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NOT ALL LINKS ARE EQUAL: LINK EXPRESSIVENESS AND DISCOURSE SCOPE IN BIM-GIS INTEGRATION

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Abstract

Linking is increasingly adopted in BIM-GIS integration to connect heterogeneous datasets without forcing full schema conversion. Application scenarios are the linked transfer e.g. of BIM and environmental data for permitting or the linking segmented 3D point clouds. However, links are often treated as purely technical connectors, while their interpretability remains implicit. We distinguish closed, shared, and open discourse space and analyze how common link paradigms support the ability to reconstruct sender intention. We also discuss practical trade-offs regarding implementation effort, tooling, and adoption. This paper is intended to help readers select appropriate linking mechanisms depending on BIM-GIS integration goals.

Introduction

Linking has become a central strategy in BIM-GIS integration, particularly where heterogeneous data structures, scales, and modeling assumptions make full schema unification impractical. A linked approach relies on establishing relationships between heterogeneous datasets instead of fully unifying their underlying data models or use naturally imperfect format conversions (Eriksson et al., 2020; Korkmaz and Basaraner, 2024). Instead of converting data between formats such as IFC and CityGML, many integration approaches rely on explicit or implicit links to establish relationships between models, elements, or representations (Liu et al., 2017; Guyo et al., 2021; Beck et al., 2020). If we assume a simple communication model involving a sender and a receiver, the sender creates both the application models and BIM/GIS links. After the data transfer, the receiver must identify the relevant parts of the application models and the intended meaning of the links. The receiving software might e.g. be a Common Data Environment, BIM-coordination software or a web-GIS.

Where the semantic intent behind a link cannot be recovered, e.g., which coordinate transformation was applied or what part-whole relationship was assumed, the receiving system either propagates a silent misinterpretation or must recompute the original analysis (if known) from scratch. The receiver cannot determine whether their interpretation corresponds to the one under which the link was created.

Semantic mismatches between established standards reflect not only technical modeling differences but fundamentally divergent domain perspectives: GIS adopts a global, landscape-oriented view prioritizing spatial relationships and regional context, while BIM employs a detailed, object-centric perspective focused on individual building components (Kolbe and Donaubauer, 2021; Tan et al., 2023; Sani et al., 2022).

An integration by linking both domains must therefore consider different semantic depths and requires flexible integration approaches. In this regard, Mohammed et al. (2026) propose multiple levels of BIM-GIS integration quality and suggest that higher integration levels rely on more expressive linking mechanisms, while also highlighting the need for clearer methodological guidance and standardization.

Despite their importance, links are often treated as technical implementation details or a matter of computational efficiency (Napps et al., 2026). As a result, assumptions about relationship semantics, scope of validity, and interpretability remain implicit, limiting transparency, reproducibility, and reuse of integration results. This is particularly problematic in BIM-GIS scenarios, where relationships may encode non-trivial analytical decisions - such as georeferencing strategies, spatial abstractions, or part-whole interpretations - that cannot be reconstructed from geometry or attributes alone.

Background and Research Questions

Previous work by Krischler et al. (2025) introduced and operationalized four link types - geospatial, geometrical, topological, and mereological - to support context-sensitive BIM-GIS integration within container-based exchange models, compliant to DIN 18290 (Multimodel-Container). The link types do not prescribe a specific technology or schema, but describe what kind of relationship is being expressed and which assumptions are made explicit. The Multimodel-schema was chosen here, as it is successfully implemented and used in (German) construction software for tendering, awarding contracts, and billing.

Geospatial links explicitly relate datasets through their geographic positioning by defining a common spatial reference or transformation parameters, enabling consistent co-registration across BIM and GIS models.

Geometrical links associate datasets via auxiliary (proxy) geometric representations, such as footprints or bounding volumes, to reference spatial subspaces where no shared identifiers or semantic alignment exist. **Topological links** describe spatial relationships such as containment, intersection, or adjacency independently of exact geometry, allowing robust connections between entities of different dimensionality. **Mereological links** capture part-whole relationships between heterogeneous representations, enabling the association of datasets that describe overlapping or corresponding parts of the same real-world entity at different levels of detail. While this work demonstrated how expressive links can be formalized, it also revealed that identical link structures can have very different meanings depending on where and how they are interpreted.

This paper takes a step back and asks: why do link modeling approaches differ so fundamentally in their expressive power and interpretability? We argue that the key, yet underexplored factor, is the discourse space in which links operate. By making discourse scope explicit, we aim to clarify the relationship between link modeling paradigms, semantic expressiveness, and practical applicability.

The paper addresses the following research questions:

RQ1: How do commonly used link modeling approaches in BIM-GIS integration differ in their level of link expressiveness for geospatial, geometrical, topological, and mereological links?

RQ2: How does link expressiveness influence the ability to reconstruct sender intention and semantic context?

RQ3: What practical requirements and trade-offs are associated with realizing different levels of link expressiveness in BIM-GIS workflows?

Analytical Framework

This paper follows an analytical and comparative research approach. It first introduces discourse space as an analytical framework to distinguish between closed (local), shared, and open (global) semantic contexts in which links between BIM and GIS data are created and interpreted.

Building on this framework, commonly used link modeling approaches from research, standardization, and practice are analyzed comparatively with respect to their level of link expressiveness. Existing approaches are examined and positioned within the discourse space framework, allowing their underlying assumptions, expressive capabilities, and limitations to be discussed systematically.

The analysis further examines how different levels of link expressiveness affect the reconstruction of sender intention and semantic context, and concludes with a discussion on practical requirements and trade-offs for realizing expressive links in BIM-GIS workflows.

Discourse Spaces in BIM-GIS Integration

We define discourse space as the semantic scope within which the meaning of a link is interpretable without additional external knowledge. Prior work implicitly reflects different semantic depth of link interpretation (Borrmann et al., 2021), ranging from schema-internal relationships (e.g. through Application Domain Extensions) to ontology-grounded semantic links (Beck, 2023; Hagedorn et al., 2023; Davar Panah, 2025; Schilling and Clemen, 2023). However, these scopes are rarely made explicit as design decision. Three discourse spaces are distinguished within this paper (Figure 1). The primary formal criterion for our "discourse spaces" is where (!) the link schema is located: in the application model (*closed*), in a standalone, use-case-specific link schema (*shared*), or in a formal, publicly accessible ontology in the sense of the Semantic Web (*open*), and whether the link is self-descriptive rather than just serving as a pointer. The W3 community describes "self-descriptive" data as a defined label, definition and comment within the representation itself without relying external documents for description (World Wide Web Consortium, 2014).

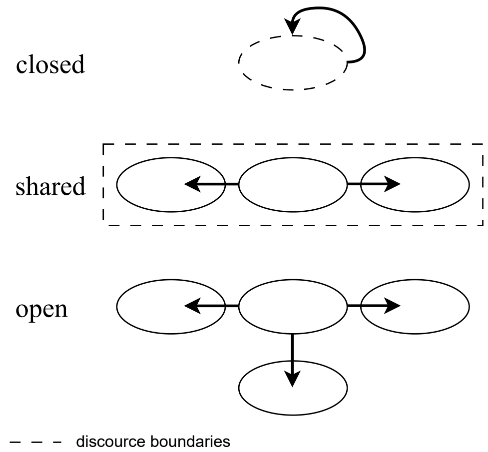

Figure 1: Link paradigms covering local, shared, and open contextual discourse.

Closed (Local) Discourse refers to links whose meaning is interpretable only within a single file, dataset, or schema. Semantics are implicit and depend on internal conventions, such as schema structure, attribute naming, or software-specific behavior. Interpretation requires knowledge of the originating data model, as no externalized semantic contract or self-descriptive semantic content exists within the link itself (e.g. a relational database schema).

Shared Discourse denotes a bounded semantic context established across multiple datasets within a project or integration setting (e.g. within information containers, where there is a semantic agreement on the linkage between datasets). Here, link meaning is self-descriptive and explicitly agreed upon through project conventions, container schemas, or link models, but remains valid only within that context.

Open (Global) Discourse describes links whose semantics are interpretable independently of a specific project and whose links are fully self-descriptive. Meaning is grounded in shared, publicly defined vocabularies or ontologies, typically using globally resolvable identifiers and interpretation does not rely on bilateral agreements (e.g. public ontologies following the FAIR-principles).

These discourse spaces are not mutually exclusive but rep-

Table 1: *Categories of Link Expressiveness and Their Impact on Intention Reconstruction*

Category	Low Expressiveness	High Expressiveness	Impact on RQ2
Direction	Non-directional	Explicitly directional	Clarifies information flow
Cardinality	Binary (1:1, 1:N)	N-ary, attributed	Preserves complex patterns
Architecture	Embedded	Reified with metadata	Enables rich context
Semantic Strength	Implicit/local	Standardized/global	Ensures consistent interpretation
Link Depth	Document-level	Attribute-level	Supports precise integration
ID Scope	Local	Global/persistent	Enables long-term validity

resent increasing degrees of semantic explicitness and external interpretability.

Link Expressiveness

In this paper, link expressiveness denotes the ability of a link representation to make relationship semantics explicit and machine-interpretable. This includes, but is not limited to:

- explicit relationship type and link directionality
- support for qualified and n-ary relations
- attachment of parameters and constraints
- explicit scope and validity context
- provenance and derivation metadata

Expressiveness is not inherently desirable in all cases as it usually introduces trade-offs in complexity, tooling and governance. The following sections analyze how expressiveness manifests across discourse spaces and link modeling paradigms.

Comparative Analysis of Link Expressiveness (RQ1)

This section presents a comparative analysis of commonly used link modeling approaches in BIM-GIS integration, examining how they differ in their ability to explicitly express geospatial, geometrical, topological, and mereological relationships. The analysis is structured along the previously introduced discourse spaces and positions existing approaches accordingly, thereby making their expressive capabilities and limitations directly comparable.

Closed Discourse: Schema-Inherent and Implicit Links

In closed (local) discourse, links are embedded within data models as references, foreign keys, or structural relationships. Common examples include relational database joins or GML XLinks. These mechanisms typically allow only minimal expressiveness: a link indicates that a relationship exists, but not what kind of relationship it is or why it was established.

Directionality, cardinality, and constraints are either implicit or fixed by the schema. For BIM-GIS integration, this limits expressiveness, particularly for geometrical and mereological (part-whole relationship) links, which often require additional parameters or contextual assumptions.

Local discourse links are easy to implement and widely supported, but they externalize semantic interpretation to documentation or human expertise. Figure 2 shows an exemplary relational database schema for buildings and parcels. The keys do not carry a self-explanatory semantic meaning. The link merely establishes a technical association whose interpretation depends entirely on understanding the specific schema design and naming conventions used by the database creators. Local discourse approaches exist primarily in everyday engineering practice. They are rarely represented in research, as published work focuses on more sophisticated approaches.

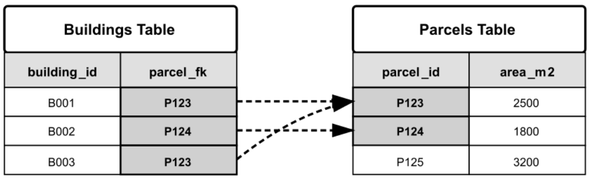

Figure 2: Example for local discourse linking.

Shared Discourse: Objectified Links in Integration Contexts

Shared discourse denotes a bounded semantic context established across multiple models within a project or integration setting. Within this scope, link meaning is fixed through explicit agreements, schemas, or link models that enable consistent interpretation among participating datasets, but remains valid only within that specific integration context.

Examples from research and standardization include information containers that intend to support the integration of heterogeneous information artifacts by organizing them in a common container while preserving their original representations. The ISO 21597 standard (Information Container for Linked Document Delivery, ICDD) introduces an explicit mechanism for representing relationships between documents by modeling links as independent, objectified entities. A similar approach, implemented in the DIN-standard 18290 (Multi-Model Container, MMC), enables links to carry types, metadata, and provenance information, supporting traceability and reproducibility in multi-model environments (Fuchs, 2015). Figure 3 shows an example link between a building model and a parcel in an MMC.

By separating information objects from their relationships, both standards establish a clear conceptual distinction between domain data and integration semantics. Links are

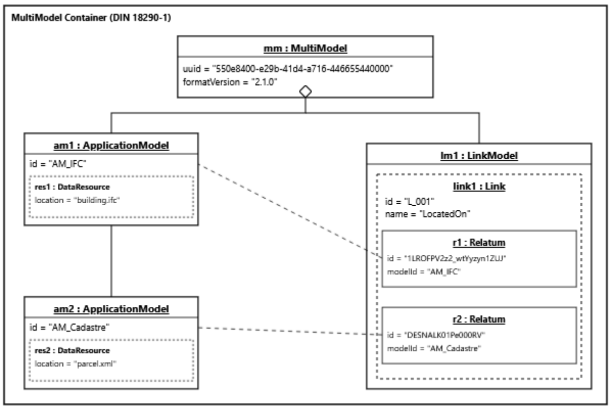

Figure 3: Example for shared discourse linking.

modeled as explicit objects with identifiers, types, and metadata, allowing richer expressiveness than schema-inherent references. In this discourse space, geospatial links can explicitly encode transformation parameters, geometrical links can reference spatial subsets, and topological or mereological relationships can be typed and directed. However, the semantics of these link types are typically defined by project agreements or domain-specific conventions rather than globally standardized vocabularies. Former research has focused on exploiting and extending both schemas to allow more semantic expressiveness, as by Hagedorn et al. (2023) or Krischler et al. (2025) and to include queries as external links.

Shared discourse enables consistent interpretation across participating tools and stakeholders, but links remain context-bound and require governance within the integration setting.

Open Discourse: Ontology- and Graph-Based Linking

Open discourse is realized through semantic web and graph-based approaches, where links are expressed using globally defined predicates and identifiers. Relationships are first-class entities that can be independently queried, extended, and reasoned over. However, the choice for a graph-based approach does not necessarily imply semantic expressiveness, but rather the quality of the used ontology (Akbarieh et al., 2025).

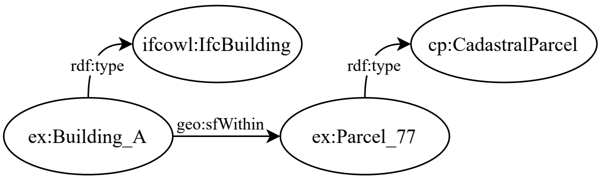

Figure 4: Example for open discourse linking.

For example, semantic web approaches that use URI-identified concepts from established ontologies, such as linking a building element to a concept from the Building Topology Ontology (BOT) (Rasmussen et al., 2020) using *bot:hasSpace*, or links expressed using standardized relationship types from domain-independent vocabularies like Dublin Core (*dcterms:isPartOf*) or schema.org (*schema:containedInPlace*) carry semantics that are globally documented and machine-interpretable without requiring knowledge of the specific BIM-GIS integration context. Works from Hbeich and Roxin (2020); Ji et al. (2024); Wang and Issa (2020) use ontological approaches to overcome integration challenges. Senthilvel (2024) presents a comprehensive approach for managing and validating semantically rich, objectified links using information containers and the BuildLinks Ontology, with a strong focus on provenance, link semantics, and standard compliance. This work allows for an open discourse as it relies on shared metadata understanding as well as semantic web technologies, even if using information containers as carrier.

This paradigm enables the highest degree of expressiveness for all four BIM-GIS link types, including qualified relations, temporal validity, and formal constraints. Mereological and topological semantics can be grounded in axiomatized vocabularies, enabling inference beyond explicitly stated links. The cost of this expressiveness lies in higher conceptual complexity, infrastructure requirements, and limited industry adoption.

Impact on Intention Reconstruction (RQ2)

Intention reconstruction refers to the ability of a receiving system to infer the semantic intent behind a link without reliance on external documentation or institutional memory. It operates on three levels: machine-readability of the link predicate, semantic reconstructability based on a shared vocabulary, and recovery of the originating analytical decision (why the link was created and under which assumptions it remains valid). The categories in Table 1 primarily address the first two levels, though all three matter in practice. Machine-readability suffices for visualization, semantic reconstructability is required for cross-organizational coordination, and intention recovery becomes critical where a link recomputed by a downstream actor may encode different assumptions than the sender intended. The link expressiveness as characterized in Table 1 influences directly whether reconstruction is possible.

Each category contributes differently to reconstruction, e.g. direction clarifies whether information flow can be traced unambiguously and cardinality determines whether complex integration patterns can be faithfully preserved or must be simplified. Architecture governs whether contextual metadata, such as provenance, derivation method, or quality indicators, can be attached to links. Semantic strength implies whether relationship meaning is locally implicit or grounded in standardized vocabularies interpretable without prior schema knowledge. Link depth affects the granularity at which relationships are expressed, from entire documents to individual attributes or geometric sub-elements. Finally, ID scope determines whether identifiers remain valid only within a single file or persist across projects and over time.

These categories do not operate independently. As Table 2 illustrates, concrete linking mechanisms combine them in characteristic patterns corresponding to the three discourse spaces. Mechanisms in schema-based closed discourse, such as `IFCExternalReference`, or `XLink`, typically exhibit unidirectional linking, limited cardinality, and isolated semantic strength, which severely constrains intention reconstruction to the mere existence of a relationship. In shared discourse, container-based mechanisms such as ICDD linksets and MMC links achieve higher semantic expressiveness through objectified link architecture, explicit directionality, m:n cardinality and standardized semantics within their container schemas, enabling receiving systems to recover relationship type, parameters, and provenance. In open discourse, OWL-based mechanisms combine all high-expressiveness characteristics from Table 1 with globally persistent identifiers, enabling full externalization of sender intention through publicly defined vocabularies that support independent interpretation, validation, and inference.

The following examples demonstrate linking in the three discourse spaces and discuss the respective implications for intention reconstruction.

Closed Discourse: Linking Buildings with Cadastral Parcels

The following Listing 1 shows an example within the IFC data model. A direct reference from an *IfcSite* entity to a cadastral parcel identifier retrieves land ownership information. The cardinality is typically 1:1, occasionally 1:n for connecting parcels. The IFC entity references external object *DESNALK01Pe000RV*, interpretable only within IFC's internal semantics. The link purpose is not explicit; intention must be inferred from metadata, file names, or workflow conventions. The link is unidirectional (cadastral file has no knowledge of this reference), yet well-established in practice.

In a closed discourse, only the information contained inside the schema can be reconstructed. Information outside of this, such as whether the target reference is an object or an attribute, and its meaning, cannot be reconstructed because, unlike the sender, the receiver does not know the schema of the link target. Similarly, the meaning of the link cannot be restored. The sender knows that a building is going to be constructed on the parcel of land to which the link is attached. However, the link does not convey this knowledge, so the recipient cannot understand it.

Listing 1: External link to another file in IFC

```
#33=IFCSITE('2PKyxyUDfD6wqc9p_1NzER',...);
#70=IFCDOCUMENTREFERENCE($,'
    DESNALK01Pe000RV',$,$,#72);
#71=IFCRELASSOCIATESDOCUMENT('1R7R97$
    uLAAv4wci$KGwn8',#18,$,$,(#33),#70);
#72=IFCDOCUMENTINFORMATION('d3L4G','1206
    _ACW.xml',$,'https://www.example.org/'
    ,$,$,$,$,$,$,$,$,$,'2025-11-25','
    2026-11-24',$,$);
```

Shared Discourse: Geospatial Linking for Unified Positioning

Listing 2 shows an example link within a container for the exchange of models between project partners. Information about the georeferencing is required to derive knowledge or understand the link. The link is part of the link model in a multi-model container with extended link types by Krischler et al. (2025). Links are stored in a separate file, but are only valid within the container context. In a shared discourse, the recipient can understand the meaning of a link because the link type and its attributes explicitly specify it. Receiving software can interpret the georeferencing intention based on the link type and additional information, such as inner and outer poses. However, the recipient can only interpret link information that is defined within the context. If the sender uses link information from outside the container context, the recipient cannot interpret it. In this example, the information can be used to transform the data into another coordinate system to visualize all geometrical models in the MMC together.

Listing 2: Extended geospatial link in MMC with additional information for georeferencing

```
<GLM:GeospatialLink type="pose">
  <GLM:GeospatialRelatum m="ContainerCRS"
      type="wktCrs"/>
  <GLM:GeospatialRelatum m="BuildingModel"
      type="innerPose" innerPoseId="#22"/>
  <GLM:outerPose>
    <GLM:Pose origin="
       411251.200,5654378.125,119.300"
       x-axis="-0.305,-0.952,0"
       z-axis="0,0,1" scale="1,1,1"/>
  </GLM:outerPose>
</GLM:GeospatialLink>
```

Open Discourse: Linking Building Parts with Point Clouds

The Listing 3 shows an example using ontologies for linking within a global context. A wall was scanned using laser scanning. The point cloud is linked as a 3D representation of the wall. The wall has a bounding box to get only the relevant part of the point cloud. The point cloud can be retrieved from a URL as a stream.

Listing 3: Link between wall and point cloud using ontologies

```
ex:Wall_23 a bot:Element;
  bot:has3DModel ex:PC_2 .
ex:PC_2 a geo:Feature;
  geo:hasGeometry ex:PC_BBox;
  dcterms:created "2025-09-07"^^xsd:date;
  dcterms:format "application/octet-stream";
  ex:url <https://pc.example.org/pc_2.laz> .
ex:PC_BBox a geo:Geometry;
  geo:asWKT "POLYGON Z((16.0 51.0 100.0,
  ...))"^^geo:wktLiteral .
```

Table 2: *Categorization of Linking Mechanisms in BIM-GIS Integration: The different Mechanism are assigned to Discourse Spaces (Disc.) for open, shared and closed*

Mechanism	Disc.	Direction	Card.	Archit.	Sem. Strength	Depth	ID Scope
Schema / Encoding-based							
IfcExternalReference	○	unidirectional	1:n	direct	isolated	Object	Global (URI)
GML XLink	○	unidirectional	1:n	direct	isolated (XML)	Object / Property	File / Global (URI)
CityJSON Extensions (lynks schema)	○	unidirectional	1:n	direct	generalized	Object / Property	File
Information Container-based							
MMC Links	◒	directional	m:n	objectified	standardized	File / Object	Container
ICDD Link-set	◒/●	bidirectional	m:n	objectified	standardized	File / Object	Container
Semantic Web-based							
OWL ObjectProperty	●	bidirectional	m:n	objectified	standardized	Object	Global (URI)

Discourse Spaces: ○ closed ◒ shared ● open

Metadata, like format and recording date, can be added for additional information, for example, with the Dublin Core terms ontology. In the open discourse, all information of the sender's intention can be reconstructed, because the meaning of each class and predicate of a link can be retrieved from the web. The sender is not limited to a certain amount of possible link information, like in schemas with a closed discourse.

Discussion: Practical Requirements and Trade-Offs (RQ3)

Different discourse spaces imply distinct practical trade-offs:

Closed discourse offers low implementation effort and broad tool support, but systematically shifts interpretation costs downstream. While well-suited to integration scenarios that are temporally bounded (e.g. a single project phase), organizationally contained (few stakeholders involved), and functionally routine (stable workflows and well-known schemas with little risk of unknown data sets that might necessitate extensions), closed discourse provides only limited potential for reuse of both the linked data and the links themselves. Because link semantics remain implicit and context-bound, the sender's intention, such as why a specific spatial, topological, or geometric relationship was established, cannot be reconstructed without gaps once the link is detached from its original environment. As a result, analytical decisions embedded in the linking process (e.g. spatial analyses, topological evaluations, or transformation derivations) are not reproducible by receiving systems and must be recomputed by downstream actors. This introduces redundancy and constrains the derivation of new knowledge, as inference requires substantial additional effort or manual interpretation, and it raises uncertainty about the dataset as a whole. The interpretation burden therefore remains with human expertise rather than being encoded in a machine-interpretable form, and the contextual knowledge that motivated linking decisions persists only implicitly, relying on external documentation, tacit assumptions, or institutional memory.

Shared discourse balances semantic expressiveness and practical feasibility, making it particularly approachable for industry-oriented BIM-GIS workflows. It enables integration without requiring full data homogenization or migration into a unified semantic model, allowing datasets to remain in their native formats while supporting explicit, structured linking. Integration can therefore be carried out within a bounded, project-specific environment in which a shared "project truth" is established, without generalizing relationships beyond the immediate context unless required. At the same time, reliance on open and standardized container and link models ensures that integration artifacts remain extensible and interpretable for future use. By externalizing sender intention through objectified link structures, such as geometric transformations, topological relations, derivation provenance, or quality indicators, shared discourse reduces redundancy in downstream processing. Analytical results produced during link creation, for example spatial or topological analyses, can be directly consumed by receiving software systems instead of being recomputed, which might lead to amortizing integration effort across multiple stakeholders and project phases. This moderate increase in architectural complexity is justified where recurring integration tasks, cross-organizational coordination, and quality assurance demand a controlled yet flexible semantic environment.

Open discourse offers the highest potential for long-term interoperability, reuse, and machine-supported reasoning, but it also introduces substantial practical barriers for current industry adoption. In contrast to closed or shared discourse, it typically presupposes that data sources are available in RDF, that suitable ontologies (T-boxes) are selected, aligned, or extended for project-specific purposes, and that instance data (A-boxes) are populated accordingly. This form of semantic engineering requires expertise, tooling, and organizational maturity that are not yet widely established in the AEC sector, resulting in significantly higher upfront effort and complexity. Where applied successfully, open discourse enables integration beyond project-specific contexts, allowing links to remain interpretable across organizational and institutional boundaries without bilateral semantic agreements. Typical application domains include legal traceability, long-term information retention for asset and infrastructure management, and the consolidation of heterogeneous models across administrative levels such as cities or regions. Moreover, open discourse enables automated reasoning and inference, supporting use cases such as consistency checking, completeness verification, and the derivation of implicit relationships. The investment in semantic infrastructure is therefore justified primarily when links are intended to function as persistent, reusable knowledge assets, enabling machine-accessible representations of sender intention, analytical provenance, and contextual validity constraints at scale.

Conclusion

This study examined the significance of links in BIM-GIS integration from the perspective of the discourse space. It demonstrated that the semantic value and practical utility of links are not determined solely by the technology, but by the context in which they arise and are interpreted. By introducing closed, shared, and open discourse as an analytical framework, the paper provided a systematic basis for comparing heterogeneous link modeling approaches and positioning existing research accordingly (RQ1). This perspective allows integration mechanisms to be evaluated not only by their formal capabilities, but by their suitability for different organizational, temporal, and functional contexts.

The analysis showed that link expressiveness directly affects the ability to reconstruct sender intention and semantic context (RQ2). In closed discourse, intent remains implicit and bound to local schemas or workflows, limiting reproducibility and reuse. Shared discourse partially externalizes intention through objectified links and contextual metadata, enabling consistent interpretation within bounded integration settings. Open discourse fully externalizes semantic intent through globally defined vocabularies and formalized relationships, enabling independent interpretation, validation, and inference beyond project-specific boundaries.

From a practical perspective (RQ3), the three discourse spaces represent distinct trade-offs rather than a linear maturity path. Closed discourse offers low entry barriers but high downstream interpretation costs; shared discourse provides an industry-viable balance between expressiveness and feasibility; and open discourse enables long-term interoperability and reasoning at the cost of substantial semantic infrastructure and expertise. Instead of advocating a single integration paradigm, this paper contributes decision support for selecting appropriate linking strategies based on required semantic depth, reuse potential, and organizational readiness.

A key limitation of this work concerns the validation of link quality and sender intention reconstruction. While the paper shows conceptually how discourse space influences the externalization of semantic intent, it does not define formal metrics to assess how accurately sender intention can be reconstructed by receiving systems. Sender intention is often tacit and context-dependent, making objective evaluation difficult without a clear ground truth. In practice, reconstruction can only be assessed indirectly, for example by evaluating whether links can be interpreted without auxiliary documentation or analytical results reproduced.

Outlook

Future work will focus on the development of an optimized link meta-model capable of operating coherently across closed, shared, and open discourse spaces while remaining compatible with existing standards and domain data models. A meta-model would define a technology-agnostic conceptual core for links, capturing relationship types, scope of validity, sender intention, and contextual metadata independently of their concrete encoding. This enables the same conceptual link to be instantiated in different technical serializations - such as schema-inherent references, container-based link models, or ontology-based representations - depending on project needs, supporting progressive semantic enrichment without forcing premature data homogenization. The proof of whether the choice of closed, shared, or open can be provided technically by ensuring that a receiving software system can interpret the links and use them for analysis and visualization. At the same time, it must be ensured that the chosen link approach is adopted by the software industry and regularly used in real BIM-GIS projects. In parallel, emerging AI-based methods offer promising opportunities to support the improvement of weakly structured or semantically inconsistent datasets and to generate links by automated methods. Potential applications include the normalization of naming conventions, the identification of implicit semantic patterns, and the assisted mapping of project-specific attributes to standardized vocabularies, as well as supporting validation and refinement of link models, e.g. by suggesting missing relations or highlighting inconsistencies.

AI Declaration

During the preparation of this work, the authors used AI tools for grammar and spelling check, paraphrase and reword. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

References

Akbarieh, A., Osadcha, I., Farghaly, K., Bosché, F., and Puust, R. (2025). Development of a Built Environment Ontology Lookup Service (BE-OLS) with a New Ontology Evaluation. In Proceedings of the 2025 European Conference on Computing in Construction.

Beck, F. (2023). Context-sensitive linking of heterogeneous information models from the building and the urban domain. PhD thesis, Technische Universität München.

Beck, F., Borrmann, A., and Kolbe, T. H. (2020). The need for a differentiation between heterogeneous information integration approaches in the field of BIM-GIS Integration: A literature review. In ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, volume VI-4-W1-2020.

Borrmann, A., Abualdenien, J., and Krijnen, T. (2021). Information containers providing deep linkage of drawings and bim models. In Proceedings of the CIB W78 - LDAC 2021, pages 823–835.

Davar Panah, S. A. (2025). Untersuchung einer Erweiterung des CityJSONStandards für die Verknüpfung heterogener Daten im Bauwesen. Master's thesis, Bauhaus-Universität Weimar, Weimar.

Eriksson, H., Johansson, T., Olsson, P.-O., Andersson, M., Engvall, J., Hast, I., and Harrie, L. (2020). Requirements, Development, and Evaluation of A National Building Standard—A Swedish Case Study. ISPRS International Journal of Geo-Information, 9(2).

Fuchs, S. (2015). Erschließung domänenübergreifender Informationsräume mit Multimodellen: = Access of cross-domain information spaces using multi-models. PhD thesis, TU Dresden, Dresden.

Guyo, E., Hartmann, T., and Ungureanu, L. (2021). Interoperability between BIM and GIS through open data standards: An overview of current literature. In Proceedings of the 9th Linked Data in Architecture and Construction Workshop.

Hagedorn, P., Senthilvel, M., Schevers, H., and Verhelst, L. (2023). Towards usable ICDD containers for ontology-driven data linking and link validation. In LDAC 2023 - Linked Data in Architecture and Construction.

Hbeich, E. and Roxin, A. (2020). Linking BIM and GIS standard ontologies with Linked Data. In Proceedings of the 8th Linked Data in Architecture and Construction Workshop, pages 126–135.

Ji, Y., Wang, Y., Wei, Y., Wang, J., and Yan, W. (2024). An Ontology-based Rule Mapping Approach for Integrating IFC and CityGML. Transactions in GIS.

Kolbe, T. H. and Donaubauer, A. (2021). Semantic 3D City Modeling and BIM. In Urban Informatics, pages 609–636. Singapore.

Korkmaz, Ö. and Basaraner, M. (2024). Ontology Based Integration of BIM and GIS for the Representation of Architectural, Structural and Functional Elements of Buildings. In Proceedings of the 31st International Workshop on Intelligent Computing in Engineering, pages 49–55.

Krischler, J., Schilling, S., Taraben, J., Sternal, M., Clemen, C., and Koch, C. (2025). A Standards-Based Approach to BIM-GIS Integration: Extending the Multi-Model Container Schema. In LDAC 2025 - Linked Data in Architecture and Construction.

Liu, X., Wang, X., Wright, G., Cheng, J. C., Li, X., and Liu, R. (2017). A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). ISPRS International Journal of Geo-Information, 6(2):53.

Mohammed, P., Behan, A., O'Sullivan, D., and McAuley, B. (2026). Level of Integration (LoInt): A Conceptual Framework for BIM-GIS Data Integration. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-4/W17-2025.

Napps, D., Winck, G., and König, M. (2026). Comparative evaluation of resource description framework and labeled property graphs for BIM-based early design decisions. Automation in Construction, 186:106854.

Rasmussen, M. H., Lefrançois, M., Schneider, G. F., and Pauwels, P. (2020). BOT: The Building Topology Ontology of the W3C Linked Building Data Group. Semantic Web, 12(1):143–161.

Sani, M. J., Musliman, I. A., and Abdul Rahman, A. (2022). IFC to CityGML Conversion Algorithm Based on Geometry and Semantic Mapping. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVI-4/W3-2021:287–293.

Schilling, S. and Clemen, C. (2023). TerrainTwin - Microservice Architecture for the Integration of Geodata (GIS) and Building Models (BIM) Using Link Models. Proceedings of the FIG Working Week.

Senthilvel, M. (2024). Linking and managing heterogeneous data using information containers : leveraging linked data for BIM Stage 3 CDEs. PhD thesis, RWTH Aachen University.

Tan, Y., Liang, Y., and Zhu, J. (2023). CityGML in the integration of BIM and the GIS: Challenges and opportunities. In Buildings, volume 13, page 1758.

Wang, N. and Issa, R. R. A. (2020). Ontology-based integration of BIM and GIS for indoor routing. In Construction Research Congress 2020: Computer Applications, pages 1010–1019.

World Wide Web Consortium (2014). Best Practices for Publishing Linked Data: W3C Working Group Note 09 January 2014.