming; and it can be financed using economic stimulus package funds. This package was federal funding provided centrally in response to the situation caused by the Corona virus.

In 2022, the faltering comprehensive connection of the local building authorities' specialist software systems was addressed via the XBau standard, with the increased prioritisation and implementation of XBau messages launched in four phases. The first phase covered XBau messages relating to the receipt of applications; the second, confirmation of receipt, notification of file numbers, and the submission of additional claims; and the third, issuing notices and charging fees. Finally, in November, phase 4 included the XBau messages for executing participations in the reference implementation.

Despite the contracts being concluded and the standardised XBau messages being provided, only two further lower building supervisory authorities actually went live in 2022. The number of administrative services digitised in the reference implementation increased significantly to 17 by the end of 2022.

The number of digitalised services continued to increase in 2023, reaching a total of 28. At the federal level, two central identity providers have been set up: Bund.ID for citizens, and MUK (My Company Account) for businesses. The first BIM-based building application scenarios were developed in 2023, taking into account the perspectives of applicants and those involved in processing and participation.

In addition, further XBau messages were implemented in phases. Connecting lower building supervisory authorities, which use specialised software systems, was seen as a challenge. Dedicated processes were therefore set up and communicated for this purpose. Local authorities were asked to inform software vendors and to upgrade. Furthermore, they must set up a technical mailbox for receiving XBau messages, connect their local software system to the XBau mailbox, configure the EfA solution for their local authority, and finally carry out a production test. This will be followed by subsequent approval and activation.

Even in 2024 and 2025, achieving comprehensive connectivity between specialist software systems via XBau remains challenging. The implementation of XBau message communication in the specialist software systems of lower building supervisory authorities is only progressing selectively, and using the XBau standard leads to the need for corrections. More than 200 launches were

only possible because many authorities began using the system without, or with an incomplete connection to, their specialist software.

In addition, the EfA solution was technically developed in 2024 to include a BIM checker interface and AI-based functions, as a proof of concept. AI support was introduced to help applicants select the correct application type, and case summary generation and AI-assisted case information were implemented to support users of the lower building supervisory authority.

Barriers

The distribution of costs between the federal states and municipalities quickly became a financial barrier in 2020, necessitating the negotiation of a distribution formula. User-related barriers were not documented in the analysed documents yet. Conversely, ineffective standard usage was recognised as a barrier in 2021, accounting for 17 codes and representing the most documented problem. Weak governance occurred particularly at the beginning of 2020 and 2021, when legal issues regarding the drafting of co-using contracts were a particular hurdle, as was the negotiation of administrative agreements with each co-using state. Organisational barriers also emerged in the early years. In 2020, the reuse alliance had to be organised within strengthened coordination mechanisms, and in 2022, communication with specialist software system vendors had to be organised.

The technical barriers are dominated by the process of integrating components. Not only is there the semantic quality and availability of the XBau message standard itself, but there is also the question of the ability and readiness of the transport layer for all local authorities in Germany, as well as the implementation and productive usage of XBau messages in all available specialised software systems within lower building supervisory authorities. Alternative solutions, such as document management systems or file sharing systems, were considered but proved to be insufficiently secure and not scalable for this use case. Another technical challenge at the outset of the project was configuration of the state-specific features.

The federal administrative structure complicated the initial collaboration, as the contractual structures had to be clarified. It also had to be clarified which state-specific adaptations were necessary, and who would take responsibility for identifying and validating the adaptation requirements in the subsidised context. The prioritisation of the rollout within municipal authorities could not be determined centrally either, as this required coordination with the respective federal states.

Success Factors

The user-centred development of the EfA solution resulted in widespread acceptance among the federal states, lower building supervisory authorities, and applicants. This applies not only to the software's user interfaces, but also

to the extent of digitisation implemented. Since 2023, process automation has also been pursued alongside the degree of digitisation, ensuring long-term user acceptance. Political support has significantly contributed to the success of the EfA solution, including support from the Federal CIO, categorisation as a focus service, and financial support for the rollout. For example, in 2023, the reported support from the federal government is estimated at up to €16.7 million for the implementation of the EfA solution.

Despite the successes achieved, there is a continuous need to expand the success factor of the digital maturity of public administration, which is planned in the expansion stages. This includes scalable, model-based audits; the comprehensive use of AI for decision support and automation; as well as proactive services and once-only access to registers, including access to geodata.

The organisational success factors included the successful management of the pilot project and the establishment of a permanently staffed department for digital building permits within the Mecklenburg-Vorpommern state government, which strengthened funding cooperation. The management of federal adaptation requirements and the subsequent technical approvals by the federal states were also organised successfully, contributing significantly to the overall success.

In terms of technical and structural preconditions, a success factor was the architecture chosen for the Process Room software, which was the core component of the EfA solution. This process- and domain-driven design compensated for weaknesses in the connection of the specialised software systems and enabled the EfA solution to be implemented and rolled out.

Ultimately, active inter-organisational cooperation is an important building block for success, as the federal, state, and local authorities work together regularly and in a goal-oriented manner. In addition to regular video conferences, in-person meetings establish cooperation and strengthen communication and trust-based collaboration.

Evaluation Results

During the evaluation interview, the digital building permit department confirmed the importance of political support as a success factor and referenced the formation of the new digital ministry and the prioritisation of planning and approval acceleration in the federal government's currently negotiated coalition agreement. All evaluation results are summarised in Table 21.2.

The department confirmed that standardisation in accordance with XBau and XPlanning is politically binding but is being implemented inconsistently from a technical perspective. In terms of cooperation, transnational working groups were also seen as promoting exchange and development. While the technical basis of the communication infrastructure is in place, the municipal connection remains patchy. Regarding personnel and skills, it was noted that a lack of skilled labour and further training are slowing down implementation.

Table 21.2 Evaluation of the Main Findings

<i>Dimension</i>	<i>Main Findings</i>	<i>Evaluation</i>
Political support	Strong federal alignment and prioritisation in coalition agreement and IT-Planungsrat decisions.	Clear enabler and driver
Standardisation	XBau/XPlanung standards exist but implementation is fragmented; coordination still weak.	Partially effective
Technical infrastructure	EfA architecture modular and scalable; local integration with legacy software remains slow.	Key bottleneck
User orientation	High usability through co-creative labs; acceptance by building authorities and applicants.	Acceptance achieved
Legal and organisational complexity	Diverse state laws, missing parallel drafting, and inconsistent workflows limit rollout speed.	Persistent structural hurdle
Funding and resources	Federal funding enabled rollout; shortage of IT-skilled staff and digital know-how at local level.	Sustainability concern
Cooperation and governance	Interstate collaboration via FITKO and forums established; still lacks fast, unified decisions.	Foundational, yet improvable

The department recommends competence centres, legal parallel drafting regulations, and financial incentives for co-using states and local authorities.

Discussion

Using the example of digital building permits, the study was thus able to show how the EfA strategy was implemented in the federal German system and confirm the theses that the federal structure makes standardised implementation more difficult. Furthermore, regarding the second thesis, it became clear that the successful reuse of central solutions depends heavily on inter-organisational cooperation and funding.

The inconsistent implementation of the XBau standard posed a major challenge to scaling the solution, and the connection to specialist software systems often remained incomplete. This finding is consistent with the results of the study by Fauth et al. (2025). The thesis that technical platform standards promote nationwide rollout cannot be confirmed unreservedly. Despite the existence of such standards, the nationwide rollout remains the main problem of the case study in question and is clearly identified as such. Brunzel (2023) emphasises that cooperative data infrastructures facilitate standardisation and data sharing, thereby strengthening platform solutions. This can be confirmed from the perspective of specialist data generated and required for

decision-making purposes. However, it is not sufficient for specialist communication from a business process point of view.

According to the fourth thesis, the user-centred development and the high degree of digitalisation in the case study examined promote acceptance among the various user groups. Although this study does not use quantitative indicators to supplement the qualitative methodology, user satisfaction is at least evaluated quantitatively in Weinkauff and Fauth (2024). These results also support the fourth thesis on user-centred software development in this study.

This case study is a comprehensive and in-depth individual case study with embedded units of analysis, as described in the literature (e.g. Yin, 2018). Germany's federal structure results in 16 different state building regulations, making uniform EfA implementation challenging due to the absence of standardised processes for building permits and varying procedures and interpretations, as previously discussed in Fauth (2021) and Fauth et al. (2024). Implementing the EfA solution therefore required a flexible reference architecture with no-code configuration to adapt to state-specific regulations (cf. Fiedler & Weinkauff, 2023).

Mecklenburg-Vorpommern, as the state responsible for development and operation, assumes central responsibility and acts as the contact centre for the digital building permit. The creation of a subsequent use alliance across federal states was also prepared in organisational and legal terms, forming the basis for scaling up. State-owned IT service providers and software development companies from the private sector then carried out the technical implementation as SaaS. Financing bottlenecks in local authorities were compensated for by federal funding via the federal states in the contractual construct, although local authorities consider the long-term operating costs of many centralised solutions to be a critical issue (Berger, 2022).

Conclusions

The case study's own code analysis revealed that ineffective use of standards was the most common issue, followed by technical barriers and federal coordination problems. Delays were caused by weaknesses in governance, particularly in the cross-state contract design. Political backing, financial support, technical modularity, and user-centred design promoted acceptance and subsequent utilisation. Productive cooperation involving all levels—federal, state, and local—was an important prerequisite for success.

Future efforts should focus on three key areas. Firstly, governance should focus on strong and binding inter-organisational agreements to overcome fragmented responsibilities within the federal system. Secondly, in terms of technology, the operational roll-out of standards must be paired with scalable integration solutions for diverse local IT landscapes. Finally, targeted investments in municipal digital maturity, staffing, and IT competence are needed to enable sustainable adoption. Addressing these challenges could see EfA solutions evolve from isolated pilot projects into reliable components of a genuinely digital administrative infrastructure.

The authors suggest supplementing individual case studies in future with comparative multi-case studies, for example on the different rollout of EfA implementation in three to four federal states. Furthermore, research into the cultural and structural conditions for digitalisation in federal administrations would be beneficial. It would also be useful to compare the EfA solution for digital building permission with other centralised EfA solutions in other administrative service areas, taking an international, comparative perspective.

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22 Driving Digital Transformation in Building Permits

BIM and Automated Checks in
Vila Nova de Gaia

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Introduction

In response to an era of rapid urban growth and digitalisation, Gaiurb, Vila Nova de Gaia's municipal urban planning and housing company, has embraced digital transformation to enhance transparency, efficiency, and accessibility in building permit processes. Since 2013, Gaiurb has been using a digital 'NoPaper' system that integrates perfectly with municipal document management and Geographic Information System (GIS) technologies. This innovation simplifies data processing and eliminates administrative barriers, creating a holistic digital ecosystem for urban planning.

Recognising the limitations of manual analysis of architectural projects, Gaiurb began a transition to Building Information Modelling (BIM) in 2018. The first step in this transition was to change the platform NoPaper, also allowing projects to be delivered in IFC format. This made it possible to analyse and anticipate potential problems in the files and define guidelines for the preparation of good practice manuals.

However, realising the full potential of BIM-based assessments requires standardised IFC classification, robust georeferencing, and accurate spatial and elemental categorisation, which have yet to be fully implemented (Building SMART, 1997).

For effective automation, regulatory reform is essential: current municipal regulations, initially drawn up for two-dimensional (2D) frameworks, lack the clarity and coherence needed for digital interpretation, often containing ambiguous rules or loaded with exceptions (Noardo et al., 2020). To solve this problem, Gaiurb advocates the transition to 3D planning standards, aligning regulations with BIM and 3D CityGML frameworks. This alignment will allow for machine-readable codes and automated compliance checks, ultimately promoting a sustainable and digitally orientated built environment in Vila Nova de Gaia. Through these digital and regulatory advances, Gaiurb is laying the foundations for a more efficient and sustainable urban future.

Background

Against a backdrop of rapid urban growth and demand for the city of Vila Nova de Gaia from investors/stakeholders, it became clear that the paper-based system was inefficient and that it would be necessary to take a step towards digitalisation, transforming the burden of bureaucratic paper processes. To this end, Gaiurb in 2010 undertook a process of digitising its organisation.

The entire digital transition process (Figure 22.1) involved systematising the entire workflow at both the external and internal levels of the organisation.

Externally, we created several digital platforms, namely the Digital Process Builder, where architects can create their processes online, with a set of document validation rules and automatic organisation of the digital process, so that it can be automatically imported into internal assessment applications. Internally, the Digital Process Visualisation module was specially designed and optimised for the documentary complexity of architectural projects.

With the procedures for submitting processes optimised for external use, the focus shifted to completing the digitalisation process within the organisation. The implementation of structured and closed workflows was a difficult task that involved the meticulous identification and mapping of all procedures. The path to digitalisation also allows for the re-engineering, simplification, and automation of several crucial points, which was reflected in:

- Simplification of procedures;
- Facilitation of parallel analyses by different teams;
- Reduction of response times by more than 20%;
- Ability to monitor all tasks and procedures;
- Automation of tasks

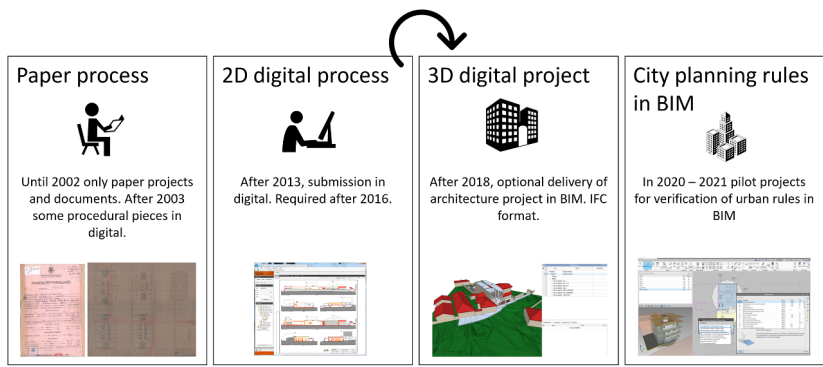


Figure 22.1 Transition process to digitalisation.

Source: Authors.

The full digitalisation of processes offers many advantages.

- a Resource savings, as the transition to digital processes within the project has led to substantial resource savings and minimised the need for physical visits to municipal services, thus increasing the efficiency and cost-effectiveness of administrative procedures for all stakeholders.
- b Competitiveness of the territory, as the success of the project has increased the transparency, speed, and efficiency of urban licensing processes, making the territory more attractive and competitive. This positive differentiation acts as a competitive advantage recognised by stakeholders in the region.
- c Decision intelligence. By integrating advanced statistical and informational components, the project has improved governance practices through the dematerialisation of procedures. This technological integration provides decision-makers with valuable knowledge and intelligence to inform their choices.
- d Transparency and accessibility. The project has improved access and transparency for citizens by providing multiple communication channels to follow administrative procedures from home. Urban planning professionals also benefit from greater efficiency and cost savings through simplified interactions with municipal services.

In terms of the environment and saving natural resources, the digital transformation has avoided the use of more than 2 million A4 sheets of paper, conserved water, and reduced CO₂ emissions, with an estimated saving of 4.4 million litres of water and 17 tCO₂. In addition, the use of the Internet for 75% of requests has avoided more than 42,500 trips, resulting in an estimated reduction of 60 tCO₂, as well as financial and time savings.

Since adopting the NoPaper system in 2013—which is integrated with document management and GIS technologies—workflows have been constantly streamlined, redundancies eliminated, and transparency enhanced.

Even so, it did not take us long to realise that digitising the bureaucratic process would not be enough, as we quickly concluded that project analysis was still being carried out in the same way, consuming too much time and relying on 2D drawings and their weaknesses.

Method

Gaiurb began analysing, evaluating, and cooperating in the implementation of new technological solutions that would optimise response times to construction processes, as well as minimise and create mechanisms for interpreting construction regulations that would reduce errors in project submissions, and in 2018, we started the transitioning to BIM, allowing applicants to submit BIM-IFC files and introducing three-dimensional (3D) workflows which allow analysis with the surrounding buildings.

A new study conducted by the GIS department was initiated to analyse the projects received in IFC, as well as cooperation on projects with commercial and academic partners, to evaluate the implementation of a new concept for project assessment based on computer automation that could be useful to both technical designers and municipal technicians.

The introduction of 3D to building permits through IFC projects meant that a 3D urban environment had to be created, comprising a building model produced in CityGML and associated with a large amount of thematic information. This CityGML urban model, produced in 2019, is based on 1:5.000 scale topographic cartography and the footprints and elevations of buildings. This information is made available to the general public via the 3D viewer and the open data portal on the Gaiacity+ platform (Gaiurb, 2025). By incorporating various levels of information, such as zoning from the Municipal Master Plan (PDM) and land subdivision licences integrated into the 3D urban model (Figure 22.2) with an LOD1.1 (Biljecki et al., 2016), alongside the availability of geographic web services based on open data standards, it provides citizens with maximum useful information for urban planning and new construction proposals.

With the individual analysis of projects in IFC and their integration into 3D visualisation platforms, it was possible to provide new interfaces for analysing the urban context of construction processes (Figure 22.3), which in many situations allows for a more comprehensive assessment of the proposed solution.

The IFC files received reveal several limitations, given that in Portugal there are still no mandatory regulations for the production and delivery of IFC projects for licensing.

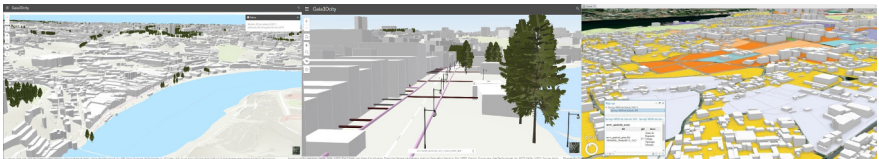


Figure 22.2 3D building city model LOD1.1.

Source: Authors.



Figure 22.3 Integration of projects in IFC Gaia3Dcity.

Source: Authors.

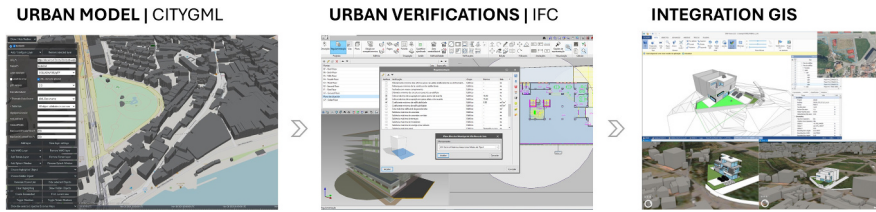


Figure 22.5 Three fundamental pillars to BIM integration: from top to bottom URBAN MODEL|CityGML; URBAN VERIFICATIONS|IFC; INTEGRATION GIS.

Source: Authors.

- Representation of the project's immediate surroundings, especially buildings, roads, and fences.
- Classification of spaces and elements according to the classification system.

However, realising the full potential of BIM-based assessments requires standardised IFC classification, robust georeferencing and accurate spatial and elemental categorisation, which have yet to be fully implemented (BuildingSMART, 1997).

This is a new, more comprehensive process, a transition and transformation in the concepts of integration from 2D to 3D. We can consider that this transformation and BIM integration were based on three fundamental pillars (Figure 22.5) of study:

- The urban model, with the construction of a 3D model of the building based on the topographic cartography of the municipality in CityGML;
- Integration of IFC projects with GIS platforms, allowing the urban model to be updated with high-quality, detailed information;
- The automation of urban planning checks, through the identification of articles in the regulations and their ability to automate rules that can be measured on IFC projects, through evaluation and cooperation in the production of IT platforms that allow the project's technical author and the municipal technician to validate a set of licensing conditions that are applied to the plot automatically.

Cooperation within the CHEK Project

As an associate partner of the CHEKdbp project, Gaiurb actively participated in defining and testing a digital urban licensing model based on IFC projects and automated verification of urban planning rules. Given the work already begun in 2018 by Gaiurb, it was possible to share knowledge with other partners, given the already high degree of development of the digitalisation of construction processes, as well as all the analyses of IFC models already carried out (Noardo et al., 2020).

Our primary questions and challenges were:

- Which legal regulations can be analysed through automation?
- What data can we extract from the BIM model to optimise urban analysis?
- What are the real impacts on the private design and construction sector?
And on the public inspection sector?

Based on these conditions, through cooperation with CHEKdbp, as well with other institutional partners, we analysed which rules in the regulations were likely to contain mathematical rules that could be analysed by computer automation (Table 22.1), thus simplifying the response time in the evaluation and extraction of project metrics.

Based on this analysis, it was possible to assess that out of a total of 554 rules, only 36, or 6%, are subject to automation, given that the rest are subjective, unclear, and have several exceptions to the main rule, requiring human analysis of the project and its immediate surroundings. For example, “In these areas, new buildings or the extension of existing buildings are permitted, provided that they are properly integrated into the surroundings, particularly with regard to compliance with alignment, roof integration, and the rhythm and size of the voids” (RPDM, 2009). This rule is an example of the level of human interpretation required. What does ‘properly integrated’ mean? The same height? A similar height? What does an ‘integrated roof’ mean? The technicians who analyse these cases have years of experience and examples of what works and what doesn’t, and they apply internal guidelines so that the analysis is not arbitrary. This type of rule is impossible to translate into an automatic process.

Although even only a small percentage of rules can be automated, these, together with the existence of architectural designs in IFC integrated into the 3D model of the city, allow for a better interpretation of the impact of the urban solution on the surroundings, having a huge and significant impact on urban planning assessments and the licensing workflow.

Cooperation with the CHEKdbp project made us realise that existing regulations were designed for 2D structures and lack the clarity and structure necessary for machine-readable interpretation. To resolve these issues, Gaiurb

Table 22.1 Main Urban Planning Regulations in the Municipality of Gaia

<i>Regulations</i>	<i>No. of Articles</i>	<i>No. of Articles for BIM (Automations)</i>
PDM	174	16
PUAR	79	7
RGEU	169	7
RMUE	132	6
Total	554	36 (6%)

advocates the adoption of intermediate-scale planning and rules based on 3D standards aligned with BIM and CityGML. This would enable regulatory reform, interoperability, and smart urban governance. This transition would support greater efficiency, environmental sustainability, and competitiveness, and position Vila Nova de Gaia at the forefront of digital urban planning, offering a replicable model for municipalities seeking to modernise their building permit systems.

Conclusions

The digital transformation of urban licensing, as undertaken by Gaiurb, reflects a systemic shift that transcends technological upgrades, calling for coordinated innovation in regulatory frameworks, institutional capacity, and planning practices. The integration of BIM and 3D geospatial models into urban building permit workflows has led to measurable gains in administrative efficiency, process transparency, and environmental sustainability. Yet, the full potential of these technologies remains constrained by legacy regulations, fragmented standards, and inconsistent implementation.

One of the clearest lessons from Gaiurb's experience is that effective automation is impossible without regulatory reform. Current municipal and national planning instruments, designed around 2D paradigms, are often vague, exception-heavy, and not suited to machine-readable interpretation. Our analysis shows that only around 6% of existing urban planning rules are currently suitable for automation—and even these often contain exceptions that require manual review. If we are to move towards automated compliance checking, urban regulations must be simplified, objectified, and drafted with digital implementation in mind.

For researchers, this necessitates further investigation into the semantic interoperability between BIM and GIS systems, particularly in the domains of rule formalisation, automated reasoning, and the integration of 3D city models. Research should also support the development of national and local standards for IFC-based submissions that account for varying regulatory conditions.

For practitioners—architects, urban planners, and municipal technicians—the focus must be on adopting common modelling practices, including consistent classification, georeferencing, and structured metadata within IFC files. Early collaboration through shared digital platforms between designers and authorities can reduce rejection rates and create more intelligent, sustainable development outcomes.

For policymakers, aligning regulations with digital workflows is imperative. Planning codes must evolve from 2D-era logic to formats that support automated verification, dynamic simulation, and digital twin integration. For example, rather than regulating solar exposure via arbitrary setbacks and angles, we can now use simulations based on actual sunlight incidence and shadow projections across seasons. Regulations should reflect this technological capacity.

National guidance mandating BIM model requirements—such as geolocation protocols, classification schemas, and data exchange standards—will provide consistency across municipalities. Alongside this, investment in open-source infrastructure and public-sector training is essential to scale the model pioneered by Gaiurb beyond local success.

Ultimately, the shift from 2D to 3D urban planning, underpinned by digital twins and intelligent regulation, represents not just a technical evolution but a governance innovation. It offers a path towards more democratic, environmentally responsible, and data-driven urban development—one that Vila Nova de Gaia is helping to lead.

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23 The Status of Digitalisation of the Planning and Building Permissions System in Ontario, Canada

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Introduction

The COVID-19 pandemic, coupled with long-standing efforts to modernise traditional development processes and increase housing supply, has accelerated the adoption of electronic development approval and building permitting systems (collectively, ‘e-permitting systems’) in Ontario’s municipalities. These systems are now widely used for application submissions, workflow and process management, and communication.

Despite the recent uptake of e-permitting systems, numerous challenges and inefficiencies persist across the ecosystem. While e-permitting systems have enabled municipalities to offer digital services to citizens, Ontario continues to lag in the adoption of digital tools, data, and processes compared to other jurisdictions. These shortcomings are compounded by a complex regulatory network and a lack of higher-level guidance and standards that result in siloed approaches across the province’s 444 municipalities.

This chapter focuses on the status of two components of the building permit system in Ontario: (1) tools, and (2) data and information. The first section reviews the adoption of digital tools across municipalities and other agencies. The second section assesses the availability of digitised data that can be used to enhance tools and processes. Finally, challenges related to each component as well as the overall approval ecosystem are analysed, and recommendations are provided.

Land Development and Building Permit Systems in Ontario

In the Province of Ontario, processes related to the development of land and construction are governed in part by two key pieces of legislation: the *Planning Act* and the *Building Code Act*. The *Planning Act* covers rules around zoning, official plans, land use, and processes for amending these (referred to as ‘development approvals’), while the *Building Code Act* governs building permitting processes (‘permitting’). Collectively, these two processes will be referred to as ‘approvals’. These acts are largely administered by 444 Ontario’s municipalities which are divided into 30 upper-tier municipalities, 241 lower-tier municipalities (each situated within an upper-tier municipality), and 173 single-tier municipalities (with combined responsibilities of lower- and upper-tier municipalities).

In addition to the *Planning Act* and *Building Code Act*, several other regulations exist, many of which are overseen by distinct approval agencies. These regulations are referred to as ‘applicable law’, and the enforcement agencies as ‘applicable law agencies’. A summary of common authorities involved in the approval process and their respective interests is listed in Table 23.1. This list is

Table 23.1 Overview of Common Approval Authorities within the Ontario Planning and Building Ecosystem

<i>Level</i>	<i>Authority Body</i>	<i>Area of Interest</i>
Federal	Transport Canada	Development near airports
Provincial	Conservation authorities ^a	Development near regulated waterbodies
	Metrolinx ^a	Development near transit corridors
	Ministry of Agriculture, Food, and Agribusiness	Construction of buildings for agriculture operations
		Construction of dairy plants/factories
	Ministry of Education	Construction of childcare facilities
		Construction of schools
	Ministry of Natural Resources and Forestry	Development on public land or shorelines
	Ministry of the Environment, Conservation, and Parks	Development of sites previously used for or located near waste disposal
		Environmental assessment for public sector projects
		Record of site condition for potentially contaminated sites
Municipal		Renewable energy projects
		Source water protection
	Ministry of Transportation	Development near provincial highways
	Niagara Escarpment Commission ^a	Development in the Niagara Escarpment
	School Boards ^a	Education development charges
	Tarion ^a	New-home warranty programme
	Building Department ^b	Building permits
	Committee of Adjustment ^b	Severances and minor variances
	Heritage Department ^b	Heritage registry and approvals
	Planning Department ^b	Official plans and amendments
Other		Plans of subdivision
		Site plans
		Zoning by-laws and amendments
	Engineering Department ^b	Various engineering permits/approvals
	Indigenous Rightsholders	Development in traditional territory
		Development near sites of archaeological or cultural significance
	Railway companies	Development near railways
	Utilities/telecommunication companies	Development near electrical infrastructure
		Development near pipelines
		Development near telecommunication infrastructure

^a Indicates groups that are government-adjacent organisations.

^b Different municipalities may refer to these departments by different names.

not comprehensive, nor do most projects involve a significant portion of these approvals; however, specific approvals are required depending on the exact location and type of project.

Background Literature

Past research indicates that approval timelines in Ontario's municipalities have increased dramatically over the last 20 years (Shahi et al., 2017; Whitell, 2020). The World Bank's Doing Business Report (2020) showed that permitting for an average warehouse in Toronto, Ontario – Canada's largest city and sole representative in the report – took 249 days, compared to an average of 152 days for Organization for Economic Cooperation and Development countries.

It has been demonstrated that e-permitting can reduce permitting timelines, with clear evidence found in many jurisdictions. In Ontario, e-permitting systems – including the potential development of a provincial system for cross-jurisdictional approvals – have been presented as one of several opportunities to address lengthy approval timelines (Rowntree Watt Bachem Riemer, 2014; Whitell et al., 2020). Other related recommendations include streamlining applicable law approvals, which often cause delays due to limited information availability and transparency, as well as the development of standards for digital data exchange and submission.

More recent research presents mixed results. A 2024 study shows the average timeline across all development approval types dropping to 20.3 months from 22.7 months in 2022 across selected Ontario municipalities. Conversely, a separate study shows timelines for site plan approvals – a component of the overall approvals system – rising to 23 months, up from six months in 2018.

A 2025 Altus study further reveals nuanced insights regarding approvals and digitalisation in Ontario. The study scored municipalities based on the digitalisation of various aspects of the development approval process; the nine Ontario municipalities achieved an average score of 77%, significantly higher than the 57% average for 14 non-Ontario municipalities. However, when comparing timelines for over 5,000 development approvals across all 23 selected municipalities, Ontario municipalities rank among the worst, comprising eight of the nine lowest performers, with approval durations averaging 18.4 months compared to 6.4 months for their counterparts. It should be noted that each province has its own unique requirements for these processes, which impact timelines.

Methodology

The taxonomy for building permit systems developed by Fauth et al. (2024) outlines four systems (legislative, organisational, procedural, and technological) and nine categories to allow for a consistent interpretation of building permit systems across the world. Utilising this framework, two categories from

the technological system were selected to review for Ontario municipalities: tools and data and information. The goal was to confirm digitalisation efforts while identifying limitations within both categories.

The 30 largest municipalities in the province – representing approximately 75% of Ontario's population – were selected for more in-depth review. This neglects the potential challenges faced by smaller, more rural communities; however, this sample makes the findings more indicative of a typical experience in the province.

For the tools category, municipal websites were reviewed in April 2025 to assess how application submission occurred for both development approvals and permitting. Submission methods were simply classified as portal-based, partially portal-based, or non-portal based. Partially portal-based systems include systems where only selected application types are submitted through the portal. While submission portals are just one component of a comprehensive e-permitting system, their public-facing nature makes them more accessible to review, as information on internal systems is not readily available. A similar review was conducted for selected applicable law agencies, which receive submissions for other approvals. Additionally, innovative efforts by Ontario municipalities, such as Building Information Modelling (BIM) projects within the approval process, were identified.

Data and information related to land development in Ontario are crucial in identifying the requirements for permitting. These requirements include the need to engage with applicable law agencies; the need for specific types of municipal applications; and the need for specific studies, reports, or other application requirements. This required information tends to be divided into two groups – geospatial and project-based. Geospatial requirements refer to requirements that are triggered when a site is located in a certain regulated area. These can include, but are not limited to, a site located in a conservation regulated area triggering an approval from a conservation authority, a site near provincial highways triggering an approval from the Ministry of Transportation, or a site located near a woodland may trigger a natural heritage study. Project-based requirements refer to requirements that are triggered only when a specific type of project is undertaken. For example, only dairy operations must seek approval from the Ministry of Agriculture, Food, and Agribusiness, among other approvals. Sometimes, a combination of both geospatial considerations and project-based requirements impacts specific requirements. These include zoning by-laws, where specific locations allow for specific types of projects, and Record of Site Condition, where the approval must be obtained only if the location was previously used for industrial uses and is being converted to another use. Access to this information is crucial for a transparent, efficient permitting system.

To evaluate data and information, the same municipal websites were again assessed in April 2025 for the availability of digitised, GIS-based planning and building data, specifically zoning by-laws and official plans. These two regulations are key determinants of what can be built on a specific parcel of land, but

also influence workflows within the approval process. Where digitised data existed, this data was classified into two categories: ‘Linked’, where planning information for a property (e.g. permitted uses, setbacks) was found either within the GIS-based system or directly connected to the relevant section of the municipality’s by-law, and ‘Unlinked’, where the zone code or designation was provided but the user would need to find the specifics on their own. A third category, where no GIS-based data existed, was also used. Finally, selected applicable law agencies were reviewed to determine the availability of their relevant data.

Results

The following section presents findings from the review of Ontario’s 30 largest municipalities, focusing on the adoption of digital tools for permitting and development approvals, as well as the availability and accessibility of key planning and building data. These results, summarised in Table 23.2, offer insight into current practices and the extent of digital transformation across the province’s municipal and applicable law agency systems.

Tools

The adoption of tools for building permitting processes has become prevalent in most of Ontario’s 30 largest municipalities. Just 7% of reviewed municipalities did not have a portal submission for building permitting intake. Twenty per cent had partially portal-based submission; in most of these cases, the submission method was dependent on the project type: simpler residential permits were applied through a portal, while permits for larger projects or non-residential projects had to be applied in person. Finally, 73% of municipalities had portal submissions for all types of projects.

The adoption of tools for development approvals significantly lags behind that of building permitting. Just 43% of municipalities reviewed have implemented portals for development approvals, and another 10% have ‘partial’ portals (for which only certain types of applications can be submitted). Forty-seven per cent of municipalities have no such systems and rely on some combination of in-person submission or email-based submission. It should be noted that the tools used for building permitting processes are often not the same tools used for development approvals.

Outside of municipalities, the adoption of digital tools by other authorities has been even more inconsistent. Of Ontario’s 36 conservation authorities, just eight offer online portal solutions, with the remaining requiring email or in-person submissions. Some other applicable law agencies have also begun to adopt online portal submission, including but not limited to the Ministry of Transportation, the Niagara Escarpment Commission, and the Ministry of the Environment, Conservation, and Parks for records of site condition.

In terms of submission requirements, most digital submissions still require the submission of PDF drawings. Some larger municipalities, including Toronto, Ottawa, Hamilton, and Brampton, require the submission of a 3D model

Table 23.2 Tool Adoption in Ontario's 30 Largest Municipalities

<i>Municipality</i>	<i>Building Permit Portal</i>	<i>Development Approval Portal</i>	<i>GIS-Based Official Plan</i>	<i>GIS-Based Zoning</i>		
Ajax						
Barrie						
Brampton						
Brantford						
Burlington						
Cambridge						
Chatham-Kent						
Clarington						
Greater Sudbury						
Guelph						
Hamilton						
Kingston						
Kitchener						
London						
Markham						
Milton						
Mississauga						
Niagara Falls						
Oakville						
Oshawa						
Ottawa						
Pickering						
Richmond Hill						
St. Catharines						
Thunder Bay						
Toronto						
Vaughan						
Waterloo						
Whitby						
Windsor						
Legend	Portal Submission		GIS-Based Data Accessibility			
(Totals under respective columns)	2	No portal	14	23	Not accessible	9
	6	Partial portal	3	7	Accessible, unlinked	18
	22	Full portal	13	0	Accessible, linked	3

(typically SketchUp files); however, these models are only used to provide 'planning context' which allow staff and the public to visualise how the development will look in the context of the existing community. These models do not contain any information that can be used to automate the processing of applications.

Finally, few municipalities have begun exploring how BIM can enhance approval processes. A review of municipal procurement sites has revealed just two cases: In 2022, Oakville conducted a project investigating how BIM can be used to review building permit applications from submission through to permit

issuance, and, in 2023, Caledon examined how BIM can bring benefits to development processes and other business areas. While these pilot projects demonstrate a growing interest in BIM, no municipalities have fully integrated BIM into their processes.

Data and Information

Upon review of the websites of Ontario's 30 most populous municipalities, just 10% did not have publicly available GIS-based zoning information. For these municipalities, it was recommended that users contact the municipality for the relevant information. Sixty per cent provided this information in an 'unlinked' form, often providing just a map with a zone code, but occasionally providing a URL link to the full zoning by-law, forcing users to manually search the by-law. Finally, 30% of municipalities had 'linked' GIS-based data, although there is still no data model enabling municipalities to link by-laws to GIS maps.

GIS-based official plan data was much less prevalent; 77% of municipalities did not have a GIS-based map for their official plan. Most of these municipalities provided PDF maps to show official plan data. Of the 23% that did have a GIS-based map, little information beyond the land use designation was provided; users would have to manually retrieve and search the official plan documentation to determine the guidelines associated with their relevant land use designations.

In addition to zoning and official plan information, municipalities are responsible for other types of data and information, such as information related to heritage areas, key development areas, and others which may impact approval processes. Each municipality has its own datasets, requirements, and methods of managing that data; some provide it through their website or through their municipal open data portals, but others require consultation with the municipality. Even the municipalities that have available GIS data do not follow a common standard. Each municipality uses its own format for storing GIS information.

Outside of municipalities, many applicable law agencies have made their data publicly accessible. For example, all 36 conservation authorities have GIS maps of their regulated areas available; Metrolinx has GIS maps showing where they are required to be involved near transit corridors, as does the Ministry of Transportation for areas near provincial highways.

Discussion

The findings illustrate Ontario's relative success in adopting permitting tools but also expose systemic challenges that hinder process efficiency. This section explores how fragmented governance, inconsistent data practices, and a lack of oversight have contributed to Ontario's poor approval timelines despite significant investments.

Lessons Learned from Review of Digital Tools

While Ontario municipalities have made notable progress in adopting digital permitting tools, authorities in Ontario still lag behind leading international jurisdictions. Most of Ontario's largest municipalities have reached 'Level 1' – Basic e-permitting without significant automation – for the submission of building permits, but many are still making the transition to 'Level 1' for development approvals.

Building permitting is generally more procedural, less subjective, and involves fewer stakeholders than development approvals. It typically acts as the final step before construction begins, making it easier for municipalities to digitalise as a standalone process. Development approvals, by contrast, take significantly longer and require more collaboration across multiple municipal departments, applicable law agencies, the public, and other external stakeholders. This discrepancy highlights one of many deficiencies within existing processes: the separation of development approvals and building permitting into distinct digital systems increases the risk of information loss and duplication, contributing to delays and a poorer applicant experience.

Despite having some of the most advanced municipalities in the country when it comes to the adoption of digital tools for approvals, the adoption of these tools has not been enough to meaningfully reduce approval timelines to durations found elsewhere in Canada and the rest of the world. One major reason is the fragmented and uncoordinated nature of digitalisation efforts. Over the past several years, the Province of Ontario has provided hundreds of millions of dollars in funding to municipalities through the Municipal Modernization Program, Audit and Accountability Fund, and the Streamline Development Approval Fund. Nationally, the Government of Canada's Housing Accelerator Fund – administered by the Canada Mortgage and Housing Corporation – provided \$4 billion to municipalities across the country.

This funding was earmarked for a variety of purposes, including reviews of the approval process, zoning reform, and the adoption of digital permitting tools. This approach, however, neglects the interconnected nature of Ontario's approval ecosystem; with over 400 municipalities and dozens of other agencies that may interact with each other throughout the approvals process, providing funding for each authority to digitalise processes independently does nothing to improve collaboration. It simply allows individual entities to digitalise their already inefficient processes.

When it comes to the use of tools to achieve target efficiencies, Ontario's municipalities are now facing a structural challenge: although many have begun to adopt tools that benefit their individual municipality, other agencies they engage with have done the same for their own benefit. There is an overall lack of alignment, and the sharing of information and data remains difficult. Initiatives such as the One Ontario programme have advocated for the development of a province-wide system to address these concerns, arguing that municipalities cannot solve this problem on their own. This requires oversight

from the Province – which is responsible for the rules and regulations in question and also defines the role of the vast majority of the agencies involved – to develop a ‘translator’ of sorts to map individual processes to a standard process while ensuring interoperability between systems. This would mirror the top-down approach taken in other jurisdictions, including the Province of British Columbia, which is currently developing its own system to allow for the processing of applications that will integrate with systems that already exist in municipalities. In May 2025, the Government of Ontario announced its intentions for the Ministry of Municipal Affairs and Housing to explore ‘building code and permit application spaces ... to better automate planning and permitting processes’, although limited details are available at the time of writing.

Data and Information Challenges in E-Permitting

Ontario municipalities have made progress in publishing data related to development approvals, but significant challenges remain in integrating that data into permitting workflows and supporting automation.

There is an overall lack of consistency in both the availability of data and the datasets themselves. While the results show that most municipalities now have publicly available GIS-based data for zoning maps, many other types of data are not easily available. Even municipalities that possess GIS-based zoning maps fail to integrate these maps with their corresponding zoning by-laws, a linkage that is essential for enabling automation and streamlining the development approval process. Further, this data differs across municipalities, creating a fragmented landscape that is difficult for applicants to navigate efficiently. Although the Province of Ontario has offered minimal direction for municipalities, it has taken an interest in data availability for some applicable law agencies. In 2024, *Ontario Regulation 41/24* required all conservation authorities to map their regulated areas and publish them to their website, establishing a precedent for the mandatory digital disclosure of planning data.

However, a core limitation remains. Where data exists, it is often detached from the larger permitting ecosystem. For users, having the data separated from the related rules and regulations requires the manual retrieval of information relevant to their project or forces the user to contact the relevant authorities for further insights. From a technological perspective, disconnected datasets mean digital tools are unable to perform basic functions – such as auto-filling application fields like zoning designations or lot and concession numbers – which can streamline and simplify the application process. This would also enable automated workflows to increase transparency and efficiency within the approvals process.

Compounding these challenges is the absence of province-wide data standards and interoperability strategies. As with digital tools, many municipalities have been digitising data according to their internal needs. Should the Province begin providing guidance and oversight, these datasets must be unified to ensure that they are consistent and interoperable. This can include developing

data models and frameworks for data related to key rules and regulations, such as zoning and official plans, which are notoriously inconsistent across municipalities.

Additional Legislative and Organisational System Considerations

Challenges related to digital tools and data in Ontario are amplified by instability and fragmentation in the broader legislative and organisational framework. Between 2019 and 2025, the Province introduced major legislative reforms intended to speed up housing approvals. The More Homes, More Choice Act aimed to reduce red tape by shortening municipal decision-making timelines and scaling back heritage and environmental protections. In 2022, the More Homes Built Faster Act restructured the role of upper-tier municipalities and conservation authorities, eliminated some site plan requirements, and introduced refund provisions for delayed applications. Most recently, the Cutting Red Tape to Build More Homes Act further removed regulations – eliminating mandatory pre-consultations and complete application requirements – while also reversing the refund policy introduced two years earlier. Some municipalities have criticised these frequent and abrupt changes as unclear and disruptive. For digital transformation efforts, this uncertainty may discourage municipal digitisation efforts as it would be costly to reconfigure every time rules change. Although intended to accelerate approvals, these reforms prioritised deregulation over system modernisation, ironically hampering digital transformation efforts and delaying sustainable improvements.

The Province also supported the development of two standards from the Digital Governance Council (DGSi), DGSi 124, which defines standards for terminology in planning and development applications and DGSi 125, which provides common fields for use in application forms. While these represent a step forward, their voluntary nature and narrow scope limit their usefulness. There is little evidence of adoption, and, on their own, they cannot drive meaningful system-wide digitalisation.

Funding potential province-wide systems or standards represents an additional challenge. Many municipalities and applicable law agencies are hesitant to lead efforts, as it would likely result in their existing systems becoming obsolete or requiring costly rework. Similarly, few agencies are willing to assume the costs and risks of building systems whose benefits are shared across hundreds of jurisdictions. This further reinforces the need for provincial leadership to coordinate development, fund implementation, and mandate adoption where necessary.

Conclusion

Ontario's municipalities and applicable law agencies have made commendable strides to embrace digital tools in recent years. However, the fragmented, multi-jurisdictional nature of these efforts has resulted in a system that

underdelivers – performing worse than both less advanced systems in Canada and more advanced systems internationally. This underperformance is caused by a variety of factors, including a lack of coordination at the highest levels, risk-averse stakeholders who are hesitant to adopt new technologies, and the absence of standardisation in key processes and regulations.

To address these concerns, the following recommendations are made:

- 1 Establish a provincial system to act as a ‘middleware’ between authorities to allow for seamless information exchange. This ‘integration layer’ approach mirrors the ongoing effort in British Columbia, allowing for the standardisation of processes and requirements while protecting the investments municipalities have made in their digital systems. This should be supported by an interoperability framework to ensure that data can readily flow between agencies to enable a true ‘one-window’ approach.
- 2 Continue standardisation efforts and incentivise or mandate adoption of standards within approval processes, such as DGSi 124 and 125. Standardising key processes, inputs, and outputs will increase transparency and allow for more automation to take place. This improves data quality, reduces cost, and improves efficiency.
- 3 Mandate and standardise digital data related to approvals. The Province should expand upon efforts such as O. Reg. 41/24 and require key datasets to be standardised and accessible to the public. This creates transparency while also promoting automation as this standardised data could be used to auto-fill applications and dictate workflows.
- 4 Align future funding with systemic outcomes. Previous funding targeted the adoption of individual tools within municipalities, further entrenching the already siloed nature of permitting. Barring a significant reduction in the number of entities involved in approvals, future modernisation programmes should shift their focus to a collaborative approach that reduces redundancy and promotes end-to-end efficiency.

Taken together, these recommendations represent a necessary shift away from isolated digitalisation towards coordinated modernisation. Further, with a robust baseline in place, innovative municipalities will be well positioned to begin transitioning to more advanced levels of e-permitting.

Data Availability

Raw data on approval durations is not published directly by Ontario municipalities. It is instead collected and analysed by third-party consultants at irregular intervals. These datasets are difficult to validate due to potentially inconsistent definitions, such as the requirements surrounding different types of approvals or where the start and end points of approval processes are measured. As a result, this study focuses on observable system characteristics instead of relying on direct performance metrics.

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24 Permitting System Digitalization in the United States

Dan Puerling

Introduction

The landscape of building and construction within the United States is intrinsically linked to a complex web of legal codes, local ordinances, and state regulations. From the initial groundbreaking to completion of construction, adherence to these stipulations is not merely a formality but a fundamental requirement for ensuring public safety, structural integrity, and environmental compliance.

Central to this regulatory framework is the permitting process, a critical gatekeeper designed to ensure that construction projects, throughout their entire life cycle, meet the necessary standards. Historically, this process—encompassing application, review, and issuance—has been deeply rooted in a paper-intensive workflow. Building contractors, whether applying for a commercial development or a residential renovation, would typically initiate their projects by submitting physical paper applications at the permitting offices of their respective city, county, or state. The subsequent review cycles, involving multiple departments and stakeholders, would similarly unfold across desks laden with documents. Communication, a crucial element for clarification and progress, often relied on the slow pace of physical mail or the fragmented nature of email exchanges, with little centralized tracking. Ultimately, the culmination of this process would see a final paper permit, either mailed to or printed by the contractor, prominently displayed at the construction site as proof of authorization.

However, technology advances have ushered in a transformative wave across the public sector, prompting many organizations throughout the United States to embark on a profound digital transformation. This paradigm shift involves a deliberate and strategic move away from the traditional, cumbersome paper-based permitting process, replacing it with sophisticated technological solutions designed to enhance efficiency, transparency, and accessibility. This chapter delves into the multifaceted journey of this digitalization, examining its practical implications through the lens of diverse municipal experiences.

The need for such transformation is underscored by the tangible benefits already being realized by municipalities. For instance, the City of Topeka

serves as a compelling example of how digital adoption translates into measurable time savings. Since the inception of its digitalization project, Topeka has witnessed a reduction in approval times for commercial permits, from an average of 66 days to a more efficient 52 days. Similarly, for remodeling permits, the city has achieved an acceleration, cutting the approval period from 31 days to a mere 20 (Topeka, 2025). These reductions not only streamline project timelines for developers and homeowners but also contribute to a more dynamic local economy.

Beyond just efficiency, digitalization can also act as a catalyst for growth. The City of Saratoga Springs, following its digital permitting overhaul, has experienced a significant surge in new construction activity. Yearly increases in new multi-family permits soared from 104 to 636, while single-family permits saw a rise from 451 to 663 annually (Saratoga Springs, 2025). Such figures suggest that a more accessible and efficient permitting process can directly stimulate development and investment within a community.

Drawing on the rich experiences of three distinct jurisdictions—a mid-sized city in the Upper Midwest, an outer-ring suburb of a large Southeastern city, and a small town near the Canadian border—this chapter provides informative case studies of this transformation. These real-world examples illuminate the challenges inherent in such a monumental shift, including the often-underestimated complexities of change management, limited available resources, and the critical importance of organizational staff consistency. Concurrently, they demonstrate the advantages that a digitized building permitting process can unlock, such as improved levels of service for applicants, greater transparency throughout the review process, and the potential for more efficient revenue generation for municipalities. While the path to digitalization often proves to be arduous and fraught with obstacles, the collective successes witnessed across these and numerous other organizations justify the considerable effort of adoption, signaling a new era for construction and development regulation in the United States.

Background

The transition from traditional paper-based processes to digital solutions in government services, often termed digital transformation, is a critical area of study in public administration and information systems. This shift is driven by the increasing need for local governments to leverage technology to modernize operations, streamline public services, and enhance interactions with stakeholders. As governments become more reliant on technology, strategically managing it as a vital resource and investment becomes paramount. This necessitates strategic planning and continuous strategizing to navigate the complexities of digital transformation, maximize technology's value, and mitigate potential negative impacts.

Digital transformation in the public sector is understood as a “holistic effort to revise the core processes and services of government” requiring fundamental changes in processes, people, policies, and especially leadership.

This transformation is not merely about converting analog information to digital formats (digitization) or delivering services through electronic networks (digitalization). Instead, it demands a comprehensive reorientation in how governments interact, engage, and collaborate with diverse stakeholders, including citizens, to improve decision-making and service delivery. The adoption and management of technology in government are highly dependent on the alignment and coevolution of technology with organizational, institutional, and environmental factors (Buyannemekh, 2025).

Historically, “e-Government” initiatives focused on using technology to transform how information and public services are produced and delivered, aiming for efficiency, productivity, and cost reduction through automation and paperless procedures. However, the concept has evolved into “Intelligent E-Government,” which incorporates advanced intelligent information technologies such as AI, IoT, Cloud computing, and Big Data to make government services more responsive and adaptive. This evolution reflects a growing expectation from citizens for more sophisticated government services and the emergence of new technologies that push the boundaries of existing e-Government systems.

Leadership plays a crucial role in driving public sector digital transformation. Leaders are responsible for establishing and communicating a vision, ensuring adequate resources (funding, personnel, technology), encouraging organizational change, overseeing implementation, and fostering collaboration, all aligned with overarching missions and objectives. Strategic leaders are defined as public officials who ensure that governmental actions are purposeful, make politically shrewd decisions based on strategic thinking, and use influence to increase effectiveness. This leadership requires a holistic perspective that transcends traditional organizational and technological boundaries, coupled with a deep understanding of operational and strategic facets of the organization, alongside technical skills.

The integration of strategic planning and continuous strategizing is vital for effective digital transformation. Strategic planning is a disciplined approach to making fundamental decisions that define an organization and its purpose, aiming to create public value. While traditionally seen as a top-down exercise, strategic planning is increasingly recognized as a collaborative activity involving different organizational levels. Its value extends to decision-making, budgeting, performance management, and service delivery. Moreover, strategizing, viewed as an activity-driven, continuous enactment of strategy, involves practitioners, social activities (praxis like meetings and negotiations), and practices (tools, methodologies, behaviors, such as data analysis and forecasting). This adaptable and ongoing approach is crucial for building capacities and proactively addressing challenges and risks inherent in digital transformation.

Examples of challenges in government technology adoption often make headlines, such as security breaches involving sensitive data, equipment failures during critical operations, and ransomware attacks leading to significant recovery costs and service interruptions. These incidents underscore the critical role of technology and the importance of its strategic management in county

government operations. Despite these challenges, the goal of digital transformation in government is to move beyond simply automating processes to fundamentally transforming organizations, enabling improved service delivery and increased value for citizens (Koo, 2019).

The broad trends of digital transformation, strategic technology management, and evolving e-Government paradigms are not abstract concepts in public administration; they have direct and profound implications for specific governmental functions. Among the most critical of these functions, particularly at the local level, is the permitting process. As municipalities strive for greater efficiency, transparency, and citizen engagement, the digitalization of permitting emerges as a tangible and highly impactful application of these overarching technological and strategic shifts. This chapter specifically examines how the principles and challenges of government digital transformation manifest within the context of building and construction permitting, an area ripe for innovation given its historical reliance on antiquated, paper-based workflows.

Method

This chapter employs a multiple case study methodology to explore the digital transformation of permitting processes within diverse local government jurisdictions in the United States. The focus is on building and planning permits, but also includes examples such as special event permits. This qualitative approach was selected to provide in-depth understanding and rich contextual detail regarding the challenges encountered and advantages realized during such transformations, allowing for a comprehensive analysis of a complex phenomenon in real-world settings. The design facilitates cross-case comparison while honoring the unique attributes of each municipal journey.

Case Selection Criteria

Three distinct municipal entities were selected as informative case studies, representing a spectrum of jurisdictional sizes, geographic locations, and existing operational contexts, thereby offering varied insights into the digitalization process:

- 1 Mid-sized city in the Upper Midwest: Chosen to represent established urban centers with moderate administrative complexity, facing transitions from legacy systems.
- 2 Small city near the Canadian border: Selected to illustrate the unique challenges and opportunities for smaller, potentially resource-constrained municipalities with varying levels of citizen technical proficiency.
- 3 Outer-ring suburb of a large Southeastern city: Included to reflect the dynamics of rapidly growing suburban areas experiencing significant development pressure and demanding sophisticated, scalable solutions.

Data Collection Methods

The primary data for this study was collected through two main avenues: semi-structured interviews and analysis of publicly available digital dashboards hosted by the respective jurisdictions.

- 1 Interviews: A series of in-depth, semi-structured interviews were conducted between the author, acting in their professional capacity as a product manager, and employees within the case study organizations (customers). This unique researcher-participant relationship, while potentially offering enhanced access and contextual understanding, was carefully managed to maintain research objectivity. Interviews targeted key personnel directly involved in or impacted by the digital permitting transformation. These included, but were not limited to, department heads, permit technicians, IT staff, and administrative personnel. The semi-structured format allowed for a flexible yet focused discussion, enabling the exploration of pre-determined themes (e.g., specific challenges, perceived benefits, implementation strategies, user experience) while also allowing for emergent topics and in-depth narratives from the participants. All interviews were conducted with a focus on capturing subjective experiences, organizational perspectives, and practical insights into the daily operational shifts brought about by digitalization. Efforts were made to ensure a diverse representation of roles and experiences within each organization. Over the course of six years in the Product Manager role, the author met with each jurisdiction between five and ten times.
- 2 Publicly Available Jurisdiction-Hosted Dashboards: Complementing the qualitative interview data, publicly accessible digital dashboards maintained by local governments provided valuable quantitative data. These dashboards, designed by the municipalities themselves for public transparency and accountability, typically offered metrics related to permitting activity, such as permit application volumes, processing times, and types of permits issued. Analysis of these dashboards provided empirical evidence to corroborate interview findings, particularly concerning reported improvements in efficiency (e.g., reduced processing times) and increases in activity (e.g., higher permit volumes). While the data from these dashboards offers valuable insights into outcomes, it is recognized that these are aggregate metrics and do not capture the nuances of individual experiences or underlying causal factors, which were explored through the interviews.

Data Analysis

The qualitative data derived from interviews underwent thematic analysis according to Daniel Turner's *Qualitative Interview Design* (Turner III & Hagstrom-Schmidt, 2022). Interviews were reviewed to identify recurring themes, patterns, and categories related to challenges, advantages, implementation strategies, and organizational impacts of digital permitting. Initial codes

were developed inductively from the data, followed by a process of refinement and categorization to form overarching themes.

The quantitative data extracted from the publicly available dashboards was analyzed descriptively to identify trends and validate claims made during interviews. Cross-case analysis was then performed, comparing the themes and quantitative insights across the three distinct case studies. This comparative approach highlighted commonalities and unique differences in their digital transformation journeys, enriching the understanding of factors influencing success and challenges in diverse municipal environments.

Ethical Considerations

Given the author's dual role as a product manager and researcher, strict ethical protocols were observed. Anonymity and confidentiality of individual responses and, where requested, the specific identity of the jurisdictions were ensured throughout the data collection and reporting phases. All quoted material was anonymized to protect participant privacy.

Results

Case Study 1: Mid-sized City in the Upper Midwest

This mid-sized city's digital permitting transformation presented a unique set of challenges and ultimately yielded significant advantages. The transition was not without its hurdles, but the city's commitment to modernization ultimately proved beneficial.

Challenges Encountered

A major obstacle was migrating from a locally installed desktop application to a server-based online system. This involved significant data migration, ensuring compatibility, and addressing concerns about internet reliability and accessibility for both staff and the public. This shift required extensive training for staff accustomed to the desktop application, and some initial resistance was encountered.

Additionally, the existing permitting database had grown considerably over time, leading to performance issues. Optimizing the data structure and reducing its size were critical to ensure the new online system was responsive and efficient. This involved identifying redundant or obsolete data, implementing archiving strategies, and potentially upgrading server infrastructure.

A segment of employees with pre-existing software development experience felt they could create a superior solution in-house, which was an additional challenge. This led to internal debates about the chosen vendor and the potential for projects not authorized by the information departments, also known as "Shadow IT," which could have undermined the official implementation. Managing these competing perspectives and ensuring buy-in from all staff was crucial.

Finally, the legacy system had a suite of custom reports that were essential for tracking permit activity, generating revenue forecasts, and complying with regulatory requirements. Replicating these reports in the new system, while maintaining their functionality and accuracy, was a complex undertaking. It required close collaboration between city staff and the software vendor.

Advantages Realized

Critically, the new system provided citizens with real-time access to permit status and estimated processing times. This significantly increased transparency compared to the previous system, where applicants often had to make phone calls or visit the permitting office to get updates. This improved citizen satisfaction and reduced the workload for city staff.

The digital system also streamlined the application, review, and approval process for special event permits, such as those required for marathons, festivals, and street closures. The system allowed for online applications, electronic routing to relevant departments (police, fire, transportation), and automated notifications. This resulted in faster processing times, better coordination among city departments, and improved safety and logistics for these events.

This initial analysis of Case Study 2 reveals the typical challenges and advantages associated with digital transformation in the public sector. The need to address technical hurdles (data migration, performance optimization), manage organizational change (employee resistance), and ensure continuity of essential functions (report migration) is evident. However, the benefits of increased transparency and streamlined processes demonstrate the potential for digital building permitting to improve both efficiency and citizen engagement.

Case Study 2: Small City Near the Canadian Border

The digital transformation in this small city, characterized by its remote location and smaller municipal footprint, presented a set of challenges largely rooted in resource scarcity and community readiness. Despite these hurdles, the implementation of digital permitting brought tangible operational improvements.

Challenges Encountered

Operating within a significantly smaller budget than other jurisdictions, this municipality faced acute resource limitations, which was a challenge from the outset of the project. This impacted every phase of the digital permitting project, from initial software acquisition to ongoing maintenance and staff training. There were fewer personnel to dedicate to the project, meaning existing staff often had to absorb new responsibilities in addition to their regular duties. This stretched resources thin and sometimes delayed progress. Furthermore, the city had to make difficult choices regarding the features of the digital

system, often opting for more cost-effective solutions rather than those with the most advanced functionalities, potentially limiting the scope of the initial digital offering. This constant pressure to justify expenditures and find economical solutions was a pervasive challenge throughout the entire transformation.

A further difficulty was that a significant segment of the city's population possessed limited technical literacy or access to reliable internet services. This presented a substantial barrier to the adoption of the new online permitting system. Many citizens were not accustomed to using government websites for transactions, lacked personal computers, or were unfamiliar with navigating online forms. This necessitated a parallel effort to provide alternative access points or extensive support for those who struggled with the digital platform, adding a layer of complexity to the implementation that larger, more tech-savvy communities might not encounter to the same degree.

An additional challenge directly related to the lack of technical experience, many citizens expressed a strong preference for the familiar, albeit outdated, paper application process. They had established routines, understood the paper forms, and valued the direct, in-person interaction at the city office. This resistance to change was not merely due to a lack of technical skill but also a comfort with established norms. Overcoming this inertia required a concerted effort to demonstrate the benefits of the digital system, often through one-on-one assistance and repeated assurances that the digital process was, in fact, simpler and faster once learned. The city had to manage expectations carefully and acknowledge the valid concerns of its constituents.

Lastly, a seemingly minor, but persistent, technical challenge was the inconsistent use of supported web browsers by both the public and, at times, city staff. The new digital permitting software was optimized for specific browsers (e.g., modern versions of Chrome, Firefox, Edge), but many users, especially older ones, were still operating with outdated browsers or less common ones that were not fully compatible. This led to frustrating user experiences, form submission errors, and increased support calls. The city had to implement clear guidelines and provide technical assistance to ensure users were accessing the system through recommended channels, a task that proved surprisingly resource-intensive given the limited IT capacity.

Advantages Realized

Despite the challenges, a notable success was the significant reduction in the issuance time for Right-of-Way (ROW) permits. Previously, these permits, critical for utilities, contractors, and residents, involved multiple manual reviews and routing steps. The digital system automated much of this workflow, allowing for concurrent reviews by relevant departments (e.g., public works, engineering) and providing clear visibility into each stage of the approval process. This decreased processing time from several days or even weeks to a matter of

days, or in some cases, hours, accelerating essential infrastructure projects and reducing inconvenience for applicants.

Perhaps the most impactful advantage for this municipality was the substantial reduction in the time city staff spent handling paper applications. Before the digital transition, front-desk personnel and administrative staff dedicated significant hours to receiving, organizing, filing, and manually routing paper permits. With the shift to online submissions, the volume of physical paperwork drastically decreased. This allowed staff to reallocate their time to more complex tasks, provide more in-depth citizen support (especially for those needing help with the new system), or focus on other critical municipal functions that were previously neglected due to the demands of paper processing. This gain in efficiency was invaluable for a city operating with limited human resources, enabling existing staff to be more productive and effective across a broader range of duties.

In sum, the experience of this small city underscores that digital transformation in the public sector is not solely a technical undertaking but also a social and organizational one. While resource limitations and community readiness posed considerable hurdles, the strategic application of technology to automate specific high-volume processes, like ROW permits, yielded tangible benefits, particularly in optimizing the scarce resource of staff time. This case study demonstrates the critical need for tailored implementation strategies that acknowledge and address the unique demographic and budgetary constraints of smaller jurisdictions.

Case Study 3: Outer-Ring Suburb of a Large Southeastern City

This outer-ring suburb's journey into digital permitting was characterized by a sophisticated internal environment and high external expectations. The city's growth trajectory and its proximity to a major urban center meant it juggled the complexities of a diverse range of development projects, which directly influenced the nuances of its digital transition.

Challenges Encountered

A persistent and often perplexing challenge for this suburb was navigating the dilemma of software versioning. The city grappled with the decision of whether to maintain existing stable versions of their digital permitting software to ensure consistent user experiences for both internal staff and external contractors, or to upgrade to newer versions that promised enhanced features, improved security, and better integration capabilities. Staying on an older version risked missing out on critical advancements, falling behind industry standards, and potentially facing unsupported software issues. Conversely, frequent upgrades, while offering new functionalities, often disrupted established workflows, necessitated retraining for staff and public users, and introduced the risk of new bugs

or compatibility issues. This constant balancing act led to meticulous planning sessions and rigorous testing protocols for every potential upgrade, consuming significant IT and project management resources. The leadership had to weigh the immediate operational stability against the long-term strategic advantages of technological advancement, a decision that often caused internal friction.

Given the city's dynamic growth and the accompanying demands on its planning and development departments, leadership exerted considerable pressure for rapid implementation and demonstrable results from the digital permitting initiative. This "pressure cooker" environment, while fostering a sense of urgency, also posed challenges. It sometimes led to truncated planning phases, ambitious timelines, and a reluctance to fully pilot or extensively test new functionalities before widespread rollout. While the desire for efficiency was understandable, this intense pressure could, at times, inadvertently compromise thoroughness, leading to unforeseen complications or requiring quick fixes that consumed resources later in the project.

A final challenge was that unlike smaller municipalities with more standardized building codes and fewer development types, this burgeoning suburb handled an extensive and highly varied range of permitting workflows. This included everything from minor residential renovations to large-scale commercial developments, complex multi-use projects, and intricate infrastructure permits. Each type often had its own unique set of application requirements, review stages, departmental sign-offs, and compliance checks. Translating this vast array of diverse, often non-linear, paper-based workflows into a cohesive, logical, and adaptable digital system was an enormous undertaking. It required detailed process mapping for hundreds of distinct scenarios, extensive configuration of the software to accommodate specific rules and routing logic, and iterative testing to ensure that no critical step was overlooked. The sheer complexity made the implementation a multi-year effort, demanding exceptional coordination between various city departments, legal counsel, and the software vendor.

Advantages Realized

Despite the intricate implementation challenges, one of the most significant and celebrated advantages was a measurable reduction in the overall duration from when a permit application was submitted to when it was officially issued. By automating submission processes, enabling parallel reviews by different departments (e.g., planning, engineering), and facilitating real-time communication between applicants and reviewers, the digital system dramatically cut down on administrative delays. Where complex permits might have previously taken months, many were now processed in weeks. This acceleration directly benefited developers and residents by allowing construction projects to commence sooner, thereby stimulating economic activity and reducing holding costs for projects.

Perhaps most notably, a crowning achievement for this city was the successful deployment of the digital permitting solution not just to the core building department, but across a multitude of related municipal departments. This created something close to a true enterprise-wide permitting and project management solution. Departments such as Public Works, Planning, and Building were integrated into the same digital platform. This eliminated silos of information, reduced redundant data entry, fostered inter-departmental collaboration, and provided a holistic view of development projects across the entire city. For example, a single application for a new commercial building would automatically trigger reviews and notifications to all relevant departments within the system, replacing the previous cumbersome process of manually routing paper files or emailing attachments between departments. This integrated approach enhanced internal efficiency, ensured greater compliance, and presented a more unified and responsive front to the public and development community.

The experience of this large suburb underscores that while digital transformation in complex urban environments brings significant technical and organizational hurdles, the potential for streamlined processes, reduced timelines, and enterprise-wide integration can yield transformative benefits. It highlights the importance of strategic planning, robust technical solutions, and persistent commitment in the face of intricate workflows and high expectations.

Conclusions

The journey toward digital transformation in the United States' municipal permitting processes, as evidenced by the diverse experiences of the case studies presented in this chapter, is a complex yet ultimately rewarding endeavor. This research, integrating insights from product management interviews and publicly available data, underscores several critical takeaways for any municipality contemplating or actively engaged in such a modernization initiative.

Firstly, it is imperative for municipalities to anticipate and prepare for significant challenges throughout the digitalization process. As demonstrated by the mid-sized city's struggle with migrating from desktop to online applications and managing internal resistance, or the small town's hurdles with resource limitations and citizen tech literacy, the path is rarely smooth. These challenges extend beyond mere technical hurdles to encompass profound organizational shifts, requiring careful attention to change management, staff training, and the strategic allocation of resources. The outer-ring suburb's experience highlights that even well-resourced entities face complexities, such as navigating version upgrades and managing diverse workflows, often compounded by internal pressures for rapid results. Acknowledging these potential obstacles upfront allows for more realistic planning, budgeting, and the development of proactive mitigation strategies.

Secondly, despite these difficulties, the case studies unequivocally show that digital transformation yields measurable, tangible benefits for both citizens and

employees. For citizens, these benefits manifest as improved service levels, greater transparency, and reduced waiting times, as exemplified by Topeka's impressive reduction in permit approval durations and Saratoga Springs' surge in new permits following their digitalization efforts. The mid-sized city's enhanced public transparency regarding permit durations and improved special event management further underscore these citizen-centric advantages. For employees, the benefits include greater efficiency, reduced administrative burden, and the freeing up of valuable time, as seen in the small town's staff being able to focus on higher-value tasks due to fewer paper applications and the suburb's achievement of an enterprise-wide permitting solution. These efficiencies contribute to more effective governance and better utilization of public resources.

Finally, and perhaps most critically, buy-in and consistent direction from leadership are absolutely essential for success. Digital transformation is not merely an IT project; it is a strategic organizational imperative that requires unwavering commitment from top municipal leadership. Leaders must champion the vision, allocate necessary resources (both financial and human), foster a culture of innovation and adaptability, and provide clear communication to mitigate resistance and align departmental efforts. Without strong leadership, projects can falter due to lack of funding, inter-departmental silos, or a failure to overcome entrenched bureaucratic inertia. The insights from the background literature emphasize that strategic leaders are crucial in driving public sector digital transformation by establishing vision, ensuring resources, and encouraging organizational change, aligning with the real-world experiences observed in these case studies.

In conclusion, while embarking on a digital transformation of the permitting process is undoubtedly a demanding undertaking, the evidence overwhelmingly suggests that the resulting improvements in efficiency, transparency, and service delivery fundamentally justify the effort of adoption. By acknowledging inherent challenges, focusing on measurable benefits, and securing robust leadership buy-in, municipalities can successfully navigate this modernization, ultimately serving their communities more effectively and preparing for the demands of future governance.

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25 Brazilian Scenario for Digital Building Permits

Initiatives from Pioneering Municipalities

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Introduction

Building permitting is a key aspect for cities to become hubs of economic development and responsibility for the population's well-being once municipalities concentrate a large part of the jobs, education, cultural facilities, and public and private services (Brasil, 2021). Despite the importance, there are deficiencies in the traditional building permitting process, which is often manual, time-consuming, costly, and prone to errors (Beach et al., 2020). In Brazil, the federal government's project Construa Brasil (2023) identified the complexity of municipal urban legislation, the lack of support for automated analysis, and the difficulty of standardizing flows and processes as the main problems.

In response to this scenario, there is a high demand from the municipalities for faster, more efficient processes that allow, in a short time, the services and permits to be made available to applicants. Nonetheless, there is still a mismatch regarding adopting digital processes, as shown in the research of the National Confederation of Municipalities conducted in 2022 with 1,379 Brazilian municipalities. The results indicated that about 60% do not have digital systems for construction permits, and only 9% have systems that allow digital use at all stages of building permits (CNM, 2022).

Notably, the evolution of software tools and data-based technologies has paved the way for automating rule checking. Despite these efforts to achieve higher levels of digitalization and even automation, standard practice in building permits remains on digital platforms for document management and not information management with GeoBIM models (Bloch & Fauth, 2023).

According to Olsson et al. (2018), although many of the techniques developed for automated checking apply, a vital difference in the field of building permitting is a high dependence on geospatial data, in addition to building data, which demands GeoBIM integration. Some leading municipalities have tested automated checks, but the wider adoption is still late (Ataide et al., 2023).

In a survey, buildingSMART International (2024) considered Estonia, Singapore, the United Arab Emirates, and Scandinavian countries as pioneers of digital building permits using BIM. In Latin America, countries like Brazil and Chile are developing their adoption of strategies for digitalization. This survey

also reported that initiatives are using BIM at the local level but with international relevance in terms of the results achieved. Municipalities such as Hamburg in Germany, Järvenpää in Finland, Salvador in Brazil, and Vienna in Austria act as pioneers in their countries (buildingSMART International, 2024).

Given this panorama, Ataíde et al. (2023) concluded that, from a technological point of view, the automation of parts of the process using GeoBIM and algorithms has advanced promisingly. However, there are organizational factors and legal barriers that challenge practical implementation.

Ullah et al. (2022), who investigated digitalization from the governmental point of view at the Estonian Municipality of Tallinn, identified that most previous studies focused on researching possible applications, prototype development, and code conversion into machine-readable formats. Nonetheless, few studies have addressed how public authorities can successfully transform digitally.

Ataíde et al. (2023) have evaluated a feasible gradual approach between digitalization levels, particularly for developing countries, which may face financial difficulties. Thus, a phased approach considers the level of effort and cultural change necessary to progressively improve processes, technology integration, and human skills over time. Ataíde et al. (2023) also cited gaps in knowledge of the development of holistic structures, implementation plans, ecosystems, and long-term interconnected strategic roadmaps that guide the transition from current workflows to the desired final state. Moreover, Fauth et al. (2024) highlighted the need for flexible and context-sensitive approaches rather than seeking a single solution. There is a demand for effective digital solutions that can adapt to the various environments, expectations, and requirements of the parties related to each region or country (Fauth et al., 2024).

Therefore, there is a growing interest in studies that enable a greater understanding of how municipalities can advance in the digital building permits stage. The literature has indicated a need for studies that consider organizational and procedural aspects, not only the technological aspect, allowing a gradual transition from traditional processes to digitalization.

This chapter aims to present the operationalization and application of a model for managing the process of digital building permits directed to medium-to large-sized municipalities in two pioneering Brazilian cities. The model operationalization and application are based on Brito et al. (2024) roadmap, which contributes to a greater understanding of how municipalities can manage the process of digital building permits, guiding the transition with a flexible and context-sensitive approach.

Digital Transformation of Building Permits

In Brazil, the building code is the main legal norm of land occupation control at the municipal level. Even with this relevance, the panorama of these codes in the national territory is quite heterogeneous, as they have different content, varied requirements, and sometimes overlap with other municipal

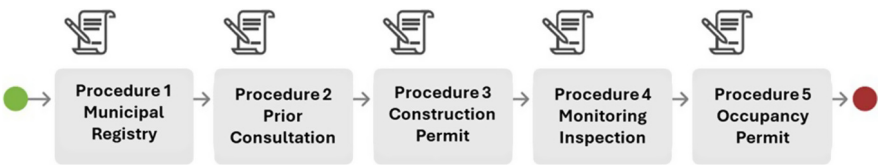


Figure 25.1 Main basic procedures in the building permit.

Source: Adapted from Construa Brasil (2023).

rules or technical standards (Construa Brasil, 2023). According to the Brazilian Institute of Geography and Statistics (IBGE, 2021), 3,792 (68.07%) of the 5,570 Brazilian municipalities had their code.

To accelerate digital transformation, the Brazilian Federal Government established the Construa Brasil project, containing goals related to the convergence of building codes, improving the process of granting construction permits for BIM diffusion, and encouraging modular coordination and industrialized construction. Therefore, based on the experience of Brazilian municipalities such as Salvador, Belo Horizonte, São Paulo, and Fortaleza, the best practice guide highlighted five basic administrative procedures performed between the applicant and the city during the building permit process, as can be seen in Figure 25.1 (Construa Brasil, 2023).

Even though considered complex, the building permit is still characterized by procedures weakly assisted by technological resources (Muniz et al., 2024). Raj et al. (2024) consider that standardization and digitalization bring several benefits that can positively impact regulators and applicants. However, according to Bloch and Fauth (2023), a crucial issue weakly addressed in previous studies comprises a clear definition of the possible, necessary, and acceptable automation levels in the building permit process. Given this scenario, Bloch and Fauth (2023) proposed four levels that range from manual to automated.

Similarly, in a conceptual study, Shahi et al. (2019) proposed a structure categorizing existing systems in municipalities on four levels. In addition, these structures were similar to the maturity levels of BIM submissions classified by buildingSMART International (2020). Table 25.1 compares these digitalization and automation levels based on these identified structures, indicating the similarities and specificities. There is a strong convergence between the maturity of the automation levels proposed by Bloch and Fauth (2023) and Shahi et al. (2019), with differentiations only in levels 2 and 3, where the first model emphasizes the integration with GeoBIM information from level 2. However, these structures do not have sufficient detail and operationalization to allow municipalities to identify actions necessary to start digitalization and advance between levels.

Recently, the CHEK DBP Maturity Model was developed in Europe to assess the maturity of municipalities in implementing digital building permit

Table 25.1 Comparison between Digitalization and Automation Level Structures

<i>Structures with Levels of Digitalization and Automation for Building Permits</i>				<i>References</i>
<i>Level 0</i>	<i>Level 1</i>	<i>Level 2</i>	<i>Level 3</i>	
Manual based on physical paper documentation	Manual based on digital document management	Semi-automated using BIM integrating geospatial information Various levels of automation using BIM	Automated checks and decision support GIS Integration with BIM for Smart Cities	Bloch and Fauth (2023) Shahi et al. (2019)
Manual transition from paper to electronic files	BIM initiation with limitations in use	Hybrid with the use of BIM in checks, but with some manual procedures	Automated with holistic code checking	buildingSMART International (2020)

processes across 35 key maturity areas, covering process, organization, technology, and information categories. In addition to the maturity model, a framework was proposed to enable the development of a strategic roadmap for municipalities to achieve higher levels incrementally (Ataíde et al., 2023). However, future work will conduct additional practical testing and the development of a virtual change management assistant to support municipalities in developing digital transformation strategies.

Brito et al. (2022) conducted a case study regarding the Brazilian scenario, analyzing the best practices and lessons learned from the municipality of Salvador to implement a BIM-based digital building permitting system for code checking. This municipality issued the first construction permit in 2022 for a project submitted in BIM (Salvador, 2022).

The municipality of Salvador is considered a pioneer in developing the Tekto platform, from mapping 140 processes to optimizing and automating the check of about 100 urban parameters based on GeoBIM integration (Torreão, 2024). Also, Brito et al. (2022) critically reflected on the Brazilian municipal context and compared it with best practices and lessons learned from international initiatives in the seven stages of digitalization identified in the literature. Table 25.2 compares the adopted practices and challenges of Salvador with global experiences.

Other Brazilian municipalities are also starting new stages of digitalization, such as Belo Horizonte, which opened a public consultation in 2023. The objective was to know the solutions existing in the market and understand the possibilities of developing a new digital platform adhering to the

Table 25.2 Comparison of Digitalization in the Brazilian Municipality with International Experiences

<i>Digitization Steps</i>	<i>The Practice Adopted/ Current Challenge in the Brazilian Municipality Studied</i>	<i>International Best Practices and Lessons Learned</i>
Analysis of legislation and regulatory codes	Digitization started in a period close to the last update of the urban master plan. This closeness did not allow a revision of the code clauses to make it objective.	• Evaluate the feasibility of automating the existing code checking. • Revise legislation appropriately with the desired degree of automation and in a manner compatible with ordinary review periods.
Building permitting process mapping and redesign	The consultancy mapped the manual processes and proposed redesign with simplifications adjusted in the CDE development.	• Cover the entire building permit lifecycle, including post-construction inspections. • Compatibility with possible manual and other regulatory checks: historical heritage/ environmental/external agencies.
CDE definitions (submission, pre-checking, and checking system)	The municipality team did not identify available technological solutions on the market for the intended digitization (automatic pre-checking by the applicant and semi-automatic checking of the municipality's objective codes).	• Determine the required functionality and the degree of interaction of technicians with automated checking during the building permitting stages. • Identify available platforms, select CDE and local code adaptation methods.
Transcription of regulatory codes	The consultancy that developed technological solutions was responsible for transcribing the codes into computable checking rules and interpretation with the municipality's technical team.	• Select the method of transcription and interpretation of codes in checkable algorithmic rules. • Use natural processing language to transcribe machine-readable codes.
CDE development (submission and checking system)	The consultancy initially developed a CDE to submit and check BIM models exported in IFC only from Autodesk® Revit software.	• Define the structure of the deliverables in open IFC and/or CityGML formats that will be checked. • Conduct tests and pilots on CDE interoperability, usability, and reliability.

(Continued)

Table 25.2 (Continued)

<i>Digitization Steps</i>	<i>The Practice Adopted/ Current Challenge in the Brazilian Municipality Studied</i>	<i>International Best Practices and Lessons Learned</i>
Management and evaluation of the digitization process	BIM implementation required training on the technologies by the municipality's internal team, as well as changes in organizational culture, procedures, and policies. Integration with GIS focused on georeferencing the particularities of the code applicable to the zoning of the municipality.	• Implement the necessary BIM/GIS integrations for the desired degree of automation. • Manage procedural, technological, and political/people BIM/GIS fields. • Integrate information from licensed projects with the regional GIS base.
Requirements for receipt and compliance of deliverables	Protocol with structuring and classification definitions for models exported in IFC from Autodesk® Revit software is available. Quality control and compliance checking procedures for deliverables have not yet been defined, under the responsibility of the consultancy.	• Establish the structure for preparing and submitting deliverables for digital permitting. • Establish and perform procedures for prior checking of the deliverable's reliability and compliance to the established structure. • Use machine learning and deep learning to check compliance.

Source: Brito et al. (2022).

municipality's demands (Belo Horizonte, 2023). The public consultation results will subsidize the acquisition of a customizable market solution or its development, duly integrated with other systems, to allow automated checking of urban parameters using BIM models. Belo Horizonte intends to create a new flow for receiving BIM submissions, which will be stored in a Common Data Environment (CDE). The scope of digitalization comprises the construction of horizontal buildings (Belo Horizonte, 2023).

Thus, practical application cases have reinforced the view of studies such as Hirvensalo (2024) that municipalities do not transform all their services into new digital processes at once. Ataíde et al. (2023) corroborate this understanding that changing a paper or electronic system to a fully digital system is not a simple transition. This type of innovation requires holistic change encompassing process and information digitalization, automation, and systems integration beyond legal and organizational adaptation.

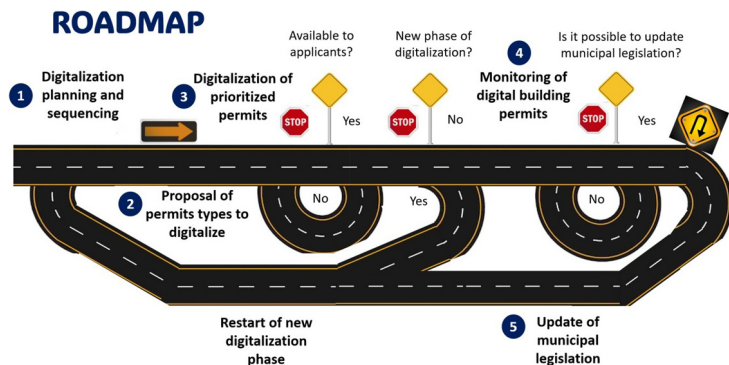


Figure 25.2 Conceptual framework for managing the digitalization process in Brazilian municipalities.

Source: Brito et al. (2024).

Therefore, Brito et al. (2024) proposed a roadmap with a conceptual structure of the model for managing the digitalization process, focused on the context of the Brazilian municipalities for construction permits. Figure 25.2 shows the roadmap with the planning and sequencing, digitalization, and monitoring stages until the restart of a new phase.

The first stage involves planning and sequencing digitalization, in which the municipality explains the building typologies of existing construction permits according to prioritization criteria, current and intended digitalization levels, and the selection of indicators for monitoring performance concerning traditional processes. As a result of this first stage, some existing construction permits are recommended for prioritization according to criteria such as the quantity demanded and the current analysis deadlines (Brito et al., 2024). In addition to the extent of digitalization, the model recommends other categories of indicators to monitor the transition shown in Figure 25.3, according to Brito et al. (2024). However, there is still a need to operationalize the conceptual framework in the model to be applied in Brazilian municipalities undergoing digitalization to evaluate the potential, ease of adoption, barriers, and impacts of use.

Research Method

The research strategy adopted is the case study, given the need to understand a complex organizational phenomenon, which is municipalities' digitalization of construction permits. The case study allows empirical investigation that preserves real-life events' holistic and meaningful characteristics, contributing to a greater understanding of individual, organizational, social, and political phenomena (Yin, 2001). Fellows and Liu (2008) also highlight the possibility of combining various data collection methods, such as interviews, observation, and documentary analysis.

Categories	Indicators
Extension	Percentage of permits that can be issued digitally in the municipality Percentage of digital permits issued in relation to the total number issued
Reduction of deadlines and time for analysis	Average percentage of reduction in the issuance deadline in relation to the traditional process
Reduction in the number of requests for clarification or design changes	Average percentage of reduction in the number of clarifications or changes in design for issuing digital permits
Increasead capacity to issue permits	Average percentage of increase in permit issuance capacity
Potential return on investment	Potential payback time on digitalization investment Potential increase in annual revenue from issuing permits

Figure 25.3 Indicators for monitoring and estimating performance concerning traditional procedures.

Source: Brito et al. (2024).

Initially, a literature review was carried out, involving the selection of scientific articles and technical publications, covering the Regulatory Room of buildingSMART International, the European Network for Digital Building Permits, and the Construa Brasil Project, aiming to provide an overview of the topic, especially in the Brazilian context.

The investigation of the initiatives of two Brazilian municipalities that are pioneers in digitalization involved a case study in the municipality of Salvador, aiming to operationalize the model for managing the digitalization process proposed by Brito et al. (2024). The model aims to manage the digital transition process of Brazilian municipalities, highlighting phased implementation, prioritization of building typologies, and performance monitoring through tailored indicators. The application of the model in the municipality of Belo Horizonte allowed the analysis and discussion of the results from the perspective of those two Brazilian municipalities with concrete actions toward more advanced levels of digitalization. Table 25.3 summarizes the characteristics of the two municipalities investigated and the data collection carried out.

Regarding the case study in the municipality of Salvador, the document analysis, observations, meetings, and interviews aimed to investigate the scenario after the first phase of digitalization of an existing typology of construction

Table 25.3 Data Collection in the Investigated Brazilian Municipalities

<i>Municipality</i>	<i>Digitalization Features</i>	<i>Data Collection</i>	<i>Period</i>
Salvador	Fifth most populous Brazilian municipality (2.4 million inhabitants) and was one of the references for best practices of the Construa Brasil Project. The first municipality to start digitalization to automate code checking through GeoBIM in 2016, having issued the first construction permit using BIM in 2022.	Observation and interviews with the municipality and platform developers to propose recommendations for implementation to operationalize the model	October 2022 to December 2023 (10 hours)
		Documentary analysis of strategic planning for operationalization of model monitoring metrics	January 2024 (4 hours)
		Model presentation meeting with the checking platform developers to receive feedback	July 2024 (2 hours)
		Meeting to present the model to the municipality and receive feedback and opportunities for improvement	November 2024 (2 hours)
Belo Horizonte	Sixth most populous Brazilian municipality (2.3 million inhabitants) and was one of the references for best practices of the Construa Brasil Project. The digital transformation journey for building permits has begun, having carried out a public consultation for acquisition or development of a checking platform using GeoBIM in 2023.	Meeting to present the model and collect information from the municipality	October 2024 (2 hours)
		Presentation of the refined model and guidance on the data required for application	January 2025 (2 hours)
		Model application meeting and results availability	February 2025 (2 hours)

permits. Furthermore, it aimed to operationalize the model’s stages related to performance monitoring through indicators and documents with recommendations for implementation.

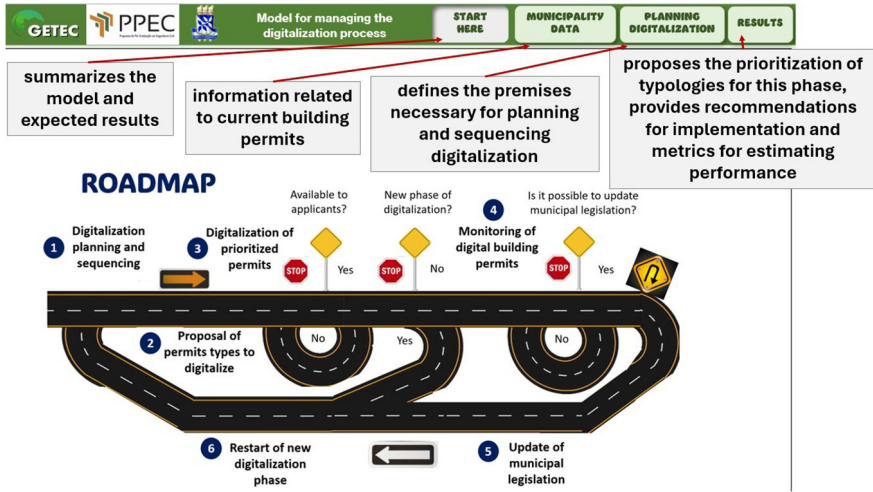


Figure 25.4 Operationalization of the model for managing the digitalization process.

The model operationalization was carried out in an electronic spreadsheet composed of four dashboards: “Start here” to provide basic information, “Municipality data” and “Planning digitalization” for the participant to fill in, and “Results” with the output of the planning and sequencing stages of the roadmap proposed by Brito et al. (2024). Figure 25.4 provides more details on each dashboard.

Tests were carried out to fill in the information and observe how the spreadsheet worked, especially in fields that involved calculations and depended on other parameters. Furthermore, improvements were also proposed during the presentation meetings with the checking platform developers and the municipality of Salvador to simplify instructions for participants.

Then, the model application in Belo Horizonte involved meetings and presentations with representatives of the municipality regarding the objective, benefits, and availability of the necessary data. The application took place through a remote meeting attended to fill out and analyze the results, lasting around 2 hours. The results included the sequencing of building typologies considered a priority in this phase of digitalization, recommendations for implementation, and simulation of indicator categories with monitoring metrics.

Finally, the discussion of the results and the formalization of the theoretical and practical contributions generated recommendations for future studies and highlighted the potential for the model’s scalability in the Brazilian scenario of digital building permits.

Results

The case study in the municipality of Salvador operationalized the model through insights and feedback from a practical case, which had already gone

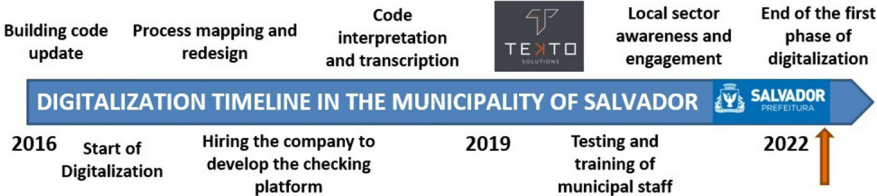


Figure 25.5 Internal steps to digitalize construction permits in Salvador municipality.

through the internal phase of the first digitalization phase, as shown in the timeline in Figure 25.5.

Based on interviews with municipality representatives and checking platform developers, document analysis of the manuals, and strategic planning, the model’s planning and sequencing prioritization criteria were operationalized. The number of construction permit requests and the deadline analysis for each building typology were adopted as criteria based on the relevance and frequency that are part of digital transformation goals. Both are quantitative criteria that municipalities can collect and that represent these objectives of reducing analysis times and increasing the capacity to issue construction permits.

Based on feedback from meetings and presentations to the municipality of Salvador, the model incorporated the local market affinity criterion as an optional additional weighting factor. Given the higher qualitative level, this criterion was operationalized based on the degree of importance (very low to very high) of the municipality’s perception of the applicants’ willingness to migrate from the traditional method to using digital permits for each typology.

This perception may consider, for example, the size and willingness to invest in technologies by builders and the availability of designers, among other motivations involved in each building typology. Based on these definitions, simulations of variations in digitalization planning and sequencing parameters were carried out to observe the weighting, sensitivity, and the results presented.

As a result of the operationalization, the model was applied with data from the municipality of Belo Horizonte, the capital of the Brazilian state of Minas Gerais, which has four building typologies with construction permits (single-family, multi-family, non-residential, and mixed). Initially, the “Municipality Data” dashboard refers to basic input information such as population, size, and current construction permit building typologies.

The next dashboard, “Planning digitalization,” allows the data insertion that will enable the model to propose the prioritization of building typologies. Thus, the municipality made available quantitative data related to the prioritization factors, assigning a medium level of importance to the number of construction permits requested and a high level to the analysis deadlines for each building typology.

Regarding the degree of affinity of the local market, the municipality did not use the optional factor. It justified that there was no information to

measure the applicants' willingness to migrate to using digital permits for each building typology.

The "Planning digitalization" dashboard also identifies the municipality's current and desired levels of digitalization and automation. Based on questions about the submission process, accepted deliverables, checking automation, communication with applicants, and issuance of building permits, the model considered that the municipality intends to migrate from a manual building permit based on digital documentation to a semi-automated building permit based on digital documentation and BIM models.

In addition, the municipality also presents information on other boundary conditions on this dashboard, such as the forecast for updating the building code and the intention to involve other related parties in the checking platform. Before checking the results, the municipality could confirm the level of extension proposed by the model, which represents the recommendation that the number of typologies be digitalized in this phase, according to the complexity of the intended level of digitalization. Figure 25.6 summarizes the main information contained in the "Municipality Data" and "Planning Digitalization" dashboards.

Another aspect to highlight as part of this sequencing is that, in the case of Belo Horizonte, the level of extension indicated by the model was low, up to 30% of building typologies, since this stage has a considerable level of complexity due to seeking level 2 of semi-automated checking with BIM models. Thus, the "Results" dashboard proposed two building typologies for construction permits to be digitalized as a priority, with multi-family having the highest priority, followed by single-family (Figure 25.7).

Although these typologies currently have slightly shorter analysis deadlines (98 and 100 days, on average, respectively) than non-residential and mixed-use typologies (103 and 117 days, respectively), the higher number of requests from applicants for these multi-family (885 requests per year) and single-family (814 requests per year) typologies were decisive criteria for the indicated sequencing.

In addition to sequencing, the model provided five documents with recommendations for implementation and five categories of indicators with metrics

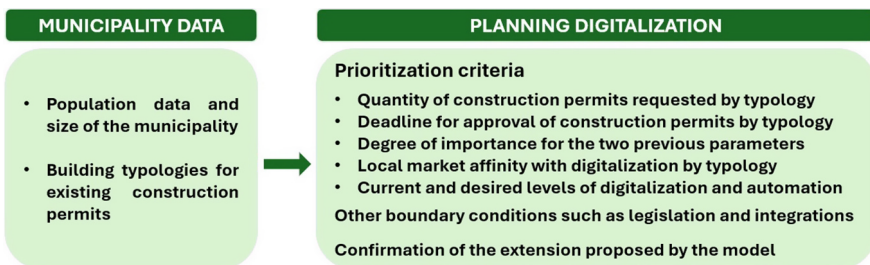


Figure 25.6 Key input information in "Municipality Data" and "Planning digitalization" dashboards.

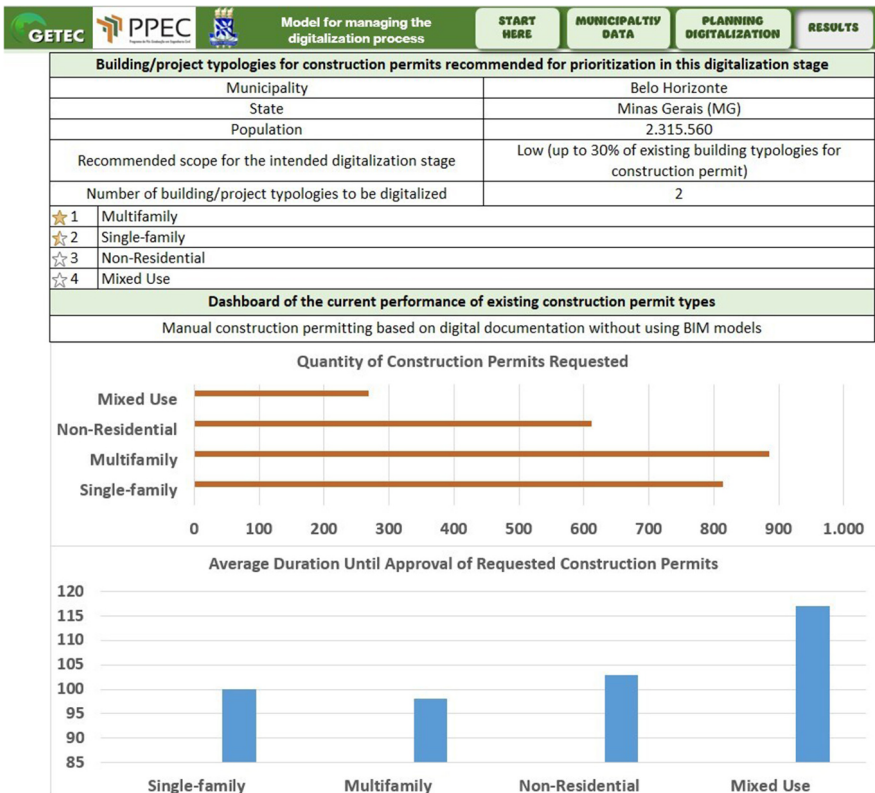


Figure 25.7 Results of digitalization planning and sequencing in Belo Horizonte.

to estimate and monitor the performance and benefits of digitalization (Figure 25.8). Regarding the extension of this phase, although the prioritization indicated two typologies of the four existing ones to be digitalized, these represent 65.88% of the potential percentage of construction permits issued.

Another relevant metric is the average percentage reduction in the analysis duration compared to the traditional process, which can reach 54.53% with the intended deadline up to 45 days after digitalization. Consequently, this reduction influences, in an inversely proportional way, the potential for increasing the capacity to issue construction permits, which could reach 119.91%, revealing the expected productivity gain.

In addition to reducing deadlines, the benefit estimate includes the metric of reducing the number of clarifications or changes for issuing digital construction permits. In the case of Belo Horizonte, this estimated percentage reached 42.86%, with a reduction from 3.5 to 2.0 in the expected average number of clarifications or design changes until the approval of construction permits after digitalization.

  		START HERE	MUNICIPALITY DATA	PLANNING DIGITALIZATION	RESULTS
Recommendations for implementation, indicated according to the desired level of digitalization and automation					
Semi-automated construction permitting based on digital documentation and BIM models					
1	Best Practices for assessing the building and construction code				
2	Competences of those responsible for managing information in the digitalization process				
3	Guidelines for defining project information requirements using BIM				
4	Requirements protocol for the development and implementation of the CDE for digital construction permits				
5	Protocol for monitoring performance and benefits achieved through digitalization				
Evaluation and simulation metrics for this stage of digitalization of construction permit					
Metrics to support indicators					Data to simulate or monitor digitalization
Number of construction permits in the reference period that would be granted digitally with the desired level of automation in the municipality					1699
Average duration (in days) until approval of construction permits before digitalization					98,96
Average value (in Brazilian currency) per construction permit paid by applicants for approval of construction permits to be digitized at this stage					R\$ 1.128,92
Indicator categories					Simulation of results after this digitalization phase
Extension of this phase of digitalization					
Percentage of building/project types for construction permits that can be granted digitally with the desired level of automation in the municipality					50,00%
Percentage of digital construction permits that could be granted with the desired level of automation in relation to the totals					65,88%
Reduction of analysis deadlines and durations					
Average percentage reduction in the duration of approval of digital construction permits compared to the traditional process					54,53%
Reduction in the number of requests for clarification or changes to submissions					
Average percentage reduction in the number of clarifications or changes in submissions for approval of digital permits					42,86%
Potential for increasing the capacity to grant construction permits					
Percentage of potential increase in the capacity for granting construction permits					119,91%
Return on investment potential					
Potential for annual increase in revenue from digital construction permits					R\$ 2.299.860,91
Potential minimum return on investment time for digitalization (in years)					3,26

Figure 25.8 Implementation recommendations and monitoring indicators for Belo Horizonte.

Regarding the potential return on investment indicator category, based on the average amount paid by applicants for construction permits, the potential for an annual increase in revenue totals approximately R\$ 2.3 million (in Brazilian reais), if the demand from applicants and the potential for increasing capacity to issue construction permits materialize. Finally, based on the municipality's estimated average investment value in this digitalization phase, the minimum potential return on investment time was calculated for 3.26 years.

Discussion

The digitalization scenario in the municipalities of Salvador and Belo Horizonte reinforces the trend raised by other studies, such as Ullah et al. (2022), Ataíde et al. (2023), and Hirvensalo (2024), that digitalization requires

a gradual approach through phases, especially when entering more advanced levels of automated checking with GeoBIM.

Fauth et al. (2024) highlighted that this phased approach might involve a division by the type of content to be checked, such as accessibility and fire safety codes, building typology, or even by the type of permit to be digitalized. In the Brazilian context, the results revealed that phasing has occurred according to the building typology, in the case of Salvador, single-tower multi-residential, and in Belo Horizonte, single-family horizontal residential, covering all the codes applicable to that typology.

This strategy, which involves transition phases, reinforces the need for an adequate selection of which building typology to start digitalization. In the case of Salvador, although the first phase has been completed, the pace of new requests for construction permits by applicants optionally submitting BIM documentation has been low. The model operationalization sought to address this issue by focusing on the context of medium to large Brazilian municipalities, establishing as prioritization criteria the demand of applicants in terms of requests and the duration of analysis of each building typology for construction permits.

However, as these data refer to traditional processes, they may not reflect the level of readiness of the local market for transition to BIM processes. Although the municipality of Belo Horizonte did not use this additional criterion during the model application, the possibility of prioritization by the degree of affinity of the local market regarding each building typology to be digitalized aims at a better representation of the intended scenario.

Another specificity about the two municipalities is that Salvador hired a specialized company to develop an automated checking platform instead of trying to use and customize existing tools. The municipality followed a different path than what occurred in some Finnish municipalities surveyed by buildingSMART International (2024).

Belo Horizonte has already sought to evaluate both possibilities, launching a public consultation in 2023 to decide whether to develop internally or hire a customized solution. This issue, in addition to indicating the various options that municipalities face in digitalization for the implementation of the CDE, reveals a growth in the maturity of market tools.

The model application also highlighted the need for municipalities to have more detailed information regarding the building typologies in construction permits, which can be subdivided internally into variations of the same typology. The non-residential typology, for example, would require digitalizing aspects applicable to commercial and industrial buildings, among other subdivisions that may occur. In the case of Belo Horizonte, construction permits are divided into four large groups. Still, no information was obtained on the number of requests and current analysis deadlines for these possible subdivisions.

Although the model has been applied in Belo Horizonte for the digitalization planning and sequencing stage, the municipality has not yet initiated the following actions, which have not allowed progress to the other stages proposed by Brito et al. (2024) in the model's roadmap, such as the use of the protocol for monitoring performance and benefits achieved in digitalization.

The results indicated the need for additional studies to assess the impact on the environment and users during the digitalization process. This process is usually long in its first phase, comprising activities ranging from planning, hiring, code transcription, platform development and customization, testing, training, and assisted operation.

Conclusions

The digitalization of construction permits causes changes in traditional processes centered on digital models, requiring municipalities to plan and sequence actions adequately. This research analyzed pioneering initiatives of the Brazilian municipalities of Salvador and Belo Horizonte through the model operationalization and application for managing the digitalization process.

The results contribute to filling the knowledge gap regarding the need to develop long-term interconnected strategic roadmaps that guide the transition with flexible and context-sensitive approaches. Furthermore, the case study and the application of the model contribute to a greater understanding of how Brazilian municipalities can advance in the digitalization process, considering organizational and procedural aspects in addition to the technological aspect addressed in another research.

As a practical contribution, the model can allow professionals involved to understand, evaluate, and monitor the actions taken by municipalities at each stage of digitalization using the proposed metrics and recommendations.

The recommendation for future studies involves applying and evaluating the model in other medium to large Brazilian municipalities and monitoring digitalization at other stages beyond planning and sequencing. There is also a need for research that investigates digitalization during the construction inspection and building use permitting phase.

Acknowledgments

The authors would like to thank the Brazilian municipalities for their willingness to participate in the research.

Data Availability

Data from organizations and participants in the case study and application of the model are confidential and must be anonymized for availability.

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26 Conclusions

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This book has shown that sustainable innovation in building permitting systems is contingent upon not only technological advancements but also an enhanced comprehension of organisational behaviour, legislative structures, and effective stakeholder collaboration. This intrinsic complexity has been embraced across the three parts of the volume, underscoring that meaningful transformation cannot be achieved through isolated interventions in a single domain, such as technology alone or the analysis of the purely administrative process. The legal, organisational, and cultural conditions necessary for change have also been discussed. Although across the chapters great diversity has been observed in how countries regulate the built environment, the same core challenges persist across jurisdictions: fragmented responsibilities, inconsistent information, lack of data and procedural interoperability, and the persistent tension between speed, quality, and accountability of the process itself. This diversity among different government levels (such as countries, regions, provinces, and municipalities) also reflects how building permitting functions as a mirror of societal priorities. Each system embodies implicit choices about how risks are shared, how public values are protected, and how discretion is balanced with rule-based governance.

Several key lessons emerge. First, digitalisation, the core topic of this book, is an essential enabler, but it is not a cure-all. Technology can speed up inefficient processes, but only a critical examination of underlying objectives and workflows leads to genuine improvement. Real transformation requires rethinking the process itself, not merely using digital tools for the existing steps. In this sense, the governance structures have to be addressed, and the distribution of professional responsibility within public administrations is required. With respect to this observation, the second point is that best practices arise where digital tools and institutional reforms evolve together, supported by clear responsibilities, transparent rules, and collaboration across disciplines. Building permitting, in fact, is not only a technical task but it carries societal responsibility; public trust depends on fairness, traceability, and the shared conviction that the system protects safety, quality, and the common good. In that sense, and it constitutes the third point to be highlighted, building permitting is an arena

where democracy materialises in everyday administrative practice, the translation of public will into the built environment. Maintaining this legitimacy is as important as achieving efficiency.

The administrative practice and path towards the digitalisation of the building permit process are discussed in the third part of the book, which has focused on actual implementations enabled by Building Information Modelling (BIM) and Geographic Information Systems, as well as their combined application (GeoBIM), and, more recently, Artificial Intelligence (AI). The case studies in this book demonstrate that digital transformation is not a one-size-fits-all journey. Municipalities, provinces, and national governments each face unique challenges and opportunities. Municipal leaders often act as pioneers, piloting new technologies and processes that, when successful, can inform broader national strategies. In federal systems, harmonising digital building permitting across diverse jurisdictions requires both strong national standards and flexibility for local adaptation. Cross-level collaboration and knowledge exchange are essential to ensure that innovation is both scalable and context-sensitive. The actual implementations described in this book allow closing the gap in the existing literature, where one of the less addressed topics was related to the needs and challenges of organisations, especially public authorities. Moreover, the importance of upskilling and reskilling strategies for human resources emerges, starting with an assessment of their effective digital maturity at both technical and procedural levels. Comparative experiences across countries highlight that digital transformation operates within different political cultures. Where it aligns with democratic accountability, transparency, and public engagement, digitalisation strengthens governance. Where these principles are neglected, it risks becoming a technocratic exercise detached from societal needs.

The book also demonstrates the value of integrating research and practice, also through technology transfer actions, to enhance data-driven processes over document-based ones. Qualitative studies, actual implementations, process visualisations, and case evidence complement each other. Together, they reveal where complexity resides and where leverage points for change can be found.

Building on these findings, several cross-cutting priorities emerge for researchers, practitioners, and policymakers seeking to advance responsible and sustainable digital building permitting. Looking ahead, several directions call for continued research and innovation:

- Design and implementation of interoperable data ecosystems that connect planning, permitting, inspecting, and building operations, as it emerges from the connection between the digital building permit and the digital building logbook to promote greater transparency along the entire value chain and building life cycle;
- Governance models that balance automation with professional discretion and accountability;

- Policy and legal frameworks that reduce administrative burden without sacrificing public safety or trust and that allow for coding building requirements in a more effective computable language, less susceptible to subjective interpretation;
- Cybersecurity and prevention of bias in the sense of utilisation of digital tools and AI-based systems for process management and compliance checking, including site inspections;
- Robust metrics, indicators, and methodologies for assessing the effectiveness, efficiency, equity, and societal impact of digital building permitting over the paper-based or just dematerialised one;
- Strategies for supporting professionals, public officials, and stakeholders in adapting to new digital tools and workflows, ensuring inclusive capacity-building and lifelong learning oriented to upskilling and reskilling of human resources;
- Continued development of shared international standards and ontologies to ensure semantic consistency and facilitate cross-border collaboration.

As digitalisation accelerates, governments must remain attentive to the democratic dimension of automation. The risk is not authoritarian control but a subtle drift towards technocratic governance, where procedural efficiency overshadows deliberation and local judgement. Digital systems should therefore support, not replace, the interpretive work that gives building permitting its social legitimacy. As digitalisation continues to reshape construction governance, it needs to be accompanied by thoughtful institutional and administrative choices. It is reductive to frame the main benefit solely as faster building permitting, as this risks evoking concerns about diminished scrutiny and weakened oversight. It will instead be a system that is efficient without being careless, innovative without losing legitimacy, and digital without forgetting its societal purpose. And finally, it will be a system able to cope effectively with the new societal, environmental, and economic challenges, upgrading the whole field to a novel approach. Ultimately, building permits are an essential mechanism to ensure that what is built contributes to resilient, safe, and sustainable cities, rather than procedures that slow construction down.

The insights presented throughout this book converge on a simple yet powerful premise: technology is only as transformative as the institutions and people who use it. The contributions in this book show that this goal is within reach if we combine technology with reflection, evidence with practice, innovation with responsibility, and the professionals and operators in the field, both now and for future generations, are accompanied in a journey to acquire new skills and revolutionise their mindsets. The digital era offers unprecedented tools, but it is reflection, dialogue, and shared purpose that will determine whether they serve bureaucracy or democracy.

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