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Review Article

Digital Twin and BIM for Automated Compliance Checking: A Systematic Review of the Missing Link and the Path Toward Generative Compliance

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Abstract

Automated Compliance Checking (ACC) is widely proposed as a remedy for inefficient manual building-regulation review, yet it remains unclear whether Building Information Modelling (BIM) or Digital Twin (DT) technology offers the more promising foundation for ACC, and how either relates to the longer-term ambition of generative, compliance-driven design. This paper reports a systematic literature review (SLR) of 141 studies (2018–2026), retrieved through a dual-stream search on Scopus and Web of Science and screened in accordance with PRISMA 2020. The corpus was analysed through three complementary methods: bibliometric trend analysis, keyword co-occurrence network analysis in VOSviewer, and AI-assisted thematic synthesis across four temporal sub-periods. The analysis shows that BIM constitutes the structural and methodological core of the field (134 papers, 22–25% implementation maturity at design and construction stages), whereas DT-related research (7 DT+ACC papers and 9 BIM-DT cross-stream papers) is peripheral, recent, and almost entirely conceptual (0% prototype rate in the cross-stream zone). No direct co-occurrence edge connects "digital twin" and "automated compliance checking" in the keyword network; a structural absence that is independently confirmed by the thematic map as an explicit research-gap entry. This un-operationalized DT–ACC integration is identified as one of the principal research gap in the field. The paper argues that, on present evidence, design-stage BIM is the only substrate simultaneously rich and mature enough to host a generative compliance architecture, while the DT–ACC link remains the field's longer-horizon target.

Keywords: Automated compliance checking; Building information modelling; Digital twin; Systematic literature review; Knowledge graphs; Generative AI; Large Language Models

Highlights

- Despite its conceptual promise, Digital Twin has produced zero tested ACC artefacts across all lifecycle phases.
- Design-stage BIM is the only currently operative substrate for AI-integrated ACC
- The evidenced next step is a guided generative extension of ACC, driven jointly by the formal constraints, the designer's prior model, and the verification diagnosis.

Introduction

Manual checking of building designs against regulatory requirements is widely regarded as slow, inconsistent, and a bottleneck in the design-to-permit pipeline. Automated Compliance Checking (ACC) has therefore been proposed as a solution, and two technological paradigms are most frequently associated with it: Building Information Modelling (BIM), which provides a structured, semantically rich representation of a building design, and the Digital Twin (DT), which extends this representation with real-time, bidirectional synchronisation between a physical asset and its digital counterpart. While both paradigms are routinely invoked in the construction-informatics literature, it remains unclear which of the two, BIM or DT, offers the more viable foundation for ACC across the building lifecycle, and how either relates to a further technological ambition that has gained prominence in recent years: the use of Generative AI to move beyond checking designs for compliance and toward generating compliant designs directly from regulatory constraints.

This paper addresses that uncertainty through a systematic literature review (SLR) that compares BIM-based and DT-based approaches to ACC across the building lifecycle, with the explicit objective of identifying which technological foundation, and which combination of artificial-intelligence (AI) techniques, best enables a future generative extension of ACC. The review is based on a corpus of 141 studies published between 2018 and 2026, retrieved through a dual-stream search strategy and screened according to the PRISMA 2020 standard (Page et al., 2021). The corpus was analysed using three complementary methods; bibliometric trend analysis, keyword co-occurrence network analysis, and AI-assisted thematic synthesis, whose combined evidence converges on a single structural finding that forms the core contribution of this paper: the absence of an operationalized link between Digital Twin technology and automated compliance checking.

The remainder of this paper is organised as follows. Section 2 describes the review methodology, including the search strategy, screening procedure, and the three-layer analytical framework. Section 3 reports the main findings: the bibliometric profile of the corpus, the structure and temporal evolution of the keyword co-occurrence network, the eight-pillar thematic map of the literature, and the lifecycle- and AI-integration profiles of the BIM, DT, and cross-stream sub-corpora. Section 4 presents the implementation-maturity matrix that consolidates these findings and articulates the principal research gap; the unoperationalized DT–ACC link, as the central finding of the review, before briefly indicating its implications for a generative extension of ACC. Section 5 concludes.

Methodology

This review follows a mixed-methods design reported in accordance with the PRISMA 2020 standard. The protocol comprises a dual-stream corpus construction and screening procedure, followed by a three-layer analytical framework applied to the resulting corpus.

1.1 Search strategy, identification, and screening

A two-stream search strategy was adopted to enable a balanced comparison of BIM-based and DT-based approaches to ACC. The two streams were executed independently on Scopus and Web of Science, using search strings targeting, respectively, the intersection of BIM with ACC and the intersection of DT with ACC. Searches were conducted on 05.03.2026 and restricted to journal articles and conference papers published in English between 2018 and 2026.

The BIM+ACC stream returned 1,849 records and the DT+ACC stream returned 507 records, yielding a combined initial pool of 2,356 publications. After removing 70 and 10 duplicates respectively, 1,779 and 497 records remained for title-and-abstract screening in Covidence. Screening proceeded through two further exclusion steps. Step 2 assessed records for substantive engagement with the intersection of BIM (or DT) and ACC, removing 1,482 records from the BIM+ACC stream and 465 from the DT+ACC stream and yielding intermediate corpora of 297 and 32 records. Step 3 required that ACC constitute a core topic rather than a peripheral mention, removing a further 163 and 25 records respectively. This left 134 BIM+ACC records and 7 DT+ACC records eligible for full-text review. A cross-stream comparison identified 9 publications addressing BIM, DT, and ACC concurrently; these were retained once to avoid duplication. The final corpus therefore comprises 141 unique studies, of which 29 specifically address the integration of AI techniques with ACC.

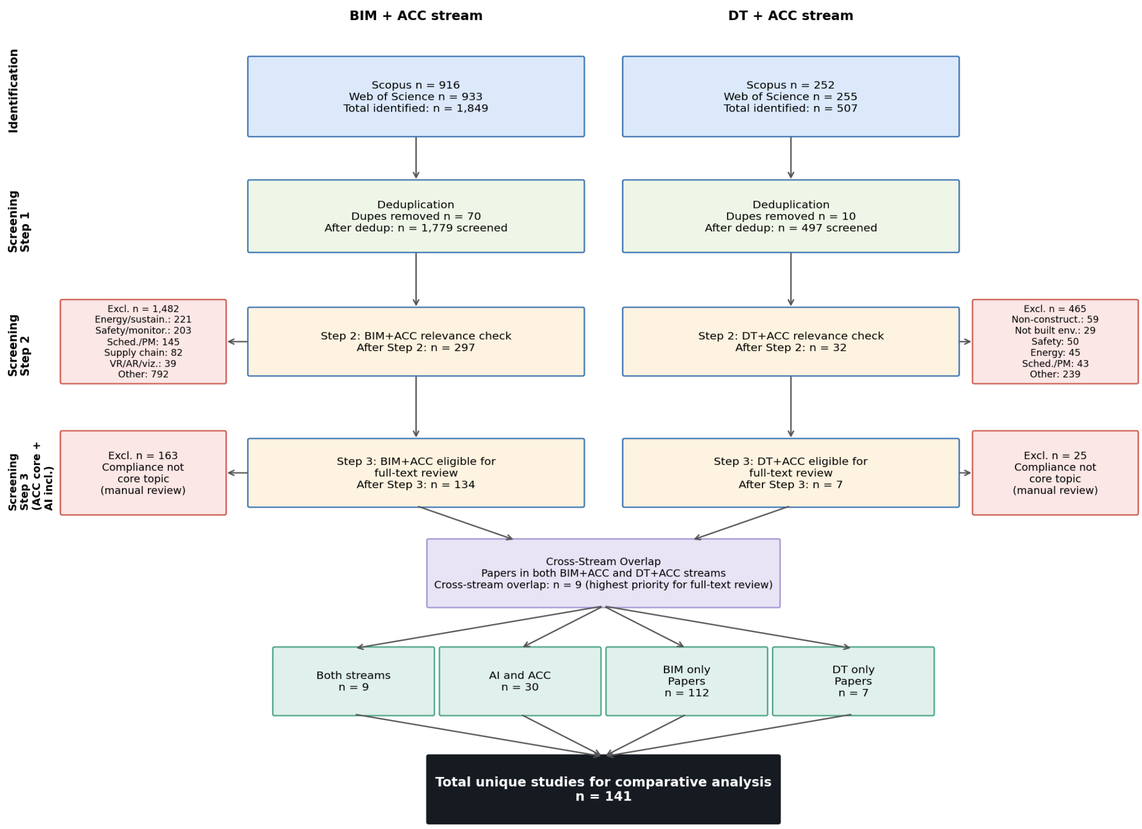

Figure 1. PRISMA 2020 flow diagram of the dual-stream search, screening, and inclusion process (Source: authors).

1.2 Analytical framework

The 141-study corpus was analysed through three complementary methods, each building on the preceding one.

Bibliometric analysis characterised the temporal and lifecycle distribution of the corpus. Annual publication counts were extracted per stream, and each paper was coded against four canonical lifecycle phases: Design, Construction, Post-construction, and Demolition, using a structured data-extraction sheet. Because most studies span more than one phase, coverage is reported as a share of the sub-corpus total rather than as mutually exclusive membership.

Keyword co-occurrence network analysis was performed in VOSviewer (v1.6.20) using full counting on author keywords, with a minimum occurrence threshold of three (van Eck & Waltman, 2010; van Eck & Waltman, 2023). A custom thesaurus resolved terminological fragmentation ("Building Information Modelling" alone appeared under seven variant labels) and was refined over three iterative cycles until the network reached a stable state. The retrieved corpus contained 422 unique keyword entries after harmonisation, of which 21 met the occurrence threshold and were retained for visualisation. The VOS layout and clustering algorithms (default resolution) determined node positioning and thematic clusters. A structural view and a temporal overlay (colouring nodes by mean publication year) are reported.

AI-assisted thematic synthesis provided the content-level counterpart to the co-occurrence network. The 141 studies were divided into four temporal sub-sets (2017–2021, 2022–2023, 2024–2025, 2026) and processed as separate notebooks, each yielding a period-specific inductive mind-map. The four maps were consolidated manually into a unified knowledge map organised around eight thematic pillars, with era markers preserved on each sub-theme.

The three methods are integrated by cross-checking the keyword network and the thematic map for convergence, the former derived deductively from co-occurrence statistics, the latter inductively from content reading, before the combined evidence is synthesised into an implementation-maturity matrix.

Results: Technology Mapping for ACC

1.3 Bibliometric profile of the corpus

The two search streams display markedly different growth trajectories. The BIM+ACC stream's first publication in the corpus dates to 2018, its peak year is 2022 (n = 25), and growth from 2018 to 2025 amounts to +200% (6→18 papers); 40 papers (30%) fall in 2018–2021 and 94 (70%) in 2022–2026. The DT+ACC stream's first publication dates to 2020, with a peak year of 2025 (n = 6); only 1 paper (6%) falls in 2018–2021 against 6 papers (94%) in 2022–2026, indicating that the stream emerged later and has grown rapidly only in the most recent period.

Taken together, the two trajectories establish the first comparative finding of the review: BIM+ACC literature has reached a plateau characteristic of a maturing field, whereas DT+ACC literature has only become measurably active from 2022 onwards and remains an emerging frontier. This asymmetry has a methodological consequence: the seven-paper DT+ACC stream is too small to support stand-alone bibliometric inference, motivating the treatment of the nine cross-stream BIM+DT papers as a distinct sub-corpus.

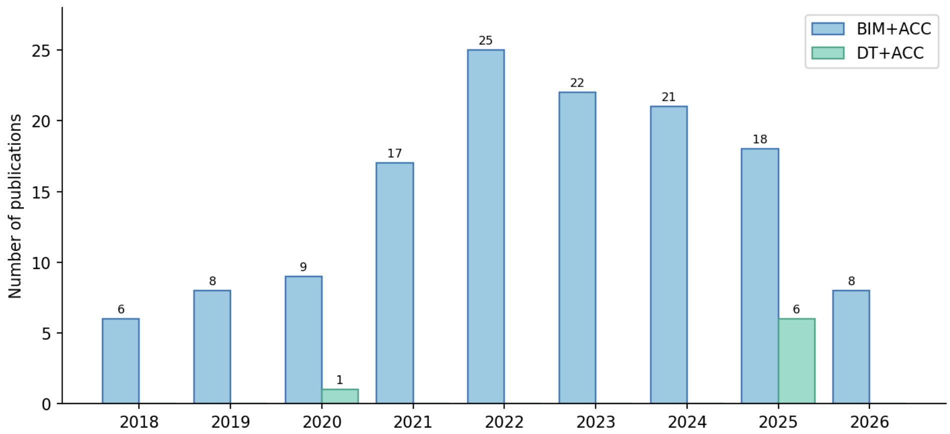

Figure 2. Annual publication counts per search stream, 2018–2026 (BIM+ACC vs DT+ACC) (Source: authors).

1.4 Structure and evolution of the keyword co-occurrence network

The harmonised network organises into four thematic clusters. Cluster 1 (blue) is centred on Building Information Modelling, with representative keywords including compliance checking, virtual permitting, and semantic enrichment, and a thematic orientation of BIM as a foundational data paradigm. Cluster 2 (green) is centred on automated compliance checking and natural language processing, with representative keywords including rule interpretation, rule checking, and knowledge graph, oriented toward ACC methodology and rule-based AI. Cluster 3 (yellow) is centred on IFC, with representative keywords including ontology, semantic web, and linked data, oriented toward semantic-web interoperability. Cluster 4 (red) is centred on digital twin and artificial intelligence, with representative keywords including large language models, construction safety, construction management, model checking, and automation, oriented toward emerging AI applications in construction.

Building information modelling emerges unambiguously as the structural centre of the field. With 81 occurrences after thesaurus consolidation (the highest of any keyword) and a total link strength (TLS) of 119, it shares strong, direct edges with every other cluster. The second- and third-ranked keywords by TLS, automated compliance checking (33 occurrences, TLS = 52) and compliance checking (16 occurrences, TLS = 34), confirm that compliance-related topics dominate the field on a BIM-centric backbone.

Digital twin, by contrast, occupies a peripheral position (10 occurrences, TLS = 20) within the emerging-applications cluster. Although a direct edge exists between digital twin and BIM, this connection is visibly thinner than BIM's edges to automated compliance checking, ontology, and IFC. Critically, no direct edge of appreciable weight connects digital twin to automated compliance checking, despite both concepts being central to the review's research question. Digital twin is instead more strongly associated with artificial intelligence, large language models, and construction safety than with the compliance-checking methodological stream. This peripheral positioning suggests that the literature currently conceptualises DT as an application layer built upon BIM rather than as an independent data paradigm for compliance checking; the absence of a direct DT–ACC co-occurrence edge is itself a substantive finding of this review.

The distribution of AI technologies across clusters reveals methodological specialisation. Natural language processing and knowledge graphs sit within the ACC cluster (green), indicating their status as established methodologies for rule extraction and interpretation. Ontology, semantic web, and linked data occupy the bridging cluster (yellow), connecting BIM-based data structures to reasoning engines. Artificial intelligence and large language models sit within the emerging-frontier cluster (red) alongside digital twin, indicating that the most recent AI advances are being pioneered within the DT/AI research community rather than the established ACC community. Model checking, a formal-verification approach, appears in the red cluster but draws visually toward the blue BIM cluster, suggesting a potential methodological bridge between formal verification and BIM-based compliance workflows.

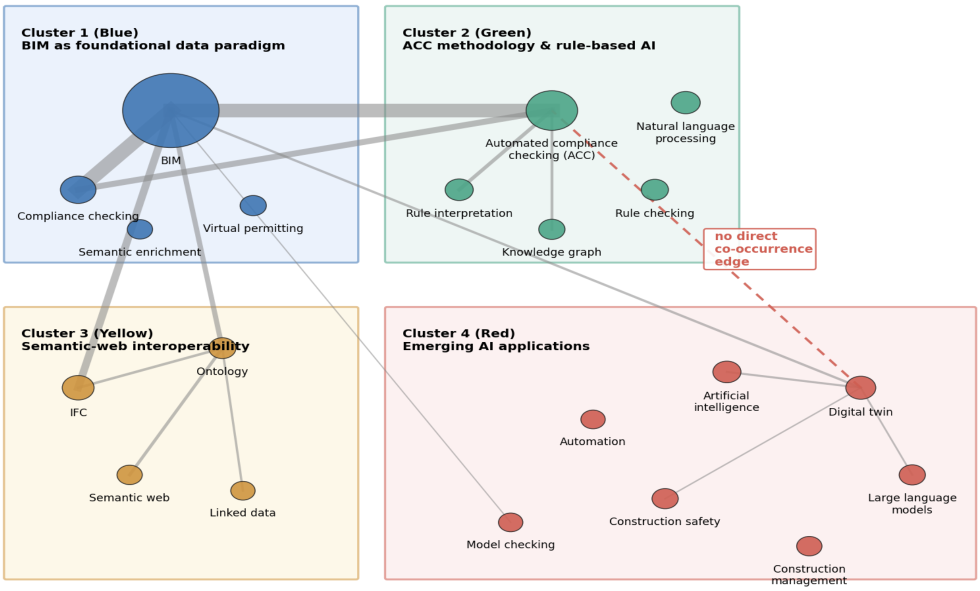

Figure 3. Aggregated keyword co-occurrence network with four thematic clusters (Source: authors).

A temporal overlay corroborates this structural reading (Figure 4). The earliest band (2021–2022) contains rule checking, rule interpretation, virtual permitting, and semantic enrichment (the foundational vocabulary of the field). The middle band (2023) is occupied by the methodologically mature core: building information modelling, automated compliance checking, compliance checking, IFC, ontology, semantic web, and model checking, reflecting their role as the stable, sustained axes of the field. The most recent band (2024–2025) contains digital twin, artificial intelligence, construction safety, automation, linked data, knowledge graph, large language models, and construction management, concentrated almost exclusively in the emerging-applications cluster. Digital twin occupies a distinctly more recent temporal position (approximately 2024) than building information modelling (approximately 2023), and large language models appear at the leading edge of the temporal distribution (2025) within the same cluster as digital twin and artificial intelligence, reinforcing the observation that LLM-based approaches to compliance checking constitute a timely and under-explored research frontier.

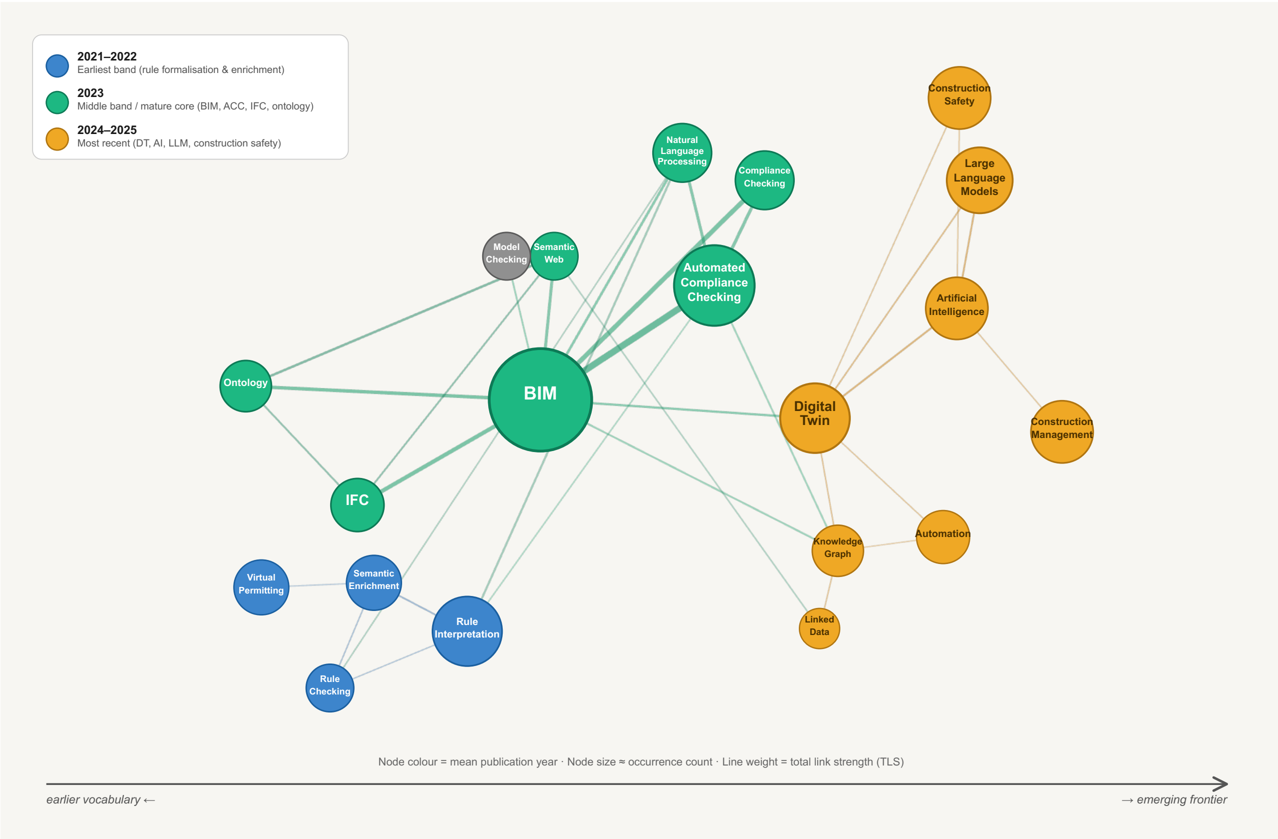

Figure 4. Simplified temporal overlay of the keyword co-occurrence network (reconstructed from VOSviewer analysis). Node colour = mean publication year | Node size ~ occurrence count | Line weight = total link strength (TLS) (Source: authors).

1.5 The thematic map: eight pillars of the field

An independently constructed thematic map, derived inductively from a reading of the 141 studies and organised into eight pillars and 34 sub-themes, converges with the keyword network on the same structure: a dominant BIM-centred methodological core, a recent and comparatively sparse Digital-Twin and AI frontier, and, most consequentially, the same absent link between Digital Twin and automated compliance checking, which the network expresses as a missing edge and the thematic map records as an explicit research-gap entry (Pillar 8).

Pillar 1 (ACC core methodology and workflow) identifies a recurring four-step verification workflow constituting the methodological spine of BIM-based ACC: rule interpretation, model preparation, verification, and reporting (Galkina & Kuzina, 2018; Mastino et al., 2020). Rule interpretation matured from early Prolog-style formalisation (Galkina & Kuzina, 2018), through a structured legal-text-parsing and Boolean-logic pipeline (Marzouk & Abdelsalam, 2026), to neural extraction via BERT with context-free-grammar (CFG) structural validation and rule-to-SHACL translation (Zhang et al., 2026).

Pillar 2 (Semantic-web and ontology foundations) shows the 2022–2023 literature reframing compliance as an ontology-reasoning problem through multi-ontology fusion; a code ontology (TBox), a designed-model ontology (ABox), their merger, and a compliance-checking results ontology, providing a "gray box" technique that remains interpretable to domain experts (Jiang et al., 2022). The semantic layer persists into the most recent period as knowledge graphs, SHACL constraint shapes, and linked-data representations underpinning executable checking (Zhang et al., 2026).

Pillar 3 (AI, ML, and LLM integration) shows AI entering the corpus along four lines: natural-language and semantic extraction dominated first by classical NLP and later by BERT-based models (Zhang et al., 2026); a human-in-the-loop strand routing low-confidence predictions to expert review (Zhang et al., 2026); a generative "design-healing" strand automating correction of non-compliant designs through graph-based topological propagation, Morris sensitivity analysis, and conditioned Latin-hypercube design-space exploration (Wu et al., 2025); and a regulatory-evolution strand using change-detection, retrieval-augmented generation, and regression testing to keep rule bases current (Zhang et al., 2026). Reported efficiency gains for the integrated human-in-the-loop approach include a 90% reduction in human effort, 95.8% translation accuracy, and 98.3% rule executability (Zhang et al., 2026).

Pillar 4 (BIM lifecycle and data standards) frames BIM as a continuous lifecycle asset spanning five stages: Pre-BIM, Design (D-BIM), Construction (C-BIM), Exploitation (E-BIM), and Reorganisation/Recycling (Re-BIM), resting on a stable data layer of GUIDs, Uniclass/Omniclass coding, and the IFC open standard as the loss-free exchange format (Galkina & Kuzina, 2018; Mastino et al., 2020).

Pillar 5 (Digital Twin and blockchain) concentrates the operational and circular-economy frontier in the most recent literature. Blockchain provides decentralised, immutable data integrity and multi-party verification, while DT supplies dynamic, real-time monitoring; their integration with smart contracts is presented as an imperative for material lifecycle management, underpinning Material Passports and Digital Product Passports mandated by EU regulation (Aklashie et al., 2026; Hulea et al., 2024; Honic et al., 2024). Integration nonetheless remains obstructed by architectural incompatibility, big-data storage conflicts, performance bottlenecks, and an interoperability-standards deficit (Palihakkara et al., 2025; Alsaffar et al., 2025).

Pillar 6 (Domain applications and safety) covers excavation safety automated through the Auto-Exca pipeline encoding OSHA cave-in slopes, guardrail rules, and egress limits (Khan et al., 2019); acoustic performance verification across design-stage prediction and in-situ measurement (Mastino et al., 2020); and a behavioural-safety strand evidenced in a 1,026-worker study (Wang et al., 2026).

Pillar 7 (Policy, adoption, and regional implementation) reports adoption assessed through a Fuzzy-COPRAS readiness framework spanning Technology, People, Process, and Policy criteria (Ullah et al., 2022), with regional implementation evidence spanning Finland, Estonia, China, Malaysia, and the UAE.

Pillar 8 (Technical challenges and research gaps) converges on two cross-cutting gaps: a semantic-pragmatic gap, in which correctly parsed regulatory text still fails to execute against geometric model data (Zhang et al., 2026), and the as-yet not operationalized integration of Digital Twin with automated compliance checking (Alsaffar et al., 2025); the principal research gap independently substantiated by the keyword co-occurrence analysis.

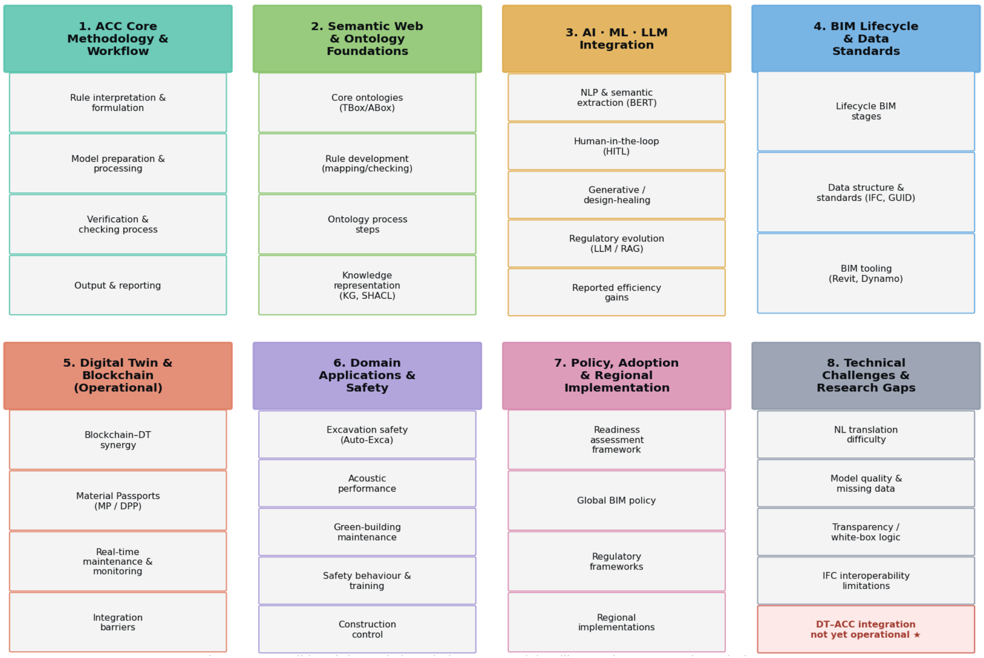

Figure 5. Consolidated thematic knowledge map of the 141-paper corpus — eight pillars and representative sub-themes (Source: authors).

1.6 Lifecycle and AI-integration profile of the BIM, DT, and cross-stream sub-corpora

The 134 BIM+ACC papers are heavily front-loaded along the lifecycle: 92% (123 papers) engage with construction and 77% (103 papers) with design, whereas post-construction is addressed by only 15% (20 papers) and demolition by 1% (1 paper). The largest single cohort addresses Design and Construction jointly, confirming that the dominant operational unit of BIM-based ACC is the pre-construction permit-readiness check. Methodologically, semantic/rule-based checking dominates every lifecycle phase, accounting for 74 of 134 papers (55%); geometry-based (n = 6), simulation-based (n = 4), and hybrid (n = 11) approaches appear chiefly at design and construction, while post-construction is dominated by 'not specified' entries (38/134, 28%).

The DT-related corpus extends meaningfully into the operational lifecycle, although its much smaller absolute size means the same percentage figures correspond to only a handful of papers. The DT+ACC stream (n = 7) covers design and construction at 86% each (6 papers in each phase) post-construction at 43% (3 papers), and demolition at 29% (2 papers); the cross-stream BIM+DT papers (n = 9) reach 89% design (8 papers), 100% construction (9 papers), 44% post-construction (4 papers), and 22% demolition (2 papers).

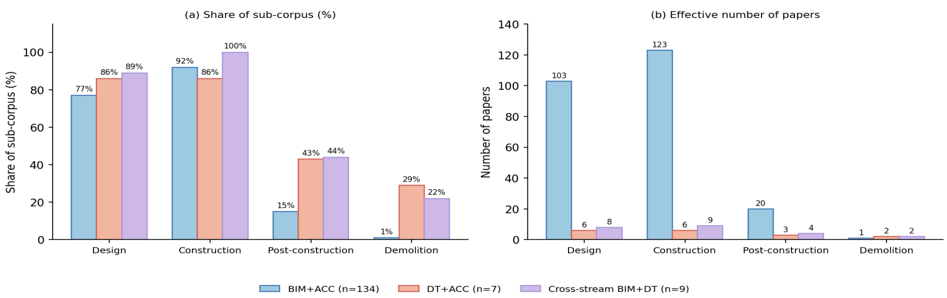

Figure 6. Lifecycle-phase coverage across the three sub-corpora — relative share (a) and effective paper counts (b) (Source: authors).

Figure 6 presents this lifecycle profile in two complementary panels: panel (a) shows the relative share of each sub-corpus addressing each phase, while panel (b) translates these shares into effective paper counts. The percentage view in panel (a) suggests that DT-related research is proportionally far more engaged with the operational lifecycle, roughly three times more likely than BIM research (43–44% vs 15%) to consider post-construction, and an order of magnitude more likely to consider demolition (22–29% vs 1%). Panel (b), however, shows that this apparent proportional advantage rests on a very small evidence base: the 43–44% post-construction figures for DT+ACC and cross-stream correspond to only 3 and 4 papers respectively, against 20 papers for BIM+ACC, and the 22–29% demolition figures correspond to just 2 papers each, against a single BIM+ACC paper. The dual representation therefore makes clear that while Digital-Twin-related research is thematically oriented toward the operational and end-of-life lifecycle to a greater degree than BIM research, this orientation is not yet backed by a substantial body of work: the absolute counts across post-construction and demolition remain in the low single digits for both DT-related sub-corpora.

The Implementation-Maturity Matrix and the Principal Research Gap

Combining the lifecycle structure of Section 3.4 with output-type evidence from the data-extraction sheet enables a 3×4 implementation-maturity matrix: rows correspond to the three sub-corpora (BIM+ACC, DT+ACC, cross-stream BIM+DT), columns to the four lifecycle phases, and each cell reports the share of papers covering that phase whose output is an implemented system or a tool/software prototype (work that has progressed beyond a conceptual framework into an operative artefact).

The BIM+ACC row shows a stable maturity band of 22–25% across the three populated phases: 25/103 papers at design (24%), 27/123 at construction (22%), and 5/20 at post-construction (25%). Meaning roughly one in four BIM+ACC papers progresses from concept to operative artefact, regardless of lifecycle phase. The DT+ACC row reports prototype-or-implementation counts of 1/6, 1/6, and 1/3 across design, construction, and post-construction (all attributable to the same single implemented system), with an empty demolition cell. The cross-stream row is the most striking finding of the matrix: zero of nine papers integrating BIM and DT for compliance deliver a prototype or implemented system in any phase of the lifecycle. The 0% line at demolition holds across all three sub-corpora.

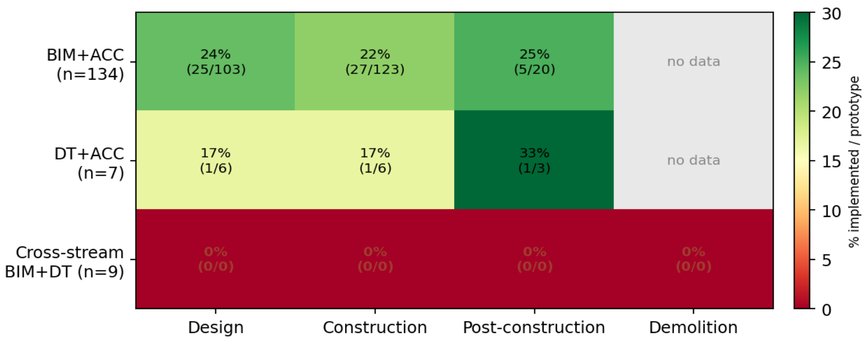

Figure 7. ACC implementation-maturity matrix across the three sub-corpora and four lifecycle phases (Source: authors).

1.7 The principal research gap: an unoperationalized DT–ACC link

Three independent lines of evidence converge on a single finding, which constitutes the core contribution of this review. First, the keyword co-occurrence network (Section 3.2) shows no appreciable direct edge between digital twin and automated compliance checking, despite both terms being central to the field's vocabulary; digital twin instead clusters with artificial intelligence, large language models, and construction safety. Second, the inductively derived thematic map (Section 3.3) independently records the same absence as an explicit research-gap entry under Pillar 8: "the as-yet not operationalized integration of Digital Twin with automated compliance checking" (Alsaffar et al., 2025). Third, the implementation-maturity matrix (Section 4) quantifies the consequence of this structural absence: the BIM-DT cross-stream zone (the nine papers that explicitly combine both paradigms in a compliance context) produces a uniform 0/0/0/0 profile across the lifecycle. Not a single cross-stream paper progresses beyond a literature review or conceptual framework to a tested artefact.

This triangulation (one representation derived deductively from co-occurrence statistics, the other inductively from content reading, both converging on the same structural absence, and both corroborated by an output-type analysis of the corpus) lends the finding a robustness that no single method could establish alone. The literature does not yet treat Digital Twin as an independent data paradigm for compliance checking; where DT-based compliance research exists, it reaches compliance checking only indirectly through BIM, and where BIM and DT are explicitly combined for compliance, the result is conceptual rather than operative.

This principal gap sits alongside three related gaps that the review's evidence also supports: the under-application of large language models to the core ACC problem, given that LLMs occupy the same temporally recent, structurally peripheral cluster as digital twin rather than the established ACC/NLP cluster (Section 3.2); the absence of real-time, sensor-based, or operational-phase compliance checking, reflecting the fact that DT's principal technical advantage (continuous live data from the built asset) is not yet exploited for compliance; and limited cross-cluster methodological synthesis, in which NLP-based, ontology-based, and LLM-based approaches are pursued largely in parallel rather than in combination.

1.8 Implications for a generative extension of ACC

The maturity matrix has a direct implication for any future generative architecture for ACC, briefly noted here. A generative architecture must, by definition, consume compliance constraints and produce candidate design or operational responses; it therefore requires a substrate that is simultaneously information-rich enough to express those constraints and mature enough to support working tools. On the evidence of this review, that substrate is design-stage BIM, and design-stage BIM alone: it is the structural centre of the keyword network (TLS = 119), it carries the field's mature four-step verification workflow (Pillar 1) and semantic-web infrastructure (Pillar 2), and it is the only sub-corpus showing a non-zero implementation-maturity band (22–25%). The operational promise of DT (continuous live data, dynamic event-state representation, real-time perception) remains, on present evidence, a longer-horizon target rather than an immediately available substrate: the cross-stream BIM-DT zone, which would be the natural host for a DT-integrated generative architecture, is currently a purely theoretical space (0/0/0/0). The principal gap identified in Section 4.1, the not operationalized DT–ACC link, therefore delimits not only where the field's research effort has and has not reached, but also where a generative extension of ACC can and cannot yet be built.

Discussion

The structural absence of an operationalised DT–ACC link identified in this review corroborates and quantifies what Alsaffar et al. (2025) described qualitatively as an integration gap, and extends it: not only does the connection remain unbuilt, but the nine papers that explicitly attempt to bridge both paradigms for compliance produce no tested artefact whatsoever, suggesting the gap is not merely technical but epistemological: the field has not yet agreed on what a DT-based compliance check would even look like in operation. The finding that BIM alone sustains a non-zero implementation-maturity band is consistent with the broader construction-informatics consensus on IFC as the field's persistent load-bearing standard (Eastman et al., 2011), and the temporal overlay of the keyword network reinforces this: LLMs and digital twin co-cluster at the emerging frontier precisely because neither has yet been absorbed into the mature checking workflow the BIM community has built over a decade. The lone proto-generative precedent in the corpus, Wu et al.'s (2025) design-healing, points toward the next open question the field must address: whether verification can be inverted from a terminal judgement into a diagnostic input that drives constrained design synthesis, closing the loop from regulation to compliant model rather than merely measuring the distance to it.

Conclusions

This paper has reported a systematic literature review of 141 studies comparing BIM-based and DT-based approaches to automated compliance checking. Three complementary analyses (bibliometric trend analysis, keyword co-occurrence network analysis, and AI-assisted thematic synthesis) converge on a single structural finding: Building Information Modelling constitutes the mature, structurally central, and implementation-ready substrate for ACC, while Digital Twin technology, whether considered alone or in explicit combination with BIM, remains structurally peripheral, temporally recent, and, in the case of BIM-DT integration specifically, entirely without a tested artefact. The absence of a direct keyword co-occurrence edge between digital twin and automated compliance checking, independently corroborated by the thematic map's explicit research-gap entry and by the 0/0/0/0 implementation-maturity profile of the cross-stream cohort, identifies the unoperationalized integration of Digital Twin with automated compliance checking as one of the principal research gaps of the field. This gap, together with the under-application of large language models to ACC, the absence of operational-phase compliance checking, and the limited synthesis of methodologies across clusters, defines both the current state of the art and the boundary conditions within which any future, including generative, extension of automated compliance checking must be positioned.

Ethical Approval Declaration

The study was conducted in accordance with established standards for research integrity and ethics. The authors declare that this research did not involve human participants or animals, and therefore, ethical approval was not required.

Informed Consent Statement

Not Applicable

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Data Availability Statement

No new data were created or analysed in this study; all data are drawn from the published studies cited.

Conflicts of Interest

The authors declare no conflict of interest.

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