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AN EVENT-SOURCED RFID-IFC COMMON DATA ENVIRONMENT FOR CONSTRUCTION COMPONENT TRACEABILITY AND ACCESSIBLE INDOOR NAVIGATION

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Abstract

Despite the widespread adoption of Building Information Modelling (BIM) in construction, the physical reality on site diverges systematically from its digital representation. This paper presents a unified three-part framework that bridges this gap by integrating passive UHF Radio Frequency Identification (RFID), the open IFC standard, and an event-sourced Common Data Environment (CDE). Part A binds GS1 Electronic Product Code (EPC) identifiers to IFC GUIDs via a dual-identifier scheme, enabling persistent cross-phase component tracking. Part B proposes a Domain-Driven Design CDE architecture in which every lifecycle event is recorded as an immutable, timestamped fact - ensuring full provenance and audit-trail capability. Part C applies the same RFID–IFC binding mechanism to accessible indoor navigation for visually impaired users. The framework was designed using the Design Science Research methodology and demonstrated through two prototypes: the INNOTRACE event-sourced CDE for precast concrete lifecycle tracking, and the ModuLeiT field deployment, which was validated with approximately 30 blind and visually impaired participants at the THM Blindenzentrum. Together, the three parts show that a single RFID–BIM paradigm can address construction logistics, quality assurance, and universal design within one coherent architecture.

Keywords: Radio Frequency Identification (RFID); Building Information Modelling (BIM); Industry Foundation Classes (IFC); Digital Twin; Indoor Navigation; Lifecycle Traceability

1 Introduction and Research Gap

1.1 The Digitalization Promise and Its Limits

Over the past two decades, Building Information Modelling (BIM) has transformed the design and planning phases of construction projects. A BIM model is a 'digital representation of the physical and functional characteristics of a facility, providing a reliable basis for decisions throughout its life cycle from inception onwards' [1]. BIM tools facilitate clash detection, quantity take-off, energy simulation and schedule integration before any components are fabricated.

However, once the project moves from planning to execution, this promise breaks down: the digital model diverges from physical reality at the moment the first component is cast. The digital twin (DT) concept has emerged as the response - extending BIM from a static design artefact to a continuously synchronised representation of the physical asset. Yet DT adoption in construction remains limited by high implementation costs, data integration barriers, and the absence of standardised practices for real-time data capture and lifecycle management [2]. The four shortcomings described below explain why.

1.2 Why BIM Alone is Insufficient: Specific Shortcomings

Current BIM practice exhibits four interrelated shortcomings that constitute a genuine research gap rather than merely being limitations:

1. **The static snapshot problem:** BIM models represent design intent (Project Information Intent, PII), rather than the continuously evolving physical state (Project Status Information, PSI). Schlenger [3] distinguishes between PII, which is information about the planned future state, and PSI, which is information about the actual, realised state of the construction site. Without an automatic update mechanism for PSI, the BIM model becomes increasingly outdated from the moment construction begins.

2. **Absence of real-time physical linkage:** Although a BIM model assigns each element a globally unique identifier (IFC GUID), it contains no mechanism to bind that identifier to a physical artefact in the real world. For example, a precast concrete panel has a GUID in the model, but the model cannot autonomously detect whether the panel has been cast, transported, damaged in transit or installed [4], [5].

3. **Information silo fragmentation:** In practice, the different phases of a construction project tend to use incompatible data systems. For example, precast manufacturers maintain their own production databases, contractors use scheduling software, and facility managers operate CAFM systems. As none of these systems are compatible with the BIM model, information silos are created between lifecycle phases [6], [7].

4. **Missing provenance and audit trail:** When a defect is discovered during servicing, it is crucial to be able to trace the entire history of the component, from mix design through curing, transportation, and installation [4]. Conventional databases that overwrite the current state cannot reconstruct this history.

Together, these four shortcomings constitute a gap that cannot be resolved by improving authoring software or introducing more BIM uses within the same paradigm. They require a fundamentally different data architecture: one that connects physical objects to their digital representations in real time, retains full provenance, and spans all lifecycle phases.

This leads to the central research question: How can passive RFID, a dual EPC–IFC GUID identifier binding, and an event-sourced Common Data Environment be combined into a unified framework that provides real-time physical–digital linkage, full lifecycle provenance, and cross-domain extensibility for construction projects?

2 Background and State of the Art

2.1 Digital Twin: From Concept to Construction

The concept of the digital twin was first articulated by Michael Grieves in an academic presentation in 2002, although the term itself was coined by Grieves and Vickers in 2017. Their foundational model identifies three essential components: the physical product; its virtual representation; and a data connection that enables bidirectional information flow [3], [8]. This model is well-established in the manufacturing sector. In construction, however, the transient, site-specific and multi-stakeholder nature of projects has slowed its adoption.

Digital twins in the built environment are cyber-physical systems that can accurately track the behaviour of built assets and represent all relevant processes during the design, construction and operation stages, requiring seamless two-way information flow between the real and virtual realms. Building Information Modelling (BIM) alone does not constitute a digital twin: while BIM captures design intent, a digital twin requires continuous real-time synchronisation. Current BIM practice is mostly confined to the design and planning phases, functioning as a prototype of an operational digital twin [3]. Rüppel and Gehring [9] propose a digital construction logistics twin that fuses BIM, bill-of-quantities data, and supplier telemetry to provide real-time material tracking – demonstrating both the potential and the current limitations of BIM-centric data integration on active construction sites.

2.2 RFID Technology in Construction

Radio frequency identification (RFID) is a wireless communication method that consists of tags, readers and a back-end system. Tags may be active (battery-powered), semi-passive or passive (no battery). Passive ultra-high frequency (UHF) tags operating in the 866–956 megahertz (MHz) range are considered optimal for construction logistics due to their longer read range compared to high frequency (HF), the absence of a battery (making them maintenance-free with a long service life), and their decreasing unit cost [10], [11].

However, the key technical constraint is signal attenuation: when embedded in concrete, UHF tags experience a reduction in read range of up to 90% due to absorption by the concrete and interference from the reinforcing steel [5], [[10]. This requires careful tag placement, typically near a surface or attached to rebar before pouring, and the selection of tag models optimised for embedded use.

2.3 RFID – BIM Integration

Initial research by Patton, Akinci and Ergen [4] identified radio-frequency identification (RFID) as a potential technology for managing the lifecycle of precast concrete, recognising that manufacturers are liable for 25 years after installation and that tracing defects requires a full component history. Motamedi and Hammad [6] then proposed the first systematic framework for the lifecycle management of facility components using RFID and BIM. This work established the conceptual link between the IFC standard and RFID identifiers, and laid the groundwork for cross-phase tracking frameworks.

Subsequent work has broadened the scope. For example, Chang and Cheng [12] demonstrated RFID-BIM integration for open-building lifecycle management, covering the repetitive assembly and disassembly of modular components. Ikonen et al. [10] implemented an information system for concrete element supply chains, importing initial data from BIM and using RFID events to update component status in real time. This system enables two-way communication with the BIM model for visualising progress. Jiang, Ma and Shang [13] visualised component status in prefabricated concrete buildings by writing the model ID of each component into the RFID tag, enabling a one-to-one correspondence between the tag and the BIM element.

A systematic review by Lopes and Turkan [14] identifies the current state of the art. The motivations for integrating RFID and BIM include improving efficiency, enabling traceability and facilitating site coordination. However, relatively few studies position sustainability or circularity as core goals. The review reveals 'a gap between the potential of these technologies to support the circular economy and the way they are currently deployed and framed'.

2.4 Open Standards: ISO 16739, ISO 19650, and GS1 EPC

The Industry Foundation Classes (IFC) ISO 16739 standard, developed by buildingSMART International, is an open, non-proprietary data model that enables interoperability throughout the construction lifecycle. The IFC standard captures the object-oriented representation of a building and all its components, including globally unique identifiers (GUIDs) for every element. The ISO 19650 series establishes the Common Data Environment (CDE) as the central information hub and defines the principles and processes of information management in BIM-based projects, distinguishing four information management states: Work in Progress, Shared, Published and Archived [15].

Open standards are fundamental: using proprietary data formats would tie the framework to specific software vendors, prevent information exchange between the many stakeholders in a construction project and compromise the long-term accessibility of lifecycle data. The IFC standard 'has matured as a BIM standard in supporting and facilitating interoperability across the various phases of the construction lifecycle' [6]. The GUID structure in IFC provides the technical basis for persistent, software-independent component identity, which is the precondition for any cross-phase tracking system.

Three further properties make open standards non-negotiable for this framework: (1) vendor independence - IFC-conformant tools from any supplier can read and write component data without licence dependencies [16]; (2) long-term accessibility - buildings outlive software products by decades, and only open formats can guarantee future readability; and (3) cross-phase interoperability - a common data language enables seamless handover between manufacturers, contractors, and facility managers without error-prone format translation.

3 Research Methodology

3.1 Design Science Research Approach

This research project adopts the Design Science Research (DSR) methodology, as formalised by Hevner and Chatterjee [17]. This methodology is particularly well-suited to projects where the primary contribution is an artefact. In this case, the artefacts are the unified RFID-BIM framework, the event-driven CDE architecture, and the EPC–IFC GUID binding mechanism. The DSR process involves four iterative phases: problem identification, design, demonstration and evaluation. The structure of this paper directly corresponds to these phases: the research gap identified in Section 1 motivates the design of the framework in Sections 4 and 5, the INNOTRACE prototype and the ModuLeiT field deployment demonstrate the framework, and it is evaluated through simulated project scenarios and expert review [18].

3.2 Domain Modelling via Event Storming

The software architecture of the framework was derived from the construction domain through a structured Event Storming workshop process [18]. Event Storming, as described by Vernon [19], is a collaborative modelling technique in which domain experts and developers identify all meaningful domain events –facts that have occurred and are relevant to the business – before deriving the system structure from them. Applied to the precast concrete lifecycle, this process identified six lifecycle phases and 37 domain events spanning production, logistics, quality assurance and installation. Five automated domain policies were also identified, which trigger consequential events without human intervention — for example, a failed inspection automatically raises an ACTION_REQUIRED alert.

From the event catalogue, ten bounded contexts were derived using Domain-Driven Design (DDD) principles [19]: Component Tracking (the core domain), Supply Chain Events, Quality Assurance, Spatial Model, User Notification, EPC Registry, IFC Synchronisation, Reporting, Access Control, and Navigation. Each context owns its data and exposes well-defined APIs, ensuring that a change in one module does not propagate unintended side effects to others. The lifecycle of each component is governed by a formal state machine with six primary states plus an ACTION_REQUIRED exception state that overrides the primary state when a quality or logistics event demands intervention. Figure 1 illustrates this state machine.

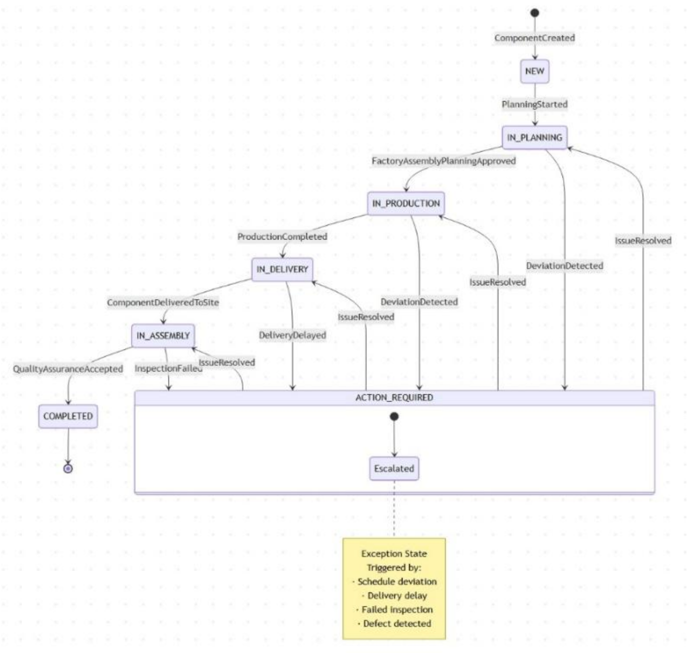

Figure 1 Component lifecycle state machine.

3.3 Event Sourcing and CQRS as the Persistence Strategy

Rather than storing the current state of a component in a relational database that is overwritten with each update, the framework adopts event sourcing as its persistence strategy [20]. In event sourcing, every state transition is recorded as an immutable, timestamped event appended to a persistent log –the event store. The current state is never stored directly; instead, it is derived on demand by replaying the relevant event sequence. This architectural choice is what makes full provenance possible: the entire history of any component, from mould preparation through decommissioning, is always recoverable by replaying its event stream up to any chosen point in time.

The Command Query Responsibility Segregation (CQRS) pattern complements event sourcing by separating write operations (commands that produce events) from read operations (queries against materialised read-model projections) [20]. This separation enables each side to be optimised independently: commands are validated against domain invariants and appended atomically; read models are denormalised projections rebuilt asynchronously from the event stream. For a construction lifecycle system with heterogeneous readers –factory scanners, logistics gates, site tablets, and navigation devices – CQRS ensures that high-frequency write operations from RFID readers do not contend with the complex queries required by project dashboards and audit reports. The INNOTRACE prototype, developed as part of this research [18], demonstrated that this architecture correctly parses IFC geometries, maintains event store consistency under concurrent scan inputs, and accurately reconstructs component history for defect investigation scenarios.

4 Framework Architecture

The framework comprises three parts that share a common architectural foundation - the EPC–IFC GUID dual-identifier binding - while addressing distinct problem domains. Part A uses this binding for construction component lifecycle tracking, with an event-sourced CDE as its data layer (Part B). Part C applies the same binding mechanism to accessible indoor navigation. The three parts are presented in this logical order: the identifier scheme first, then the event-driven data environment it feeds, then the navigation extension that reuses both.

4.1 Part A: EPC-IFC GUID Dual Identifier Scheme

The core technical innovation of Part A is the dual-identifier binding between the GS1 Electronic Product Code (EPC), which is stored on an RFID tag, and the IFC GUID, which is assigned to a BIM element. This relationship is described as a 'dual-identifier scheme' rather than a simple lookup table because neither identifier is subordinate to the other. They exist in different identity spaces and serve different systems.

- The EPC (as defined in GS1 TDS 2.3) is a globally unique identifier of physical objects encoded in the tag's memory bank. Its URI structure guarantees its uniqueness worldwide across all types of physical objects and applications [21]. The EPC is scanned by field readers and appears in RFID event streams.
- The IFC GUID is a 128-bit identifier that is assigned when the model is created and is persistently associated with a BIM element, remaining so across software and file format boundaries. It serves as the object's address in the digital model and in all BIM-based workflows (IFC 4.3 specification).

This binding is established when the tag is assigned (usually during manufacturing or delivery), by recording the pair (EPC URI, IFC GUID) in a persistent registry. From that point onwards, every RFID scan event carries the EPC, which the registry then resolves to the IFC GUID. This enables the BIM system to update the element's status without human intervention. This dual-identification system means that the RFID and BIM infrastructures can be maintained and replaced independently – a property that a single merged identifier would not provide.

In the INNOTRACE prototype, the binding persisted as the domain event 'EPCIntegratedIntoComponent', which records the EPC URI, IFC GUID, timestamp, operator identifier and GPS coordinates of the tagging location. This means that the binding itself is a first-class auditable fact in the event log rather than a configuration entry that could be silently overwritten.

4.2 Part B: Event-Driven Common Data Environment

4.2.1 Why an Append-Only Event Log?

Applying event sourcing to construction (as described in Section 3.3) yields four concrete operational benefits:

1. Full audit trail: Every scan, inspection, delivery and status change is permanently recorded alongside a timestamp, the identity of the person performing the action and their location. This satisfies the legal and warranty requirements of precast concrete manufacturers.
2. Temporal reconstruction: The state of any component at a previous point in time can be reconstructed by replaying the event log up to that timestamp, enabling retrospective defect investigation.
3. Conflict-free multi-party updates: Multiple field readers and stakeholders can append events concurrently without locking or overwriting each other's data.
4. Digital twin synchronisation: The event log is the single authoritative record of physical reality, whereas the BIM model is a derived projection, not the master record.

4.2.2 ISO 19650 CDE vs. Event-Driven CDE

The ISO 19650 CDE is essentially a document-centric workflow system. It defines status codes ('Work in Progress', 'Shared', 'Published' and 'Archived'), roles and approval processes for exchanging information containers, primarily documents and model files, between project parties [22], [23]. The CDE, as defined in ISO 19650, is designed for the periodic, structured exchange of artefacts that have been reviewed by humans.

The event-driven CDE proposed in this framework, however, is event-centric and operates in near real-time. Rather than routing information containers through approval workflows, it ingests streams of RFID scan events, IoT sensor readings and human inspection records as immutable facts. The event log functions as the system's 'single source of truth' with a granularity finer than that achievable by any document-based system. This distinction mirrors the difference between CDE maturity stages 2 (file-based, structured data) and 3 (query-based, federated, linked data), as described by Jaskuła [24].

4.2.3 Domain-Driven Design Influence

The ten bounded contexts identified in Section 3.2 (e.g. Component Tracking, Supply Chain Events, Spatial Model) each own their data and expose defined APIs. For construction software this yields three structural advantages:

1. The code vocabulary mirrors the domain vocabulary of construction engineers, reducing misunderstandings between developers and domain experts.
2. Bounded contexts limit the blast radius of changes – a modification to the supply chain module does not break the spatial model.
3. The separation of aggregate roots (e.g. Component, ScanEvent) from read-model projections (e.g. ComponentStatusView) supports the CQRS pattern, which enables event sourcing at scale [3].

5 Application Domains

5.1 Part A in Practice: Precast Concrete Lifecycle Tracking

Precast concrete provides an ideal testing ground for the framework because its components have clearly defined lifecycle phases that are suitable for RFID scanning.
(1) mould preparation and rebar placement;
(2) concrete pouring and curing;
(3) quality inspection at the factory;
(4) storage and inventory management;
(5) transport to the site;
(6) installation and alignment verification;
(7) Post-installation inspection;
(8) Long-term facility management and end-of-life.

The RFID tag is embedded in phase 1, attached to the rebar before the concrete is poured. As noted in Section 2.2, signal attenuation in concrete reduces the read range to 10–20 cm [5], requiring surface-proximate placement or tags optimised for embedded use [10].
Phase (3) - factory inspection - is the most critical from a quality assurance perspective. This is when dimensional compliance, reinforcement placement and mix quality are verified before the component leaves the manufacturer's control. Statutory quality assurance obligations mean it is essential that the inspection outcome - whether the component passes or fails, the remediation steps required, and the final approval - is recorded immutably at this stage. If the component is later found to be defective during service, the full factory inspection record can be replayed to determine whether the defect was present at manufacture (indicating a production fault), or arose subsequently (indicating a transport, installation or maintenance fault). Without this log, root-cause analysis would be guesswork.

Han et al. [25] and Lopes & Turkan [14] confirm that automated progress monitoring via RFID scanning at gates (factory exit, site entry and installation zone) reduces the burden of manual inspection and enables updates to the BIM model to be made dynamically and in near real-time. Gao et al. [26] present a BIM- and IoT-driven smart tracking system for precast construction, mapping the complex information flow between design intent and as-built status.

The viability of this lifecycle tracking approach was evaluated using the INNOTRACE prototype [18] in simulated project scenarios. The evaluation confirmed the correct parsing of IFC models, the consistent binding of EPC identifiers to IFC GUIDs, the atomic event store writes under concurrent scan inputs and the accurate temporal reconstruction of component history for the simulated defect investigation scenarios. Figure 2 shows the INNOTRACE project dashboard, which provides a single operator view by aggregating real-time component status, scan event history and IFC model synchronisation state.

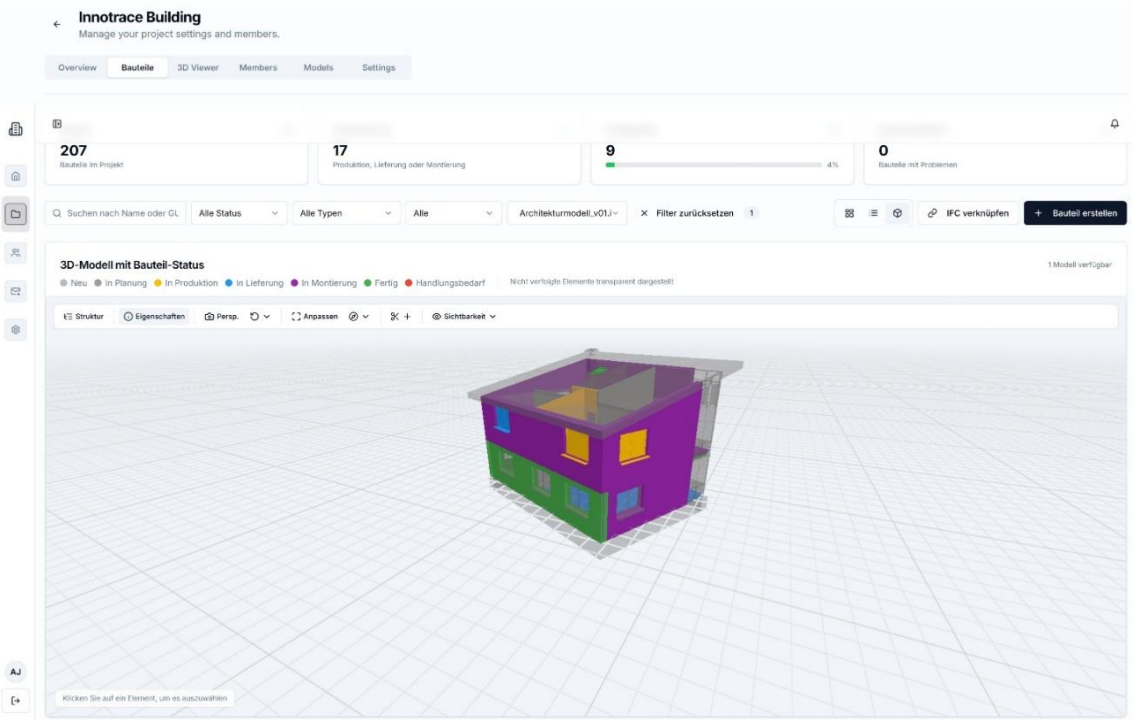

Figure 2 INNOTRACE CDE component tracking interface with colour-coded 3D BIM viewer. Lifecycle states are mapped to individual building elements in real time.

5.2 Part C: RFID-BIM for Accessible Indoor Navigation

Part C demonstrates the same RFID–BIM architecture in an entirely different domain: accessible indoor navigation for visually impaired and mobility-restricted users, developed within the ModuLeiT project [27]. Passive UHF RFID tags (860–960 MHz, ISO/IEC 18000-6) are integrated into carpet tiles as floor-embedded guidance indicators. Each tag is modelled in the BIM system as an `IfcBuildingElementProxy` element and assigned a unique serial number (UID) that functions as the EPC - bound to its corresponding IFC GUID via the same dual-identifier mechanism as Part A. A BIM-based turn-by-turn navigation app, connected via Bluetooth to a white cane carrying a UHF reader, resolves each scanned tag EPC to spatial context (room, accessible route, point of interest) from the IFC model and delivers audio and haptic output to the user. The system was validated in a practical field test (AP 8) at the Blindenzentrum (BliZ) of THM with approximately 30 blind and visually impaired students and staff. Participants evaluated tactile detectability of the floor tiles with the white cane, optical contrast perception, and the usability of the navigation app via a structured questionnaire. Long-term durability of the RFID-integrated carpet tiles was assessed using the Vettermann drum test (ISO 10361, DIN EN 1307) over 20,000 revolutions.

Architectural commonalities with Part A:

- Passive UHF RFID tags embedded in the built environment (in floor coverings rather than structural components) serve as fixed, maintenance-free reference points.
- Each tag carries an EPC linked to a BIM element (a spatial zone or waypoint in the IFC model) via the same EPC – IFC GUID binding mechanism.
- A portable reader device (the eGuiDev) scans the floor as the user walks, identifying the tag and resolving the IFC GUID to retrieve location and navigation context from the BIM model.
- The BIM model functions as the single source of truth for spatial information.

Fundamental differences:

- The data consumed is spatial context (e.g. room name, accessible route, obstacle information and exit directions), rather than component lifecycle status.
- The consumer of the data is an end user who requires real-time, multisensory feedback (audio and haptic), not a project manager who is reviewing a dashboard.
- The update frequency is continuous (step-by-step navigation) rather than event-driven (scanning at logistics checkpoints).
- The referenced IFC elements are spaces and routes (IfcSpace, IndoorGML topology) rather than building components (IfcBeam, IfcSlab).

The need for indoor navigation has been recognised: 75% of the world's population live in cities and humans spend around 90% of their time indoors [28]. The theoretical foundation for Part C is provided by BIM-based path planning considering obstacles [29] and two-level routing approaches using IFC semantics [28].

Could the Part B CDE support Part C?

In principle, yes, but significant adaptations would be required. The event-driven CDE of Part B would need to:

1. model navigation events (e.g. tag scans during pedestrian travel) as first-class domain events, distinct from logistics scan events;
2. expose a low-latency, real-time query API for the eGuiDev, since navigation requires a response time of less than a second;
3. manage IFC spatial elements (rooms, corridors and exits) alongside building components; and
4. incorporate accessibility attributes (e.g. ramp grades, door widths, tactile indicator coverage) as IFC properties linked to events. The core event log and the EPC–IFC GUID registry would be reused without modification, and the bounded contexts and read-model projections would be extended to include a new Navigation domain. This demonstrates the extensibility property of the DDD architecture.

6 Evaluation

6.1 Technical Risks and Limitations

The framework, as described, carries the following acknowledged technical risks:

1. RFID signal attenuation in concrete (the most significant factor for real-world deployment). A 90% reduction in read range occurs when tags are embedded in concrete [5], meaning that standard UHF tags may be unreliable in fully encapsulated conditions. Specialised embedded tags, careful placement protocols and reader antenna optimisation are required. For existing structures, retroactive tagging is impractical.
2. EPC–IFC GUID registry consistency: The dual- identifier binding is only as reliable as the registry that maintains it. If a tag is replaced or damaged, or if the BIM model is revised (creating a new IFC GUID for the same physical element), the binding becomes inconsistent. Registry

governance and versioning protocols are necessary, but are not specified enough in the current literature.

3. Event log scalability under high event volumes: An append-only log capturing every RFID scan event across a large construction project involving hundreds of readers and thousands of components accumulates data at high velocity. Event sourcing at this scale requires careful partitioning, efficient projection rebuilds and effective storage management strategies.
4. Multi-stakeholder trust and data governance: Different project parties (e.g. manufacturer, contractor, subcontractor and client) may distrust event data written by others [24].
5. For Part C specifically: The navigation system depends on the continued presence and legibility of floor-embedded tags. Renovation work, replacing the floor, or even using heavy cleaning equipment could displace or damage the tags, breaking the navigation network.

The most significant risk for real-world deployment is item (1), the problem of embedding RFID, because it affects the physical basis of the entire Part A use case and cannot be solved purely through software.

6.2 Scalability Claims and Weaknesses

The paper argues for scalability on three grounds:

(a) the event log architecture scales horizontally (events can be partitioned by project or component range);
(b) IFC GUIDs can be used for any number of building elements; and
(c) the EPC standard supports countless unique identifiers globally [21].

However, potential weaknesses include:

(i) the computational cost of replaying long event logs to reconstruct the current state degrades as projects age;
(ii) dependency on reliable field connectivity (RFID readers must transmit to a backend in areas with poor network coverage, which is a significant constraint in remote or underground sites); and
(iii) the organisational scalability problem. The framework requires all supply chain actors to use compatible readers and transmit events in a standardised format. This presents an adoption challenge that technology alone cannot solve [14].

Nguyen and Adhikari [2] confirm this broader pattern: digital twin adoption in construction is limited not only by technological immaturity, but also by high implementation costs and data integration challenges.

6.3 Field Validation: Three Key Variables for Part A

The three variables a field validation should prioritise are:

1. The tag read success rate across lifecycle phases, measured as the percentage of expected scan events successfully captured. This directly quantifies the reliability of the physical–digital linkage under real site conditions. A low rate at any phase (e.g. after pouring concrete) would indicate where the framework is breaking down and where additional engineering is needed (e.g. tag placement or antenna design).
2. The temporal lag between a physical event and a BIM model update (i.e. the time from an RFID scan to a BIM element status change, measured in seconds or minutes). This measures the quality of real-time synchronisation – the defining characteristic that distinguishes a digital twin from a periodic snapshot. For schedule management, a lag exceeding the project's decision cycle (typically a few hours) would render the system operationally ineffective.

3. Accuracy of defect root-cause attribution (the proportion of defect investigations in which the event log correctly identifies the phase and responsible party): This validates the framework's provenance and audit trail claims. Ground-truth data from deliberate test incidents (e.g. a controlled defect introduced at a specific lifecycle phase) is required and is then compared against the event log's reconstruction of events.

7 Discussion and Conclusion

The three parts of the framework share a single mechanism — the EPC–IFC GUID registry described in Section 4.1 — which means that engineering improvements in one use case (e.g. better embedded tag performance, more robust registry governance, richer IFC property sets) transfer directly to the others. This synergistic property is absent from prior single-use RFID-BIM integrations and constitutes the framework's principal scientific contribution.

The framework addresses the research gap identified in Section 1.2 by converting BIM from a static design artefact into an operationally synchronised digital twin, providing the missing physical-to-digital feedback loop in the process. Unlike previous studies [6], [13], [25], which address individual lifecycle phases in isolation, the event log architecture maintains continuity across all phases under a single data model.

A key distinction between this framework and prior RFID-BIM integrations lies in the treatment of component identity and state. Earlier systems, including those reviewed by Lopes and Turkan [14] and Han et al. [25], store component status as an overwritable record: each RFID scan updates a status field, discarding the previous value. By contrast, this framework treats the EPC–IFC GUID binding as a first-class domain event and records every subsequent state change as an immutable fact in the event log. The architectural implication is significant: in the earlier paradigm, provenance must be reconstructed from backup archives or access logs, which are typically incomplete; in the event-sourced paradigm, provenance is the primary artefact and the current state is a derived projection. The INNOTRACE prototype confirmed this distinction in practice [18].

This paper presents a unified RFID-BIM framework for construction component lifecycle tracking, lifecycle traceability, and accessible indoor navigation. The four shortcomings identified in Section 1.2 are addressed through a dual-identifier EPC–IFC GUID binding scheme, an append-only event-sourced CDE, and a Domain-Driven Design architecture.

The precast concrete use case demonstrates lifecycle tracking across eight phases. From a provenance perspective, quality assurance at the factory inspection phase is identified as the most critical. The indoor navigation use case shows how the framework can be extended to accessible wayfinding by sharing the RFID–IFC binding mechanism, despite having fundamentally different data semantics and real-time requirements.

The event-driven CDE extends the ISO 19650 CDE concept from document-centric workflow management to near real-time physical - digital synchronisation - the architectural step required to close the gap identified in Section 1.2. Future work should prioritise optimised tag embedding protocols for concrete structures, and organisational adoption frameworks that enable multi-CDE trust in shared event data.

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