Smart and Sustainable Built Environment

Digital twins for smart cities: addressing shared influences in building permitting and road infrastructure planning

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Abstract

Purpose – This study investigates shared influencing factors between building permitting and road infrastructure planning and examines how these overlaps inform cross-domain digital twin information requirements in smart city contexts.

Design/methodology/approach – An exploratory multi-method research design was employed, combining a structured literature review, regulatory document analysis, ethnographic reflection, and evaluation through a focus group comprising international built environment practitioners. The study focuses on identifying and categorising shared factors and mapping them to associated information requirements rather than testing predefined hypotheses.

Findings – The findings identify 16 shared influencing factors spanning regulatory, spatial, technical, and governance dimensions that simultaneously affect building permitting and road infrastructure planning processes. These factors are organised into primary, secondary, and tertiary tiers and conceptually mapped to corresponding information requirements relevant to cross-domain digital twin implementation.

Research limitations/implications – A multi-jurisdictional evaluation reflects expert perspectives from selected regulatory contexts. Further empirical testing across diverse jurisdictions is required to assess scalability and contextual adaptation.

Practical implications – The study provides planning authorities, infrastructure managers, and digital twin developers with a structured framework to identify cross-domain dependencies, prioritise critical constraints, and support the staged implementation of interoperable digital twin systems.

Social implications – By illuminating the interdependencies between built environment domains, this research promotes more coordinated and sustainable planning practices, ultimately benefiting urban communities.

Originality/value – The research advances digital twin discourse by offering a structured cross-domain mapping of shared planning factors and associated information needs, linking regulatory coordination challenges with digital twin design considerations.

Keywords Digital twins, Smart cities, Building permitting, Road infrastructure planning, Information requirements

Paper type Research article

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1. Introduction

Infrastructure development is central to economic growth and societal well-being, yet the construction industry faces mounting challenges from resource scarcity, including shortages of skilled labour and materials (Alsharef *et al.*, 2024). Maximising the use of existing resources therefore demands innovative approaches that move beyond traditional practices. At the same time, rapid urbanisation and technological innovation have driven the emergence of smart cities—urban environments that employ digital technologies to improve performance, sustainability, and quality of life. Central to their operation are building permitting and road infrastructure planning (Hine, 1998), processes that not only shape the physical landscape but also influence economic development, environmental sustainability, and social equity.

Building permitting acts as a regulatory gateway to ensure compliance with legal, environmental, and safety standards (Noardo *et al.*, 2022). While digitalisation has advanced in areas such as automated code compliance, significant gaps remain, with most studies neglecting systemic and interdisciplinary perspectives. The permitting process spans diverse information requirements, from design and application to review, stakeholder engagement, and permit-related inspections as staged compliance checks that require systematic planning and coordination (Fauth, 2022; Seiss *et al.*, 2025). Current practices, largely manual and time-intensive, lead to delays across project timelines (Malsane *et al.*, 2015). Digitalisation offers opportunities to streamline these processes; however, it cannot alone resolve the complexities of multi-stakeholder involvement (Noardo *et al.*, 2020). Thus, foundational frameworks are needed to support effective adoption across sectors (Papadonikolaki *et al.*, 2020). In parallel, road infrastructure projects, though governed by distinct mechanisms, are influenced by similar regulatory, spatial, and technical factors (Cruz and Sarmento, 2019). Yet, while extensive research exists on building permitting and road planning individually, little work has addressed their shared factors (Bloch and Fauth, 2023; Fauth and Brilakis, 2024). Identifying these overlaps is therefore essential to streamline development, reduce administrative burdens, and improve delivery.

Digital twin technologies, understood as virtual replicas of assets, systems, or processes, offer a potential mechanism for improving coordination between building permitting and road infrastructure planning. By leveraging real-time data and predictive analytics, they enable simulation, monitoring, and optimisation of infrastructure performance (Sacks *et al.*, 2020). In the context of permitting and road planning, digital twins can support more coordinated data management and collaboration; however, their success depends on addressing regulatory constraints, interoperability challenges, and the need for standardised information models. Defining specific information requirements is therefore critical to clarify what data is needed, how it should be structured, and how it can be securely exchanged (Sacks *et al.*, 2020). For example, digital twins could enable automated verification of setback compliance by simultaneously assessing building geometry and road visibility requirements within a shared spatial model, building on prior work on BIM/GIS-based permitting and automated compliance checking (Olsson *et al.*, 2018; Malsane *et al.*, 2015; Noardo *et al.*, 2020). Similarly, digital twins could simulate alternative access point configurations to evaluate traffic safety, emergency access, and junction performance before permit approval, drawing on established traffic impact and road safety assessment practices (Hine, 1998; Hokao and Mohamed, 1999; Federal Highway Administration, 2016). Integrated drainage models could assess the combined runoff impacts of new buildings and adjacent road surfaces, while shared utility twins could reduce excavation conflicts by providing a common view of underground assets (Lloyd *et al.*, 2002; Sacks *et al.*, 2020). These examples demonstrate how digital twins can move beyond isolated domain applications to support coordinated, cross-sector decision-making in smart city contexts (Deng *et al.*, 2021; Sacks *et al.*, 2020).

Cross-domain digital twin integration depends on interoperable information structures. Open standards such as IFC and CityGML support geometric and semantic representation across building and urban infrastructure contexts, while APIs and common data environments enable controlled information exchange between permitting, road infrastructure, and municipal systems. However, despite growing interest in digital twins across the built environment, research and implementation efforts remain largely domain-specific. Building permitting and road infrastructure planning are typically addressed through siloed regulatory frameworks, data structures, and institutional processes. This fragmentation limits coordinated urban development and creates challenges for the cross-domain integration required by digital twin applications.

Digital twin concepts provide the broader motivation for this study. However, no digital twin is developed or implemented within the scope of this research. Instead, the study addresses a prerequisite for such applications: understanding the information required to connect digital twins of different built assets and the information that is shared across asset domains. Exploratory research is therefore needed to identify relevant use cases and information requirements before technical development can take place. The focus of this study is on the relationship between road assets and the information required in building permitting. It is assumed that, once available, road digital twins could serve as an important data source to support and enhance building permit processes.

Accordingly, this study investigates shared influencing factors between building permitting and road infrastructure planning and examines how these overlaps can inform structured cross-domain information requirements for digital twin applications. Rather than presenting fully developed information requirements, the study establishes a foundation by linking shared influencing factors, representing what matters in both domains, with corresponding information requirements, representing what data is needed. Drawing on literature, regulatory documents, and expert insights, the study aims to identify and categorise shared factors influencing permitting and road planning in smart city contexts. This study is explicitly framed as exploratory research, focusing on discovery and classification rather than definitive modelling (Waters, 2007).

The paper is structured as follows. The Background section reviews road infrastructure planning, building permitting, and digital twin-enabled smart city development. The Research Methodology section describes the data collection, analysis, classification, and focus group evaluation. The Key Findings section presents the primary, secondary, and tertiary shared factors and their associated information requirements. The Discussion section examines implications for digital twin implementation, governance, interoperability, limitations, and future research. Finally, the Conclusions section summarises the study's contribution.

2. Background

Urban infrastructure systems are increasingly expected to support sustainable, resilient, and citizen-centric development within the context of smart cities (Silva *et al.*, 2018; Deng *et al.*, 2021). However, the planning, permitting, and approval processes for these systems have traditionally evolved in isolation, leading to fragmented practices and duplicated efforts (Noardo *et al.*, 2022). Road infrastructure projects and building permitting procedures, in particular, are frequently managed by separate regulatory pathways, even though they share multiple overlapping requirements, stakeholders, and spatial interactions (Pauls *et al.*, 2024; Fauth *et al.*, 2024a, b). This fragmented governance and information workflow often creates inefficiencies, delays, and missed opportunities for harmonised urban development (Karoui and Sassi, 2016; Meijer and Visscher, 2017). Recent advances in digital technologies, especially digital twins, offer the potential to bridge these gaps by integrating data, automating compliance checks, and enabling coordinated urban planning (Sacks *et al.*, 2020; Alvi *et al.*, 2025). Against this backdrop, this section reviews current practices and challenges in road infrastructure planning, building permitting, and digital twin-enabled smart city development to contextualise the subsequent cross-domain analysis.

2.1 Road infrastructure perspective

Planning processes for road infrastructure are shaped by a range of practice-oriented frameworks, regulatory codes, and design standards that outline common requirements for infrastructure coordination. These practices become particularly relevant when evaluating how road systems interact with adjacent building developments. Regulatory compliance typically involves adhering to local, regional, and national requirements, including guidelines for road alignment, grading, drainage, signage, and pavement materials. Traffic Impact Assessments, for instance, are widely used to assess potential changes in traffic volume, congestion, and required modifications to intersections or roadways (US Department of Transportation Federal Highway Administration, 2019). In addition, environmental considerations are guided by Environmental Impact Assessments, which evaluate effects on air and water quality, noise levels, and ecosystems, often requiring mitigation strategies where adverse impacts are expected (Ouis, 2001; US EPA, 2013). Road safety practices are shaped by standards addressing sight distances, pedestrian infrastructure, and intersection design, often evaluated through safety audits.

Technical planning also draws on detailed engineering specifications that outline geometric design, structural calculations, and material use. Public engagement is commonly incorporated through consultations with local authorities, community groups, and stakeholders, offering opportunities to integrate local knowledge and address concerns (United Nations, 2015). In addition, road planning typically requires coordination with broader transportation infrastructure to ensure compatibility with existing and future systems (Federal Highway Administration, 2016). Taken together, these procedural and regulatory characteristics illustrate that road infrastructure planning is governed through technical assessments, statutory compliance processes, and multi-agency coordination mechanisms that often operate independently of building permitting systems. However, limited research examines how these requirements align or conflict with building permitting processes. This gap has direct implications for digital twin implementation, as digital twins rely on interoperable information structures across domains. Where regulatory standards governing roads and buildings operate independently, the resulting fragmentation can hinder the integration of shared spatial, technical, and compliance data within unified digital twin environments.

2.2 Building permits perspective

Building permits are critical regulatory instruments in urban development, ensuring adherence to building codes, zoning laws, and safety and environmental standards. Traditionally, these processes have relied on manual workflows, involving physical submissions, in-person consultations, and manual compliance checks. While these methods are thorough, they are also characterized by inefficiencies, lack of transparency, and inconsistencies, particularly across jurisdictions, which often result in delays and cost overruns in construction projects (Meijer and Visscher, 2017). The increasing complexity of urban environments and construction projects has necessitated innovative approaches to streamline building permit processes and meet modern urbanisation demands (Karoui and Sassi, 2016).

The digitalisation of building permit processes has emerged as a critical area of innovation. By integrating advanced technologies such as Building Information Modeling (BIM), Geographic Information Systems (GIS), and Automated Compliance Checking (ACC) systems, municipalities and regulatory bodies are improving efficiency, accuracy, and transparency. For instance, Swedish researchers have implemented a system that integrates BIM with geospatial data to automatically verify compliance with regulations governing building heights and footprints (Olsson *et al.*, 2018). Such innovations address long-standing bottlenecks in traditional systems while supporting real-time application tracking and decision-making.

Technologies have significantly contributed to transforming building permit processes. These technologies enable the processing and interpretation of complex regulatory frameworks, the automation of compliance checks, and enhanced decision-making support. These methods include natural language processing (NLP) for extracting and classifying regulatory requirements and logic-based reasoning systems for compliance assessment [(Salama and El-Gohary, 2016; Zhang and El-Gohary, 2021)]. Ontological approaches, such as the Ontology-Based Building Permit Review (OntoBPR), have further streamlined these processes by transforming regulatory codes into machine-readable formats, enabling accurate and efficient compliance assessments (Hagedorn *et al.*, 2025).

Despite these advancements, several challenges persist. Regulatory variability remains a significant barrier, as differences in building codes and legal frameworks across jurisdictions limit the feasibility of universally applicable digital solutions (Bloch and Fauth, 2023). In parallel, fragmentation within the construction industry, where stakeholders rely on heterogeneous tools, standards, and workflows, further exacerbates interoperability challenges and constrains the effective integration of digital systems (Zhang and El-Gohary, 2021). Additionally, while digital platforms can enhance workflow efficiency, their effectiveness in building permitting depends on standardised frameworks and multidisciplinary collaboration to manage the interplay of technical evidence, legal requirements, and societal considerations (Fauth *et al.*, 2024a, b). Without such coordination, digitalisation risks reinforcing fragmented reviews and inconsistent decisions rather than improving permit quality or transparency (Fauth *et al.*, 2024a, b; Seiss *et al.*, 2025). Although inspection-support technologies are advancing, they are rarely discussed as part of integrated end-to-end regulatory workflows (Eiris *et al.*, 2021).

Although research has made significant strides in addressing procedural inefficiencies and promoting technological integration, these efforts largely remain confined to individual processes, tools, or regulatory checks. As a result, the built environment continues to be addressed in a fragmented manner, despite consisting of multiple interdependent systems. This fragmentation indicates untapped potential in connecting and reusing existing data across systems to support more holistic decision-making. Therefore, the following section situates digital twins within smart city development and explains how they may support more integrated information exchange across building permitting and road infrastructure planning.

2.3 Towards digital twin-enabled smart cities

The concept of smart cities has emerged in response to rapid urbanisation and societal demands for sustainable, resilient, and citizen-centric infrastructure (Silva *et al.*, 2018). In this study, sustainable smart cities refer to urban systems that promote resource efficiency, coordinated infrastructure development, and reduced duplication of regulatory processes. Resilience is understood as the capacity of urban governance and infrastructure systems to adapt to evolving regulatory, environmental, and technological conditions without generating systemic inefficiencies or conflicts. By identifying shared cross-domain factors and supporting interoperable information structures, this research contributes to both sustainability (through improved coordination and reduced redundancy) and resilience (through adaptable and scalable digital twin integration across regulatory domains).

Smart cities employ digital technologies to improve performance, quality of life, and resource efficiency. Among these, digital twins have attracted significant attention as synchronised, real-time, data-driven representations of urban assets and processes (Deng *et al.*, 2021; Sacks *et al.*, 2020). As virtual replicas of physical assets, digital twins allow planners to simulate, monitor, and optimise performance (Alvi *et al.*, 2025). They provide centralised, continuously updated views of both macro- and micro-level conditions, bridging siloed domains such as road planning and building permitting. This integration enables shared data environments, accelerates approvals, and supports proactive compliance.

Key benefits discussed in the literature include enhanced situational awareness through timely data updates and predictive modelling to support safety and efficiency, automated compliance checks to reduce rework, and cross-sector collaboration enabled by data integration (Deng *et al.*, 2021). In the context of building permitting, such benefits relate less to continuous real-time monitoring and more to maintaining up-to-date, consistent information across defined project stages, permit conditions, and renewal cycles. However, evidence of their effectiveness in delivering sustainability and resilience outcomes remains limited, highlighting the need for case studies in operational settings. This implementation gap is also increasingly framed as a public-governance challenge, particularly around data governance, institutional capacity, and cross-stakeholder collaboration, rather than a purely technical limitation (van der Heijden, 2024).

Parallel digitalisation efforts are evident in building permitting. Cloud-based frameworks now integrate workflows, processing, and analytics to improve efficiency and transparency. For example, a data-mining-based recommendation engine tested on New York City permit data improved planning and approvals (Eirinaki *et al*., 2018). Reviews of state-of-the-art digital permitting highlight advances in compliance automation, yet also note challenges in participation, scalability, and geospatial interoperability (Noardo *et al.*, 2022). Pilot studies, such as Vienna's BIM- and AR-based permitting system (Urban *et al.*, 2024), and frameworks for e-permitting maturity (Shahi *et al.*, 2019), demonstrate progress, though harmonising processes and regulations remains a barrier. AR has also been increasingly discussed as an enabling technology in construction digitalisation, although its regulatory uptake remains uneven (Oke and Arowoiya, 2022). Similarly, digitalisation efforts are emerging in road infrastructure approvals. The BeGeBIM project in Germany showed how BIM-based verification accelerates highway approvals and improves transparency (Pauls *et al.*, 2024), while Dubai Municipality's IFC-based models exemplify resilient, adaptable permitting (Ismail *et al.*, 2024). Together, these developments highlight opportunities for convergence between building and road permitting to reduce redundancy and support smart city goals.

Despite this progress, research on digital transformation typically treats these domains separately. Building studies emphasise BIM and compliance automation (Salama and El-Gohary, 2016; Malsane *et al.*, 2015), while road planning research focuses on geospatial data and simulations (AASHTO, 2018; Federal Highway Administration, 2016; Hokao and Mohamed, 1999). These siloed approaches overlook the shared regulatory, informational, and institutional interdependencies that shape both processes. Addressing these gaps is essential for developing integrated digital twin frameworks to support sustainable and resilient smart cities.

3. Research Methodology

Our research design follows principles of exploratory studies (Waters, 2007; Sandelowski, 1995; Méndez, 2013). Exploratory approaches enable structured investigation into phenomena that are insufficiently theorised, focusing on generating categories, mapping relationships, and identifying information requirements. Accordingly, the methods employed in this study are intended to develop an initial framework for understanding the phenomenon, rather than an exhaustive or definitive one. As shown in Figure 1, this study employs a structured multi-method research design to identify, analyse, and classify the shared factors and information requirements in building permitting and road infrastructure planning. The methodology is divided into three key phases: Data Collection, Analysis, and Classification, each contributing to a comprehensive understanding of the shared influences and their implications.

3.1 Data collection

The Data Collection phase involves gathering information from diverse sources to build a foundation for analysis. Literature review is conducted to explore research on building permitting and road infrastructure planning, focusing on the interconnections between building and road compliance requirements. This includes examining both brownfield and greenfield project demands.

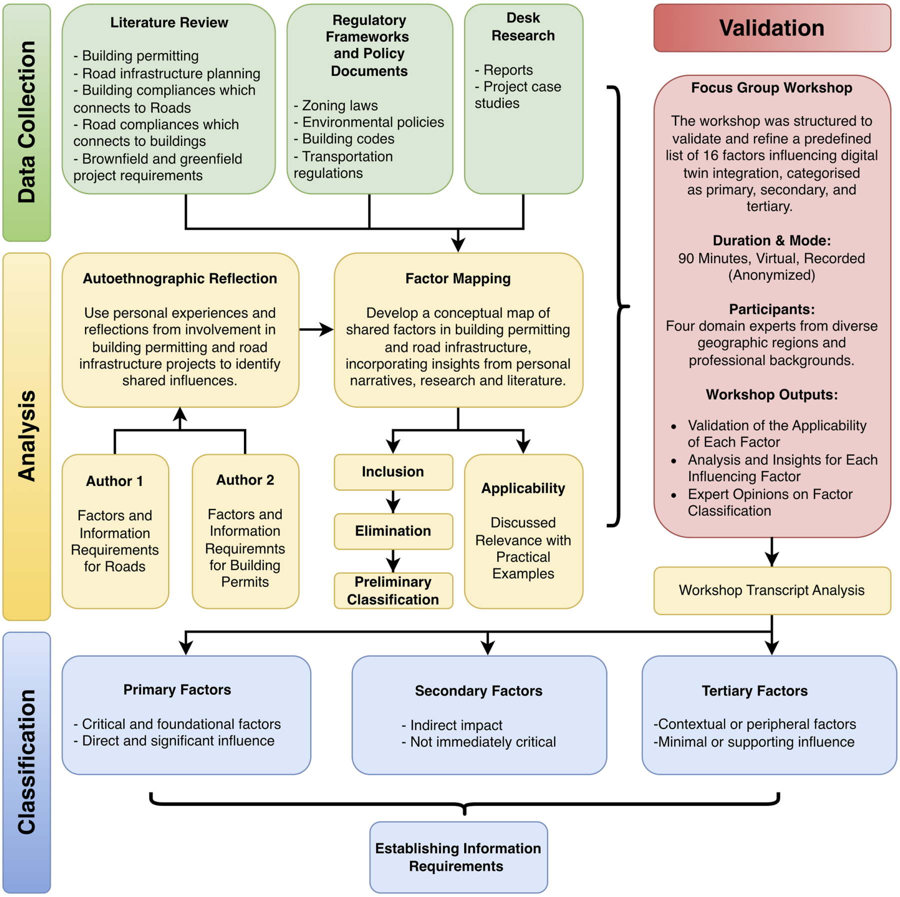

Figure 1. Research methodology. Source: Authors' own work

To ensure that the analysis reflected a range of governance and implementation models, efforts were made to include literature and case examples from multiple jurisdictions, aiming for an international perspective. It needs to be noted that the international perspective adopted in this study is analytical rather than normative: it does not seek to harmonise building permitting requirements across jurisdictions, but to examine how different legal and governance contexts address comparable building permitting challenges and how these differences influence processes, responsibilities, and decision-making. Regulatory frameworks and policy documents are also reviewed, encompassing zoning laws, environmental policies, building codes, and transportation regulations.

These documents provide critical insights into governance and compliance challenges. Additionally, desk research is carried out, analysing previous work and case studies to understand real-world implementation and identify recurring challenges in infrastructure development.

3.2 Analysis

In the analysis phase, we examined the collected data through collaborative reflection, drawing on our professional experiences in digital building permitting (Author JF) and road infrastructure planning (Author VKR). This experiential lens helped us identify recurring patterns and practical frictions encountered in both domains, providing context to supplement the literature and regulatory analysis. While not formalised through journaling or ethnographic protocols, our reflective discussions followed a structured format: we independently reviewed the literature and regulatory sources, generated initial factor lists, and then conducted iterative meetings to compare and rationalise the emerging shared factors. Insights from these discussions were combined with reflective analysis of the authors' professional experience in building permitting research and practice to inform the development of the factor map and its subsequent classification into primary, secondary, and tertiary categories. This process is referred to here as a light-touch autoethnographic analysis (Méndez, 2013; Grosse, 2018), in the sense that it draws on situated, experiential knowledge to support sense-making and early-stage conceptualisation. Unlike full ethnographic approaches, this analysis does not aim to provide systematic cultural description or longitudinal immersion. Instead, it serves as a pragmatic heuristic to support initial factor identification and structuring in a research area where established analytical frameworks are lacking. Similar reflective and autoethnographic approaches (e.g. Méndez, 2013; Grosse, 2018) have been used in construction and built environment research to support theory-building and conceptual development in complex socio-technical domains.

3.3 Classification

The Classification phase organises the identified shared factors into three categories based on their significance and impact. Primary factors are critical and foundational, exerting a direct and significant influence on both processes. Secondary factors pertain to the effects of accompanying infrastructure and utilities, indirectly shaping outcomes and ensuring overall system coherence.

Tertiary factors, on the other hand, are contextual or peripheral, offering minimal or supporting influence.

The classification of factors into primary, secondary, and tertiary categories is intended to support prioritisation in practical digital twin implementations. Rather than assigning numerical weights, the tiers reflect the order in which factors typically require attention during planning, permitting, and approval processes, with primary factors demanding early and mandatory consideration, secondary factors influencing design optimisation and coordination, and tertiary factors providing contextual or future-oriented considerations.

This tiered classification provides a nuanced understanding of the factors and their varying levels of importance. It also serves as the basis for establishing the specific information requirements necessary for integrating digital twin technologies. These requirements define the data and processes needed to enhance the efficiency, transparency, and effectiveness of building permitting and road infrastructure planning.

3.4 Focus group workshop

To gather expert insights on the potential integration of building permit and road infrastructure systems, we conducted a 90-min virtual focus group workshop (Krueger and Casey, 2009; Sandelowski, 1995). A focus group workshop was employed as an exploratory method to facilitate expert discussion and collective reflection on an initial set of factors. Given the exploratory nature of the study, the focus group was not intended to provide representative or statistically reliable validation, but to support refinement through expert interaction. The session involved four domain experts from diverse geographic regions and professional backgrounds, including a chief building official from Ontario, Canada; an asset management coordinator from Indiana, USA; a principal highway engineer from the UK; and a head of digital twins from a national transport initiative. Their demographics are presented in Table 1. Recognizing the jurisdiction specific nature of building codes and legal frameworks, the inclusion of multiple jurisdictions serves an exploratory and comparative purpose, rather than

Table 1. Participant demographics

Participant ID	Role/Title	Organisation	Country	Sector focus	Years of experience
Participant 1	Senior Building Official	Local Government Authority	Canada	Building regulation, permitting, shared services	25+ years
Participant 2	Asset Management Coordinator	Municipal Government	United States	Asset management, infrastructure planning	10+ years
Participant 3	Infrastructure Engineer	City Administration	United Kingdom	Highway engineering, planning application review	5+ years
Participant 4	Digital Twins Programme Lead	National Transport Initiative	United Kingdom	Digital twins, strategic transport and infrastructure	5+ years

Source(s): Authors' own work

aiming for universal generalisation. This diversity of the participants' backgrounds ensured a representation of perspectives across municipal building regulation, asset management, infrastructure planning, and digital twin implementation. During the workshop, each factor was introduced sequentially by the facilitators and discussed collectively. Participants were invited to affirm, contest, or enrich each factor based on their professional experience, allowing for interaction and cross-fertilisation of perspectives within the group. For each identified factor, participants were asked whether they agreed that the factor constituted a shared influence between building permitting and road infrastructure planning, and whether they could provide examples from their professional experience. The guiding question format was: "Do you consider this factor to be a shared consideration between building permitting and road infrastructure planning? If so, can you provide practical examples or contextual insights?" This structured evalution approach ensured consistency across all 16 factors discussed.

Further, the workshop was used to refine a predefined list of 16 factors, classified as primary, secondary, and tertiary. Participants were introduced to each factor individually and asked to provide feedback, either affirming, contesting, or enriching the factor based on their professional experience. The session was recorded and transcribed with the participants' consent, and all transcripts were anonymised to preserve confidentiality. Following the session, participants were provided with the anonymised transcript for review, allowing them to verify the accuracy and ensure the level of anonymity was satisfactory. The data was collected in line with the ethical approval granted by the University of Cambridge Department of Engineering Research Ethics Committee (Application no. 415).

4. Findings

This section is structured as follows: shared factors are first identified and categorised into primary, secondary, and tertiary tiers. For each factor, the corresponding information requirements relevant for both building permitting and road infrastructure planning are then outlined. The subsequent subsections describe each factor based on the research findings and summarise the associated focus group discussion.

The identified factors encompass a range of technical, environmental, and socio-economic considerations. These factors are qualitatively mapped according to their relative influence on building permitting and road infrastructure planning, based on a comparative interpretation of the literature, regulatory requirements, and expert feedback (Figure 2). The mapping represents a qualitative, interpretive synthesis rather than a quantitative assessment, with relative intensity reflecting how strongly a factor shapes decision-making and coordination

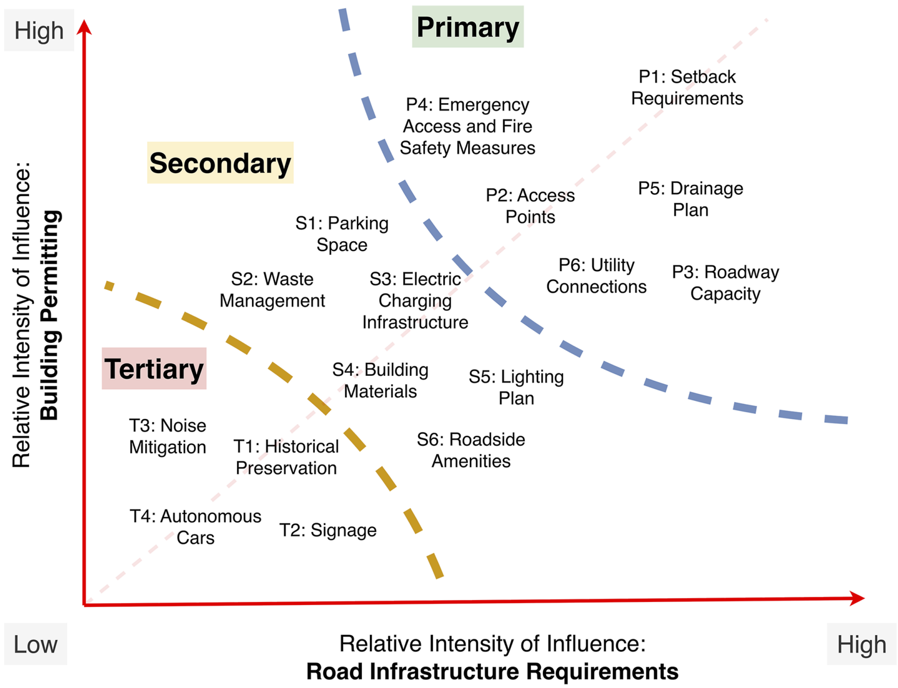

Figure 2. Mapping factors influencing building permitting and road infrastructure requirements into primary, secondary, and tertiary according to their relative intensity of influence in these domains. Source: Authors' own work

requirements in each domain. Factors classified as primary exert direct and mandatory influence, secondary factors have indirect or conditional influence, and tertiary factors provide contextual or supporting influence.

4.1 Primary factors

These are critical and foundational considerations that directly influence both road and building infrastructure planning and permitting. Primary factors typically require early and coordinated attention from multiple stakeholders due to their substantial impact on safety, functionality, regulatory compliance, and spatial integration. Their omission or mismanagement can result in significant design conflicts, operational inefficiencies, or legal non-compliance. Table 2 summarises the key primary factors, associated information requirements, units, and practical examples derived from regulatory analysis and stakeholder evaluation.

4.1.1 Setback requirements. They directly affect visibility, safety, and the overall functionality of urban infrastructure. In road planning, adequate setbacks ensure unobstructed sightlines at intersections and along roadways, which are crucial for preventing accidents and enhancing pedestrian and vehicular safety. Similarly, in building permitting, setbacks maintain a safe distance between structures and adjacent roads, reducing risks from vehicle impact, noise, air pollution and fire safety (Das, 2017). Setbacks also allow space for essential roadside elements, such as drainage systems, sidewalks, and green buffers, promoting environmental sustainability and usability. By aligning with zoning regulations, setbacks ensure that both buildings and roads are integrated seamlessly into the urban fabric, prioritising safety while supporting efficient traffic flow and accessibility.

Table 2. Primary shared factors and corresponding information requirements

Sl. No.	Factor	Description	Information requirement	Units	Examples
P1	Setback Requirements	Ensures safe distance between the building and the road, typically regulated by local zoning laws	Property boundary maps and land parcel details for visibility and safety compliance	Metres	Minimum setback of 3 m from property boundary to road for safety
			Zoning laws and local setback regulations ensuring clearances for visibility at junctions and intersections.	Textual regulations	Zoning laws specifying front setback requirements for residential zones
			Survey data showing distances to nearby roads for safe building placement	GIS Coordinates, Metres	Survey map showing adjacent roads and building footprint distances
P2	Access Points	Specifies the entry and exit points for vehicles onto the property, ensuring safe and efficient traffic	Specific permits for site entry and exit points connecting roads and buildings	Permit Number, Coordinates	Permit to connect a driveway to a state highway
			Geographical connection details to align access points with surrounding transport infrastructure	GIS Coordinates	Access point aligned with a planned junction at 35.671°N, 139.765°E
			Plans for junctions and road intersections, ensuring smooth connectivity for traffic	Intersection Layouts, CAD Drawings	CAD drawings of junctions showing turning lanes and signal locations
			Traffic impact analysis for vehicle ingress/egress	Vehicle count/ hour	Report showing peak-hour traffic counts entering/exiting (e.g. 200 vehicles/hour)
			Compliance with accessibility guide-lines for pedestrians and vehicles	Compliance Checklist	Checklist meeting ADA or equivalent standards (e.g. Ramps for disabled access)
P3	Roadway Capacity	Assesses the building's impact on road capacity, considering traffic flow and congestion	Traffic volume studies that consider the impact of large public/commercial buildings or residential societies	Vehicles/hour, PCU	Peak traffic volume of 1,500 vehicles/hour during commercial building operating hours

(*continued*)

Table 2. Continued

Sl. No.	Factor	Description	Information requirement	Units	Examples
P4	Emergency Access and Fire Safety Measures	Provides clear access routes for emergency vehicles to the building in case of emergencies	Fire safety compliance points (e.g. hydrants, sprinklers) for emergency access near buildings and roads	Distance (m), Coverage Area (m^2)	Hydrant located within 30 m of building entrances
			Dimensions and layouts of emergency access routes linking buildings and roads	Metres	Access route width of 6 m for fire trucks (e.g. Fire lane along the north side)
			Turning radius for emergency vehicles accessing both buildings and roads	Metres	Turning radius of 12 m for fire trucks (e.g. Roundabout designed for emergency vehicle turning)
P5	Drainage Plan	Outlines measures to prevent flooding, erosion, and water pollution, ensuring compliance with regulations	Location of drainage systems and their integration with roads and surrounding areas	Metres, Slope (%)	Site layout showing drainage channels with a 2% slope leading to the main stormwater system
			Capacity and design of drainage structures to handle road and building runoff	Cubic Metres (m^3/s)	Drainage designed to handle a peak flow of 0.5 m^3/s during heavy rainfall
P6	Utility Connections	Specifies connections to water, electricity, gas, etc., ensuring access to essential services	Location of utility connections for shared use by roads and buildings	GIS Coordinates	Connection points for water and electricity shared between a road junction and nearby buildings
			Capacity of utility lines to support combined road and building demands	Kilowatts (kW), Litres/day	Electricity supply of 150 kW and water supply of 10,000 litres/day for a mixed- use development

Source(s): Authors' own work

Participants Response: During the focus group discussion, participants unanimously agreed that setback requirements represent a critical shared factor between road planning and building permitting. Participant 3 noted that setbacks are critical "*so that there's nothing from the property or the planning application that's going to encroach on the highway — sub drainage systems, trees, overhanging windows and things like that*".

From the building authority perspective, setbacks were also linked to demolition safety and protection of underground utilities, as Participant 2 explained that when demolishing structures, "*it's obviously very important to have distance between the structure that you're tearing down and the road . . . not disrupting any underground utilities*". These practitioner insights confirm that while setbacks may be governed through different regulatory lenses, they function as a shared spatial constraint across both domains.

They emphasised that while both sectors enforce setbacks, their purposes differ slightly. From the road perspective, setbacks ensure that developments do not encroach on the highway, preventing interference with drainage systems, utilities, trees, or pedestrian pathways.

Similarly, for buildings, setbacks are essential to avoid impacting surrounding infrastructure and to comply with zoning laws. Participant insights highlighted additional considerations, such as maintaining safe distances during demolition activities to protect underground utilities and neighbouring structures. Overall, setbacks play a pivotal role in coordinating safe and compliant development between road and building systems.

4.1.2 Access points. They determine how effectively a building or development integrates with the surrounding transport network. In some countries, such as Canada, the placement and design of access points require specific permits to ensure they align with local regulations and maintain safety standards (Wray, 1953). These points serve as the vital geographical connections between buildings and roads, enabling smooth ingress and egress for vehicles and pedestrians. Proper planning of access points also supports transport network optimisation, ensuring that junctions and intersections remain functional and congestion-free (Hine, 1998).

Poorly designed access points can disrupt traffic flow, increase accident risks, and compromise accessibility. For instance, placing an access point in front of a fire hydrant can lead to additional costs, requiring redesign or relocation to meet safety and operational standards. Therefore, they must be carefully located and designed in tandem with road infrastructure to facilitate seamless connectivity and ensure compliance with planning and safety standards.

Participants Response: All participants strongly agreed that access points, such as driveways and vehicle entryways, are a critical shared factor between road infrastructure and building developments. They highlighted the importance of coordination to ensure safe and efficient connections between properties and adjacent roads. Participant 1 specifically pointed out the significance of properly planned access points, particularly for corner properties where streets intersect, to maintain safe separation between driveways and intersections. Aligning the understanding between building authorities and road planners helps prevent traffic conflicts and enhances safety.

4.1.3 Roadway capacity. This directly impacts the ability of infrastructure to handle the demands generated by large-scale developments. A big commercial or public building or a large residential society significantly influences traffic patterns, requiring detailed analysis of roadway capacity to accommodate increased vehicle flow without causing congestion (Hokao and Mohamed, 1999). The increased traffic also affects parking space requirements (already presented above), as a greater influx of vehicles necessitates carefully planned parking solutions to prevent bottlenecks. Additionally, the load on the roadway—both in terms of vehicular volume and axle weights—must be accounted for to ensure pavement durability and safety.

Public transport also plays a critical role in alleviating pressure on roadway capacity, particularly during rush hours. In some countries, planning departments request traffic peak models to evaluate the projected strain on infrastructure. These models, which simulate traffic conditions during peak hours, are reviewed by transport specialists as part of the building permit process, influencing the outcome at an organisational level.

Applicants may also seek exemptions from parking space requirements by demonstrating sufficient public transport availability as compensation (Fauth, 2022). However, producing these proofs is often cost-intensive, requiring the services of specialised consulting firms.

The integration of digital twin technologies could, in principle, streamline this process by enabling automated traffic simulations, peak-hour analysis, and scenario planning.

However, this assumes that planning departments have the in-house capacity to develop, maintain, and operate such systems. In many cases, the expertise and tools needed for traffic modelling reside with external consultants—limiting access, increasing costs, and potentially replicating the same limitations faced in traditional modelling. Without investing in the necessary human resources and long-term capability building, digital twins risk becoming similarly dependent on external expertise. Thus, while digital twins offer potential efficiencies, their successful implementation hinges on institutional investment in skills and internal data governance structures.

Participants Response: Participants agreed that roadway capacity is a significant shared factor, primarily considered during the planning and development approval stages rather than at the building permit level. Participant 4 emphasised that for large-scale developments, such as new housing estates, authorities evaluate the impact on local and regional road networks, often requiring developers to contribute to infrastructure upgrades. Participant 3 echoed this, noting that when developments approach or exceed the capacity limits of existing roads or junctions, intervention is required to mitigate congestion.

Both Participant 1 and Participant 2 highlighted that while roadway capacity is critical, it is typically addressed during early planning stages and not during the building permit process itself. Examples included large commercial developments where traffic impacts are assessed prior to construction approval.

4.1.4 Emergency access and fire safety measures. They directly relate to public safety and regulatory compliance. For buildings, provisions such as fire safety points, adequate evacuation routes, and medical emergency access are essential, especially for larger societies or specific facilities like hospitals. Larger societies or buildings require wider entrances and unobstructed pathways to ensure quick access to emergency vehicles (Galiano and Moretti, 2021). On the road side, dedicated lanes and clear markings are crucial to facilitating quick response times during emergencies. Compliance with standards like the English Building Regulations Part B5 ensures that both roads and buildings are designed to support fire safety and emergency operations.

Participants Response: Participants agreed that emergency access and fire safety measures are a crucial shared factor between road and building planning. Participant 1 emphasised that ensuring clear access routes for emergency vehicles, such as fire engines, and proper placement of fire hydrants are key considerations during both road layout and building permitting processes. These measures are essential to guarantee that all buildings are accessible for firefighting and other emergency services. No additional comments or disagreements were raised by the other participants, reinforcing consensus on the importance of this factor.

4.1.5 Drainage plan. Effective water management is essential to maintain structural integrity and prevent flooding. Both buildings and roads require systems to keep rainwater away, protecting foundations, pavements, and overall usability. Proper planning must consider elevation for drainage flow, ensuring that water is directed efficiently without pooling, especially in areas prone to heavy rainfall (Lloyd *et al.*, 2002). In some cases, a sub-approval process is necessary to integrate drainage systems with broader municipal networks. Additionally, societal and city connections for drainage are vital, as these systems must link seamlessly to existing infrastructure to support sustainable urban water management.

Participants Response: Participants unanimously agreed that drainage planning is a critical shared factor between building developments and road infrastructure. Participant1 stressed the importance of having an organised drainage system to prevent water accumulation around buildings, ensuring proper grading and runoff management to designated outlets—key concerns also shared by road authorities. Participant2 reinforced its significance, particularly in the US, where managing water pollution, flooding, and erosion is a primary concern, though state-level enforcement may vary. Participant4 added that in the UK, drainage responsibilities are spread across multiple stakeholders—including water companies, local authorities, and national bodies—each with different objectives, further highlighting the complexity and importance of coordinated drainage planning. Overall, drainage was categorised as a primary factor essential for compliance, safety, and environmental protection.

4.1.6 Utility connections. They ensure the seamless provision of essential services like water, electricity, and gas. Proper planning is crucial to avoid rework and disruptions, especially in densely populated areas, by ensuring that utility networks are laid out efficiently and integrated with construction plans from the outset. In countries like India, utility coordination often involves multiple agencies, necessitating approvals and clearances to align with regional standards and minimise delays. For roads, utility connections must account for access points and potential future upgrades, while buildings require reliable connections for operational efficiency.

Participants Response: Participants agreed that utility connections covering water mains, electrical lines, gas lines, and telecommunications are a crucial shared factor, particularly from a safety and coordination perspective. Participant 2 highlighted its primary importance in the US, where utility locating is mandated prior to any construction to prevent accidental damage. Participant 1 reinforced the need for organised and well-planned utility placement before building activities commence. Participant 3 added that in highway projects, knowing the exact locations of underground utilities is critical to avoid damage, with digital twin-based underground mapping emerging as a valuable tool. They noted that while utility layouts in building projects are often coordinated through pre-defined utility provider plans, the risks of utility damage—such as power strikes or gas leaks—remain significant across both contexts. Participant 4 emphasised the importance of aligning strategic and tactical planning to ensure utility placement does not obstruct other infrastructure elements.

This highlights a potential disconnect between assumed responsibility for utility planning and the real-world risks posed across domains. While the coordination mechanisms may differ, the safety, cost, and operational consequences of poor utility planning are equally severe for both buildings and roads. Overall, the factor was consistently deemed primary, particularly from safety, planning, and coordination standpoints.

4.2 Secondary factors

These are shared considerations that form a second or additional layer of infrastructure planning. While not as directly critical as primary factors, they support and influence the broader performance, functionality, or integration of buildings and road systems. Secondary factors often become relevant during early-stage planning or large-scale developments and typically have an indirect but important impact on system coordination, user experience, or compliance with broader policy objectives. Table 3 summarises the secondary factors, associated information requirements, units, and practical examples derived from regulatory analysis and stakeholder evaluation.

4.2.1 Parking space. This directly impacts accessibility, traffic management, and compliance with regulations. The availability of parking spaces is essential for ensuring that buildings and adjacent road infrastructure can accommodate the vehicles generated by users without causing congestion (Lloyd *et al.*, 2002). Proper planning of parking spaces, in alignment with regulations like Germany-specific ordinances for parking and English Building Regulations Part (Chrest *et al.*, 2012), ensures accessibility for all, including individuals with disabilities. In road planning, parking influences traffic flow and road capacity, requiring integration with nearby access points and transport hubs. For buildings,

Table 3. Secondary shared factors and corresponding information requirements

Sl. No.	Factor	Description	Information requirement	Units	Examples
S1	Parking Space	Determines the quantity and configuration of parking spaces required for building occupants and visitors	Parking space layouts with connections to roads or public transport facilities	Number of spaces, Square Metres	Site plan showing 50 parking spaces (e.g. Multi-level parking with 2,000 m^2 area)
			Site layout plans that ensure parking availability based on user density and building type	Vehicle Capacity	Multi-storey car park designed for 200 vehicles
			Data on parking demand influenced by proximity to major roads or highways	Vehicle/hour	Traffic analysis showing peak parking demand of 150 vehicles/ hour
S2	Waste Management	Includes strategies for waste disposal, recycling, and ongoing waste management	Waste collection route layouts involving road access for disposal vehicles	Route Map, GIS Data	Waste truck route map with access points (e.g. Weekly pickup access on the east entrance)
S3	Electric Charging Infrastructure	Specifies the number, type, and location of electric vehicle charging stations on the property	Compliance with national EV infrastructure standards for installation	Standards Compliance	IEC 61851 compliance for EV chargers (e.g. DC fast charging setup)
			Locations for normal and electric vehicle parking with chargers near road- ways	Coordinates	EV parking bays located within 50 m of main building entrance
			Grid capacity and layout of charging stations based on traffic and user density	Kilowatts (kW)	Charging station with 150 kW fast chargers supporting 5 vehicles simultaneously

(*continued*)

Table 3. Continued

Sl. No.	Factor	Description	Information requirement	Units	Examples
S4	Building Materials	Specifies materials to be used in construction, ensuring compliance with safety and quality standards	Type of road (e.g. highway, arterial) influencing material choices, particularly for windows or glass	Material Type, Noise Reduction (dB)	Laminated safety glass designed to reduce highway noise by 20 dB
			Distance to the nearest road impacting structural and aesthetic material requirements	Metres	Building facade located 10 m from a highway requiring high-durability finishes
			Compliance with building material standards for durability and noise reduction near roads	Material Compliance	Glass certified to meet EN 12758 for acoustic performance
S5	Lighting Plan	Ensures safety and visibility with appropriate lighting design along the building and surrounding area	Placement of streetlights and building lights ensuring visibility for shared spaces	Lux Levels, Metres	Streetlights providing 50 lux at 10 m intervals along a road adjacent to a building entrance
			Integration of lighting plans with road and building security systems	GIS Coordinates, Compliance	Security lights aligned with CCTV coverage for shared spaces between roads and buildings
S6	Roadside Amenities	Includes amenities such as benches, bicycle racks, etc., enhancing the area's usability and attractiveness	Accessibility and location of shared amenities connected to both roads and buildings	GIS Coordinates, Area (m^2)	Rest stop with benches and bicycle racks located 1 km from a commercial zone
			Utility connections (e.g. water, electricity) for roadside and building amenities	Utility Load (kW), Water Usage (litres/day)	Washroom facility with 10 kW electricity load and 2,000 litres/day water consumption

Source(s): Authors' own work

adequate parking provision not only supports functional operations but also satisfies zoning and permitting requirements, ensuring a balanced and efficient urban design. Failing to provide appropriate parking solutions can result in bottlenecks and non-compliance.

Participants Response: Participants recognised parking space as a shared factor, though they noted its significance varies by region and planning approach. In the UK, Participant 3 highlighted that parking on highways is not an automatic right, with efforts made to provide sufficient parking within property boundaries (curtilage) to prevent spillover onto roads. However, strategic limitations on destination parking aim to influence travel behaviour and reduce car dependency. Participant 1 shared a similar perspective, explaining that on-street parking is not always prioritised, especially on narrow private roads, with designated off-street parking provided instead. Conversely, Participant 2 noted that in the suburban US context, where car ownership is high, parking provisions are less of a restrictive factor, particularly outside urban centres. Overall, while parking is relevant, participants suggested its impact may be context-dependent and possibly of secondary importance in some regions.

4.2.2 Waste management. This ensures the efficient handling and disposal of waste while maintaining hygiene and accessibility. The location of waste disposal rooms plays a critical role, requiring strategic placement within buildings to provide easy access for collection vehicles via adjacent roads. For example, the Israel model highlights how optimising the proximity between waste storage facilities and roads can streamline operations and reduce disruptions (HM Government, 2021).

Roads must accommodate waste collection vehicles with appropriate turning radii and designated stopping zones, while buildings must include waste disposal rooms designed for seamless transfer to the road network. In dense urban environments, particularly in some countries, waste collection vehicles may be unable to access buildings or plots directly due to narrow streets. This necessitates additional considerations, such as the creation of centralised waste collection points at accessible locations, or the implementation of smaller, more manoeuvrable waste collection vehicles. Buildings in these areas may require dedicated pathways or designated drop-off zones that allow for manual transfer of waste to collection points. Roads must also accommodate waste collection operations by ensuring adequate turning radii, designated stopping zones, and efficient routing to minimise disruptions to traffic and pedestrians.

Participants Response: Participants expressed mixed views on the significance of waste management as a shared factor. Participant 3 noted that while buildings require designated waste storage areas, road infrastructure must accommodate the movement of refuse vehicles, ensuring adequate access and manoeuvrability. However, Participant 1 and Participant 2 felt that waste management is typically not a consideration at the building permit stage, particularly for residential developments, making it more of a tertiary factor. Participant 4 highlighted that the relevance of this factor is highly dependent on the scale of development—large commercial complexes or substantial housing estates may require more deliberate planning for waste collection routes and vehicle access, whereas smaller developments do not. Overall, waste management was seen as a context-specific factor, with greater importance at larger development scales.

4.2.3 Electric Vehicle (EV) charging infrastructure. This supports the transition to sustainable transport and aligns with evolving regulations and user demands (Fauth *et al.*, 2024a, b). The English Building Regulations Part S (Grote *et al.*, 2019) mandates the provision of electric vehicle (EV) charging points in new residential and commercial developments, ensuring that buildings accommodate the growing shift towards electric mobility. Proper planning of EV infrastructure also impacts parking for both normal and electric vehicles, requiring integration with road networks to ensure accessibility and efficiency. Roads must provide charging facilities in public areas, rest stops, and parking zones, while buildings need to incorporate private or shared charging stations within their premises.

However, the widespread deployment of EV charging infrastructure introduces significant demands on the electricity grid. In dense urban areas or large developments, high concentrations of charging stations may lead to grid overload, requiring assessments of local grid capacity and potential upgrades to handle increased loads. This necessitates collaboration between urban planners, utility providers, and developers to ensure the grid can bear the additional demand without compromising reliability. Smart charging systems and load management strategies, such as off-peak charging incentives or battery storage solutions, can help mitigate strain on the grid while optimising energy distribution.

Participants Response: Participants recognised that EV charging infrastructure is emerging as a shared factor, but its significance varies across regions and planning frameworks. Participant 1 reflected on how EV chargers were briefly mandated in the building code but later removed due to construction cost concerns and uncertainties about future technology adoption. Participant 3 highlighted the UK perspective, where integrating chargers into communal areas poses challenges, though home charging is seen positively for balancing electricity demand. Participant 2 noted that in the US, EV charging is currently treated similarly to petrol stations, with infrastructure incentives focused on commercial spaces rather than individual homes, making it more of a tertiary factor. Participant 4 added that local authorities in some areas are beginning to mandate specific numbers of EV chargers per parking space and mentioned the strategic considerations of bidirectional charging and local energy networks. Overall, participants acknowledged the factor's growing importance, particularly concerning grid capacity and parking, though its current implementation remains varied and context-dependent.

4.2.4 Building materials. The type of road and its distance to a building, such as a highway or arterial road, significantly affect the choice of materials, particularly for elements like windows and facades. Buildings near high-traffic roads require materials that offer noise reduction, such as laminated or double-glazed glass, to ensure interior comfort and compliance with acoustic regulations. Similarly, materials must withstand potential vibration or damage caused by heavy vehicles on adjacent roads.

Participants Response: Participants generally viewed building materials as having minimal direct overlap between road infrastructure and building planning. Participant 1noted that in their jurisdiction, the type of roadway surface (e.g. concrete or asphalt) has little influence on building material choices, particularly since lower speed limits in residential areas reduce noise concerns. Participant 4 added an interesting perspective, suggesting that while the specific materials used may not currently be a shared factor, future adaptability and repurposing of materials—considering long-term innovations and evolving infrastructure needs—could become relevant. Overall, building materials were perceived as a tertiary factor with potential future implications rather than an immediate shared concern.

4.2.5 Lighting plan. This directly impacts safety, accessibility, and the usability of shared spaces (HM Government, 2022). Adequate lighting ensures the security of pedestrian pathways, enhancing visibility and reducing accidents. This includes examining both brownfield (previously developed or redeveloped land) and greenfield (previously undeveloped land) project contexts, as these typically present different regulatory, infrastructure, and coordination demands. For greenfield developments lighting plans must be designed from scratch, integrating connection points for roads and buildings seamlessly, while brownfield developments require careful retrofitting to align with existing infrastructure. The positioning of street lamps must be meticulously planned to provide uniform illumination, avoiding dark spots that compromise safety.

Participants Response: Participants acknowledged that lighting is a shared factor, but with differing priorities and considerations for roads and buildings. Participant 3 high-lighted the dual perspective: buildings require lighting to ensure occupant safety, while road authorities focus on street lighting to maintain road safety, with careful attention to avoid light pollution spilling onto adjacent properties. Participant 1 reinforced that, although both sectors address lighting, their concerns are distinct and not directly connected, making it more of a tertiary shared factor. Participant 4 briefly added that from a health and safety standpoint, internal building lighting and external interface lighting may overlap slightly but typically remain separate considerations. Overall, lighting is recognised as relevant to both domains but with limited direct interdependence.

4.2.6 Roadside amenities. They enhance the functionality and user experience of the surrounding infrastructure, especially in large-scale developments (International Dark-Sky Association and Illuminating Engineering Society, 2011). In big projects like commercial hubs, residential societies, or highway rest stops, amenities such as benches, bicycle racks, restrooms, and green spaces become relevant to improve usability and attract users. While these features are not central to the structural planning of roads or buildings, they add value by supporting pedestrian engagement, promoting sustainability, and meeting user needs.

Participants Response: Participants recognised that roadside amenities—such as bicycle racks, benches, or small parks—can have relevance, particularly in the context of larger developments, though they generally considered it a tertiary factor. Participant 4 shared that, in some regions, local authorities may publish street design guidelines requiring developers to incorporate such amenities to align with broader urban strategies promoting active travel and localised living. Participant 1 added that while these features might be considered when planning new developments or village centers, they typically do not fall under the purview of building permitting or inspection processes. Overall, roadside amenities were viewed as a shared factor of lower priority, often addressed at a broader planning or urban design level.

4.3 Tertiary factors

These are contextual or peripheral considerations that have minimal direct influence on the coordination between road infrastructure and building systems. Often relevant only in specific scenarios, regions, or project types, tertiary factors typically relate to supporting features or future-oriented concerns. While they may not significantly affect immediate planning or permitting decisions, they contribute to broader goals such as sustainability, quality of life, or long-term adaptability. Table 4 summarises the tertiary factors, associated information requirements, units, and practical examples derived from regulatory analysis and stakeholder evaluation.

4.3.1 Historical preservation. This primarily influences projects in areas with cultural or architectural significance. While not a universal requirement, preserving heritage structures, becomes critical when development occurs near such landmarks. Ensuring that both roads and buildings align with preservation guidelines prevents damage and maintains the integrity of these sites. Although it may not directly dictate most projects, historical preservation often serves as an important consideration in planning discussions, highlighting the need to balance modern development with cultural heritage protection.

Participants Response: Participants generally considered historical preservation to be a tertiary shared factor, with its influence being context-specific and relatively rare. Participant 1 mentioned that while their jurisdiction has some heritage-designated buildings, the coordination between building authorities and road authorities on this issue is minimal.

Participant 4 shared a UK example where road construction near mediaeval structures required special precautions to mitigate the impact of vibrations, but noted that such considerations primarily affect how construction is carried out rather than determining whether or where to build. Participant 2 echoed the view that historical preservation rarely alters road or building plans in the US, citing a single rare instance where a farmhouse was relocated for a highway project. Overall, the factor was acknowledged as relevant in select cases but typically considered low priority.

4.3.2 Signage. Its primary role is to provide information, enhance safety, and support navigation rather than directly influencing construction. However, specific permit procedures for signage ensure that its placement, design, and size comply with local regulations and zoning codes. For roads, signage must align with traffic standards to maintain safety and clarity, while for buildings, it is often required for accessibility, branding, or compliance purposes.

Participants Response: Participants viewed signage as a tertiary factor with minimal overlap between road and building planning processes. Participant1 noted that signage, such as

Table 4. Tertiary shared factors and corresponding information requirements

Sl. No.	Factor	Description	Information requirement	Units	Examples
T1	Historical Preservation	Ensures compliance with regulations for preserving historical sites or structures	Location of historical sites and proximity to roads and buildings	Meters, GIS Coordinates	Historical monument located 50 m from a proposed building site
			Guidelines for vibration control during construction near historical structures	Vibration Level (mm/s)	Vibration monitoring report ensuring levels below 5 mm/s near heritage buildings
			Compliance with heritage preservation laws affecting building and road de- sign	Textual Regulations	Approval documents from heritage authorities under Archaeological Survey of India guidelines
T2	Signage	Ensures compliance with regulations for signage design, placement, and advertising	Location and specifications for regulatory, directional, and informational signage	GIS Coordinates, Dimensions	Regulatory signs placed every 200 m on a highway or at building entrances
			Compliance with visibility, durability, and reflectivity standards for both roads and buildings	Reflectivity (Cd/ lx/m^2)	High-intensity reflective signs visible from 200 m at night
T3	Noise Mitigation	Includes measures such as soundproofing, barriers, or landscaping to reduce noise impact on the building	Placement of noise barriers near roads to protect adjacent buildings	Decibels (dB), Barrier Height (m)	Noise barriers 3 m high reducing road noise to below 50 dB at nearby residential areas
			Soundproofing requirements for buildings near high-traffic roads	Decibels (dB) Reduction	Soundproof windows reducing noise levels by 20 dB for buildings near high- ways
			Landscaping or green buffers to mitigate noise impact for roads and buildings	Area (m^2), Plant Density	Green buffer of 500 m^2 with trees planted at 3 m intervals along the road- side
T4	Autonomous Cars	Supports infrastructure and technology for safe autonomous vehicle operation, including geofencing and V2X communication	Mapping requirements for geofencing and autonomous vehicle navigation near roads and buildings	GIS Coordinates, Digital Maps	Geofenced routes covering main building driveways and adjacent roads
			Road markings, sensors, and infrastructure compatible with autonomous vehicle standards for adjoining building areas	Lane Markings, Sensor Positions	High-contrast lane markings and road-side sensors integrated with V2X systems

Source(s): Authors' own work

road signs or directional signs to buildings, typically does not factor into building inspection or permitting considerations in their jurisdiction. It was not discussed further by other participants, suggesting general consensus that signage is of low priority when evaluating shared concerns between roads and buildings.

4.3.3 Noise mitigation. This enhances the quality of life and aligns with emerging sustainability goals (MacDonald *et al.*, 2008). For roads, factors like building materials, junction designs, and landscaping play a significant role in reducing noise generated by traffic. Similarly, for buildings, the use of soundproof materials and strategic design can mitigate noise pollution from adjacent roads. As urbanisation increases, noise mitigation may become a mandatory criterion for building permits, influencing both construction practices and road design standards. In countries like India, addressing noise concerns involves coordination with multiple agencies and approvals, particularly for projects near residential or sensitive zones.

Participants Response: Participants generally viewed noise mitigation as a tertiary factor with limited relevance in typical road and building projects. Participant 1 and Participant 2 both noted that it is not a priority in their respective regions, and is rarely a significant consideration during planning or permitting. However, Participant 4 highlighted exceptions, noting that in specific contexts such as developments near airports or major railways, noise mitigation becomes more critical, with regulations mandating specific planning measures. While not typically a shared priority in standard road-building scenarios, noise mitigation may gain importance in specialised cases involving significant noise sources.

4.3.4 Autonomous cars. They represent a new consideration in infrastructure planning, focusing on future-ready designs and technological integration. With the increasing adoption of autonomous vehicles, factors such as visibility, clear lane markings, and dedicated drop-off or parking zones need to be incorporated into planning. For roads, this involves ensuring infrastructure like V2X communication systems and geofencing capabilities. For buildings, designing access points and parking facilities to accommodate autonomous cars becomes relevant.

Participants Response: Participants agreed that autonomous vehicles currently do not play a significant role in road or building planning processes. Participant 1 and Participant 2 both confirmed that AV considerations are not yet factored into planning or permitting in their jurisdictions. However, Participant 2 highlighted that infrastructure developments, such as the expansion of 5G networks and small cell towers in the US, may lay the groundwork for future AV integration. While presently viewed as a tertiary or non-factor, participants acknowledged that AVs and related technologies—such as autonomous delivery bots or drones—could become more relevant over time. Participant 4 emphasised the need for concrete evidence and established design standards before autonomous systems can meaningfully influence planning policies. Overall, while not an immediate concern, AVs were identified as a potentially significant factor in the future.

Taken together, the tiered classification highlights that not all shared factors require the same level of coordination or data integration. Primary factors indicate non-negotiable constraints that must be addressed early through shared information environments, while secondary and tertiary factors suggest opportunities for staged or context-specific integration. This distinction has direct implications for how digital twin systems are scoped, prioritised, and operationalised across building permitting and road infrastructure planning.

5. Discussion

The identification and categorisation of shared influencing factors across building permitting and road infrastructure planning highlight practical opportunities for more integrated, digitally enabled urban development. By organising these influences into primary, secondary, and tertiary tiers, the study clarifies which cross-domain interactions are most consequential and therefore most suitable for early coordination and digital support, responding to recognised gaps in how permitting digitalisation has been studied and operationalised across contexts (Bloch and Fauth, 2023).

5.1 Tiered factors and what they imply for cross-domain coordination

Participants showed strong agreement on the primacy of factors. These are foundational because they directly affect safety, functionality, and regulatory compliance, and failures in early alignment often generate downstream conflicts, redesign, and delay. The consistency of views around setbacks and utilities, in particular, suggests these are non-negotiable constraints that should be prioritised in integrated workflows and, where appropriate, embedded as early-stage "gates" in digitally supported planning and permitting processes.

Secondary factors were viewed as important but more context-dependent. They contribute to user experience, sustainability, and long-term adaptability, yet their relevance varies across jurisdictions and planning cultures. This reinforces the need for flexible approaches that allow local policy priorities and behavioural patterns to shape how such factors are represented and evaluated, rather than assuming a single universal weighting.

Tertiary factors were generally described as peripheral or highly situational. Nevertheless, identifying them remains valuable: these influences often reflect emerging societal expectations and technological change, and may increase in significance as regulations and mobility systems evolve. A tiered framing allows such factors to be incorporated selectively when relevant, without overwhelming early-stage coordination with low-probability constraints.

5.2 From shared factors to operational digital twin information requirements

A central contribution of this study is the structured mapping between shared cross-domain factors and associated information requirements, showing how planning influences can be translated into concrete data needs for digitally enabled coordination. This linkage is essential for operationalising digital twins and related digital planning systems because it clarifies what information must be captured, shared, and maintained to support simulation, compliance checking, and multi-stakeholder decision-making, consistent with broader arguments that digital twin effectiveness depends on well-defined information systems and requirements (Sacks *et al.*, 2020).

While many digital twin efforts in practice still emphasise high-level data categories, cross-domain coordination requires greater specificity, particularly where regulatory interpretation depends on spatial parameters, functional intent, and performance thresholds. The proposed mapping therefore supports a shift from general digital twin aspirations towards implementable requirements that can be embedded within sector data models and workflows. Future work should refine and standardise these requirements to improve interoperability and support reliable cross-domain decision-making.

5.3 Implementation requirements: governance, interoperability, and adaptable rules

Workshop feedback reinforced that technical capability alone is insufficient. Participants emphasised the need for clearer communication channels and shared data platforms across building and road authorities so that shared factors can be addressed consistently in practice. In this sense, digital twins should be understood as socio-technical coordination mechanisms: their value depends on harmonised policies, aligned responsibilities, and workable routines for secure data exchange, not solely on software integration—an issue echoed in wider debates about aligning governance, regulation, and policy-making across transport-related institutions (Cruz and Sarmento, 2019).

From an interoperability perspective, cross-domain digital twins require consistent, high-quality data spanning both permitting and road planning contexts. Fragmented data silos and incompatible formats remain a major barrier, often driven by authorities and private actors using different data models and tools. Open standards and a shared spatial reference can mitigate this: building representations are commonly supported by IFC, while city-scale and infrastructure contexts are often handled through geospatial standards and platforms (e.g. CityGML and spatial databases). Recent infrastructure extensions within IFC (e.g. alignment- and bridge-related schemas) strengthen the potential for shared representations, particularly when coupled with GIS-based alignment of road networks and building proposals. These challenges are aligned with prior GeoBIM research that has highlighted technical interoperability constraints in building permit use cases and the associated organisational frictions around data exchange (Noardo *et al.*, 2020).

Regulatory dynamism presents a further requirement. Zoning rules, environmental codes, and permitting constraints change over time, and static models quickly become misaligned with current policy, creating rework and delays. Modular, rule-based compliance components—supported by semantic models or rule engines—can help systems respond to evolving requirements, enabling continuous alignment between road infrastructure planning and building permitting, building on earlier work in automated compliance checking while extending it to cross-domain coordination settings (Malsane *et al.*, 2015). This capability is closely tied to the granularity of information requirements: the more precisely spatial and functional constraints are defined (for example, what constitutes a compliant setback in relation to a road safety envelope), the more reliably digital systems can automate checks and simulate cross-domain impacts.

5.4 Practical pathway: staged adoption and illustrative applications

The tiered structure supports staged implementation rather than a "fully unified" digital twin from the outset. Primary factors can be modelled first and used to support early-stage coordination and approval gating (e.g. setbacks, access points, drainage, emergency access, and utilities). Secondary factors can be incorporated next to support optimisation, scenario comparison, and policy alignment, while tertiary factors can be activated selectively for specific sites or emerging needs. This staged approach helps authorities focus organisational and computational resources on high-impact constraints while preserving extensibility.

The shared factors also indicate clear entry points for practical applications. A shared digital environment can support setback management by checking building proposals against road safety envelopes, visibility constraints, and zoning rules within a unified spatial context. Access point planning can be evaluated through scenario-based simulations that consider driveway placement, pedestrian safety, and emergency vehicle access across building–road interfaces. Utility coordination is a particularly high-value use case: integrating subsurface assets into a shared model can reduce service conflicts and improve excavation planning by replacing fragmented drawings with a common, updatable representation.

5.5 Limitations and future research

This study provides a conceptual foundation, but several limitations remain. First, the findings are presented at a relatively high level and will require adaptation to specific jurisdictions and project contexts. Second, the proposed tiering of factors and the factor–information requirement mapping require broader validation through additional expert engagement and applied case studies, including quantitative assessment of agreement and transferability. Third, regulatory and technological conditions were necessarily simplified, whereas real-world practice is dynamic and shaped by local contingencies. Finally, the information requirements listed should be treated as an initial, evolving specification rather than an exhaustive catalogue, and will require iterative refinement through prototyping and stakeholder feedback.

Future work will proceed through two pilot implementations that operationalise the tiers and information requirements in real decision workflows. Pilot 1 will focus on primary-factor early-stage gating, integrating building proposals with adjacent road constraints to support automated/semi-automated checks for setbacks, access points, drainage interfaces, emergency access, and utility coordination. Pilot 2 will test configurable extension to secondary/tertiary factors (e.g. parking/EV infrastructure, lighting, and site-specific amenities) to evaluate scalability across jurisdictions. Evaluation will use a mixed-method design combining: (1) technical performance (agreement of automated checks with expert determinations; rate of early detection of cross-domain conflicts such as access/utility clashes; completeness and timeliness against specified information requirements), (2) process outcomes (review iterations, time-to-decision, and avoidable redesign/rework events versus baseline workflows), and (3) user/governance outcomes (usability, transparency, and stakeholder trust via structured surveys/interviews). Interdisciplinary delivery will be supported by a cross-domain working group (permitting officials, road authorities, GIS/GeoBIM specialists, utilities, and digital twin engineers) with recurring co-design sessions and a lightweight governance protocol for rule updates, data responsibilities, and privacy/security constraints.

Future implementations should also consider equitable access to digital twin-enabled permitting information, ensuring that smaller municipalities, non-technical stakeholders, and community participants are not excluded from decision-making processes due to limited technical capacity or data access.

6. Conclusions

This study presents an exploratory framework that identifies and classifies shared factors between building permitting and road infrastructure planning, linking them to information requirements relevant for digital twin implementations. By adopting a cross-domain perspective, it provides a structured lens for understanding how interdependencies between regulatory, technical, and organisational aspects shape integrated urban planning processes.

A key insight is that digital twins should be understood not merely as technical optimisation tools, but as socio-technical and governance instruments that influence how evidence, responsibilities, and decisions are coordinated across institutional boundaries. The proposed classification into primary, secondary, and tertiary factors highlights that integration is not an all-or-nothing endeavour; rather, it can be approached incrementally, aligned with regulatory constraints and organisational capacities.

Beyond institutional stakeholders, public engagement and community input represent an important but underexplored dimension of digital twin–supported decision-making. Digital twins may act as boundary objects that translate complex technical information into more accessible representations for non-expert stakeholders, supporting transparency and deliberation. However, how community input is captured, validated, and meaningfully integrated into authoritative datasets and regulatory decisions remains an open research question, particularly in building permitting contexts.

The findings further suggest that regulatory variability across jurisdictions is not an obstacle to be eliminated through harmonisation, but a contextual condition that digital twin frameworks must accommodate. Shared data and integrated decision-making do not emerge automatically from technical interoperability, but require negotiation, alignment, and coordination across actors with differing mandates and risk perceptions.

Overall, the framework provides an initial basis for reflecting on how digital twin development efforts, municipal practices, and policy discussions can move beyond isolated digital tools toward more coherent and context-sensitive integration between building permitting and road infrastructure planning. By making these interdependencies explicit, the study supports more informed discussions on the role of digital twins in shaping resilient and sustainable urban systems.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely to assist with language editing and stylistic refinement across the manuscript. The tool was not used to generate scientific content, analyses, interpretations, figures, or conclusions. All content was reviewed, verified, and revised by the authors, who take full responsibility for the accuracy, originality, and integrity of the published work.

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