Targeted Data Exchange for Efficient MEP Openings in BIM using IDS

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Abstract: Effective coordination of openings for Mechanical, Electrical, and Plumbing (MEP) systems within structural models remains a significant hurdle in modern Building Information Modeling (BIM) processes, frequently resulting in project inefficiencies and rework. Current practices rely on provisional placeholders lacking direct semantic and geometric linkage to host elements, necessitating tedious manual transformations. This paper introduces a demand-driven framework that automates the conversion of provisional voids into semantically structured IfcOpeningElement instances – complete with system associations, preserved design attributes, and precise spatial integration within host elements – thereby enhancing cross-disciplinary coordination and model fidelity in BIM workflows. Combining Information Delivery Specification (IDS) with advanced spatial reasoning capabilities facilitates precise extraction and mapping of non-geometric attributes and spatial characteristics. The methodology enhances the automated reconciliation of design intent across disciplines. This work contributes a concrete method for automating cross-disciplinary coordination of openings in BIM, improving the reliability of MEP-structure integration and reducing manual modeling overhead in data-rich, federated models.

Keywords: Building Information Modeling (BIM), MEP Coordination, Information Delivery Specification (IDS), Automated Workflows

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1 Introduction

Coordinating Mechanical, Electrical, and Plumbing (MEP) systems with structural elements represents a complex challenge in contemporary construction projects [1]. The precise planning and execution of openings and breakthroughs – where MEP services such as Heating, Ventilation, and Air Conditioning (HVAC) ducts, electrical conduits, and plumbing pipes must penetrate structural components like walls, slabs, and beams – has been a significant source of coordination difficulties, costly on-site modifications, and substantial project delays. Traditional coordination approaches, which rely heavily on 2D drawings and manual work across disciplines, have proven inadequate for managing the increasing complexity of modern building systems. [2], [3]

The advent of Building Information Modeling (BIM) has fundamentally transformed this reactive problem-solving paradigm into a proactive coordination approach [1], [4]. Model-based clash detection enables the automated identification of critical geometric overlaps between discipline-specific models during the planning phase, reducing the need for time-consuming coordination efforts in later project stages.

However, despite these advances, the coordination of MEP openings remains hindered by a fundamental modeling constraint: MEP engineers cannot directly create *IfcOpeningElements* – the designated BIM elements for physical openings – in their authoring environments because *IfcOpeningElements* require a host component, such as walls, slabs, or beams. These structural elements typically originate from architectural or structural models, so provisional placeholders for openings are added to the structural Industry Foundation Classes (IFC) models by architects or structural engineers. As a result, MEP engineers cannot create *IfcOpeningElements* themselves and must rely on these placeholders to represent openings in their models. To coordinate openings, MEP planners use *IfcBuildingElementProxy* elements with the *PredefinedType ProvisionForVoid* (*BEP-PV*) as volumetric placeholders to express their breakthrough requirements. These proxies communicate the intended size, shape, and position of openings and carry MEP-specific metadata such as system assignments, identification numbers, and dimensions. However, this approach introduces a critical limitation: they lack the semantic links to host elements required for downstream processing and implementation. This deficiency is a well-recognized problem within the industry. *BuildingSMART* has highlighted the need for automated workflows that convert *BEP-PV* placeholders into proper *IfcOpeningElements* while preserving critical attributes and ensuring correct spatial integration within host elements [5]. Existing solutions, as discussed in the following *State of the Art* section, rely on manual post-processing, which are misaligned with industry demands for efficient, selective, and software-neutral data exchange processes.

This paper addresses these limitations by proposing a framework for MEP opening coordination. Expanding our prior work [6], the proposed framework enables the automated transformation of *BEP-PV* proposals into properly coordinated *IfcOpeningElements*. Although the presented approach does not automate this process at the authoring software level, it offers a structured and reproducible framework that integrates the resulting openings within structural models with minimal manual effort. This contribution supports *buildingSMART's* automation goals and promotes more scalable, open, and interoperable BIM workflows across software environments.

2 State of the Art: IFC-Based Coordination of Openings

In current BIM workflows, openings and penetrations are coordinated by sharing domain models via IFC exports. Typically, MEP engineers insert *Provision for Void* placeholders in the architectural or structural model to reserve space for openings. In IFC, this is implemented using a *BEP-PV*. The IFC schema describes this usage explicitly: a building element proxy “as a provision for voids” represents a requested volume of space, which may later become an actual opening [7].

Such proxies carry a solid swept volume (matching or exceeding the thickness of the host element) and can be annotated with properties (via *Pset_BuildingElementProxyProvisionForVoid*) for shape, size, or system information. For example, an MEP duct might be represented by a cylindrical proxy with properties for diameter and required depth linked to a system ID in the property set. When imported into other platforms (e.g., structural BIM or clash-detection tools), the *BEP-PV* appears as a generic proxy object that flags a requested opening.

Ultimately, the architect or structural engineer must convert these placeholder volumes into real openings in the building elements. In IFC, this is done using *IfcOpeningElement* (or *IfcOpeningStandardCase* for prismatic holes) inserted into the host via an *IfcRelVoidsElement* link. An *IfcOpeningElement* "represents a void within any element that has a physical manifestation". It is assigned a *PredefinedType* of *OPENING* or *RECESS* and may carry its own property set (e.g., *Pset_OpeningElementCommon* for purpose, status, fire rating, etc.) [8].

In practice, however, this conversion is not automated: designers must create these openings manually. ArchiCAD, for example, imports *BEP-PV* proxies as generic Morph objects flagged as provisions for void; users must then manually convert each Morph object into an ArchiCAD opening. Only after this manual step does the element become an *IfcOpeningElement* tied to its host upon export. Revit requires a similar manual acceptance of the void request [9].

The handling of *BEP-PV* across common tools remains fragmented. ArchiCAD provides a "Convert Provision for Void" command but lacks full automation. Revit's IFC export includes *BEP-PV* elements, yet offers no native workflow for automatically updating openings. Tekla Structures can export voids as *IfcOpeningElement* or generic subtractions but does not interpret imported *BEP-PV* to generate openings. Coordination platforms like Navisworks or Solibri visualize *BEP-PV*, but do not translate them into actionable geometry.

Due to these limitations, current workflows remain predominantly supply driven. Teams exchange full IFC models to communicate opening requests, which introduces inefficiencies and increases the risk of errors. Semantic information, such as system assignments or dimensional properties, is often lost during manual reimplementation. BuildingSMART Germany explicitly calls for the "automated conversion of opening proposals (ProvisionForVoid) into real openings including automatic labeling and transfer of properties" [5].

In summary, IFC-based opening coordination today relies on *BEP-PV* proxies as placeholders and manual conversion to *IfcOpeningElement*s. Automation is minimal, and interoperability suffers due to redundant modeling efforts and semantic loss. There is a pressing need for improved tooling and structured, demand-driven workflows to bridge the gap between placeholder elements and semantically rich, host-integrated openings.

3 Methodology

Building on our earlier work [6], which introduced a *pull-based* workflow concept using Information Delivery Specification (IDS), this paper further develops and operationalizes the approach within a targeted application context for MEP opening coordination. Our methodology addresses the established coordination gap by extending the traditional IDS-driven *pull* approach with geometric reasoning capabilities, enabling the automated transformation of *BEP-PV* into semantically and geometrically compliant *IfcOpeningElements*.

The *pull-based* method enables information requesters to actively articulate data needs using IDS, which serve as transport containers and validation mechanisms for targeted data extraction, as elaborated in [6]. This demand-driven process ensures that only relevant information is retrieved and integrated, reducing coordination cycles and improving data quality across discipline-specific models. The IDS framework operates through two primary components: the *Applicability* criteria that establish the specification's scope by identifying relevant IFC entities and element types, and the *Requirements* that articulate specific data constraints, encompassing mandatory attributes, acceptable value ranges, and formatting standards. For our opening coordination workflow, IDS specifications define the semantic requirements for *BEP-PV* elements, including their classification, dimensional properties, system assignments, and identification parameters.

However, a critical limitation of IDS is its inherent inability to represent or process geometric data. While it excels at specifying semantic requirements, it cannot capture spatial characteristics essential for opening coordination, such as precise positioning, geometric relationships, and spatial intersections with host elements. To address this limitation, our methodology integrates a geometric feature extraction pipeline alongside the IDS-based semantic validation process. This dual-processing approach enables comprehensive handling of both semantic and spatial data requirements, bridging the gap between semantic specifications and geometric implementation. The geometrical analysis process extracts spatial characteristics from *BEP-PV* elements, including bounding box coordinates, centroid positions, and volumetric properties, while the IDS framework ensures semantic compliance and attribute preservation throughout the transformation process.

Figure 1 illustrates the conceptual framework contrasting the traditional push-based workflow, where information is actively sent from the provider to recipients without a specific request, with our proposed *pull-based* approach for automated *BEP-PV* to *IfcOpeningElement* transformation.

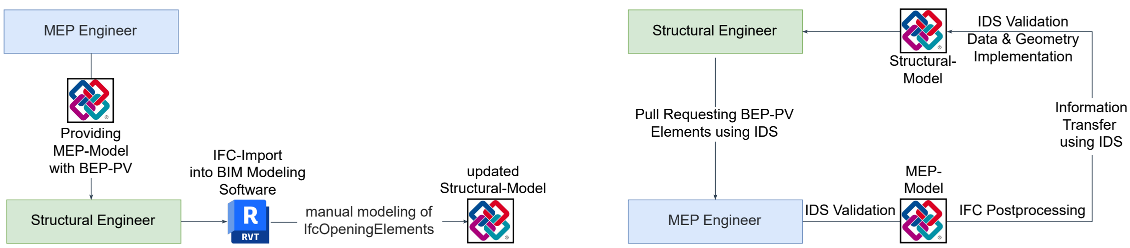

Figure 1: Comparison Push-based Approach (left) and Pull-based Approach (right)

The workflow operates through three sequential phases: semantic validation, geometric feature extraction, and spatial association. During the semantic validation phase, IDS specifications are applied to verify that *BEP-PV* elements meet predefined requirements for attributes, classifications, and property assignments. This validation ensures data quality and completeness before proceeding to geometric processing, preventing downstream errors and maintaining semantic integrity throughout the transformation process.

The geometric feature extraction phase employs computational geometry algorithms to analyze the spatial properties of validated *BEP-PV* elements. This process extracts essential geometric descriptors, including three-dimensional bounding boxes, centroid coordinates, principal axes orientations, and volumetric extents. These geometric features serve as the foundation for subsequent spatial reasoning operations, enabling precise positioning and orientation analysis within the broader model context.

The extraction process accommodates various geometric representations and coordinate systems, ensuring consistency across diverse modeling approaches and software environments.

The methodology employs a spatial reasoning approach based on bounding volume intersection analysis to associate *BEP-PV* elements with their corresponding host elements. Each provision element's extracted geometric features are systematically compared against potential host elements, including walls, slabs, beams, and other structural components. The spatial association algorithm evaluates geometric relationships through intersection testing, proximity analysis, and containment detection. When a meaningful spatial overlap is identified between a provision element and a structural component, the algorithm establishes a host relationship and prepares the data for the creation of an *IfcOpeningElement*. This automated spatial reasoning process eliminates manual host identification while maintaining accuracy through geometric validation, enabling scalable processing of large-scale opening coordination scenarios while preserving the semantic richness of the original *BEP-PV* elements throughout the transformation into compliant *IfcOpeningElements*.

4 Implementation

The already mentioned pull-based transformation of *BEP-PV* elements into *IfcOpeningElements* is implemented through a structured Python-based workflow, covering IDS creation, IFC validation, geometry extraction, collision detection, and IFC model editing. This approach ensures automation and software neutrality when coordinating MEP openings.

The process starts with generating an IDS file that filters *IfcBuildingElementProxy* entities with *PredefinedType = PROVISIONFORVOID*. The IDS includes mandatory attributes such as GUID, Depth, Height, and Width to identify and describe provision elements in the MEP IFC model. Validation is conducted using the *IfcTester* Python Package, which parses the model and extracts compliant elements based on the defined criteria [10]. These validated elements serve as the basis for downstream geometric and semantic analysis. Figure 2 illustrates the *IDS-Pull-Request* and the resulting validated *BEP-PV* element.

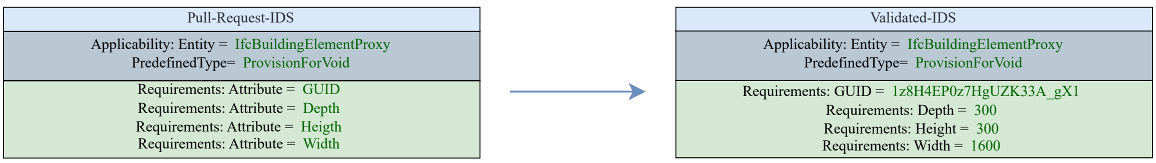

Figure 2: IDS-Pull-Request and Validated BEP-PV element

Since the IDS schema does not support spatial information, the developed software framework uses the Python Package *IfcOpenShell* to extract geometry from validated elements [11]. Each *BEP-PV* is processed to compute an axis-aligned bounding box (AABB), which simplifies spatial containment and overlap checks. The bounding box serves as a proxy for spatial reasoning, enabling lightweight yet practical geometric comparisons.

In parallel, all associated metadata, including values from *Pset_BuildingElementProxyProvisionForVoid*, is extracted to preserve the element's semantic context. The geometric and property data form a comprehensive digital representation of the void reservation, which can be compared against potential host elements.

Collision detection is performed by loading the MEP and structural IFC models simultaneously. The algorithm checks for 3D AABB intersections between provision elements and structural components like walls or slabs. Bounding boxes are evaluated along the global X, Y, and Z axes to detect spatial overlaps.

Precomputed intersections identify candidate host elements, whose corresponding GUIDs and classifications are read from the input data to associate *BEP-PV* reservations with their structural hosts. This mapping enables the placement of semantically correct and geometrically accurate openings in the model.

An exemplary *Answer-IDS*, as illustrated in Figure 3, is generated for each valid pairing to capture all relevant details: bounding box coordinates, element dimensions, source and host GUIDs, and metadata. This structured file is used for automated transformation into *IfcOpeningElements*.

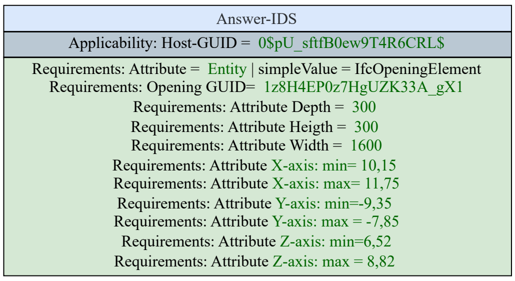

Figure 3: Information Transport - Answer-IDS

The transformation phase generates a new *IfcOpeningElement* for each validated provision, using geometry and placement derived from the Answer-IDS. Rectangular cross-sections are defined using *IfcRectangleProfileDef* and extruded with *IfcExtrudedAreaSolid* to reflect the required dimensions. Each opening is placed relative to the host's local coordinate system.

Openings are linked to host elements via *IfcRelVoidsElement* to establish the logical relationship. In cases of multi-host overlaps, appropriate relationship networks are created. These connections ensure BIM tools correctly interpret the modifications and support downstream use in coordination or quantity take-off.

The final result is a modified IFC model containing semantically rich, host-integrated *IfcOpeningElements* based on MEP provision inputs.

5 Discussion and Conclusion

This paper presents a pull-based framework for the automated transformation of *BEP-PV* elements into semantically integrated *IfcOpeningElements*, using IDS to formalize demand-driven information exchange. Combining IDS validation with spatial reasoning enables rule-based extraction and mapping of geometric and semantic data, supporting consistent and scalable coordination between MEP and structural domains.

Using IDS as a lightweight filtering and specification tool proved effective for defining information needs in a structured, machine-readable format. This improves clarity in interdisciplinary communication and helps avoid information overload by delivering only relevant model data. Geometry extraction through bounding box analysis provided a viable method for automating host-element association and placement of openings, substantially reducing manual workload.

Nonetheless, several limitations remain. The framework assumes a well-structured source model with complete semantic data, which is not always guaranteed – especially in legacy or inconsistently modeled projects. The current geometric matching approach, based on axis-aligned bounding boxes, offers simplicity but may lack precision in detecting complex or irregular openings. Enhancing the system with tolerance-based logic or semantic pattern recognition could improve robustness.

Interoperability also poses challenges. While IDS is platform-neutral, its effectiveness depends on consistent implementation and support within authoring tools. Broader adoption will benefit from standardized validation pipelines and extended IDS definitions, potentially covering aspects such as grouped systems or sequencing requirements.

Despite these constraints, the proposed workflow aligns with current trends in model-based delivery and automation in BIM.

6 Outlook

Future improvements to the *pull-based* workflow for transforming *BEP-PV* elements into *IfcOpeningElements* should focus on enhancing both geometric precision and semantic robustness – e.g., the ability to accurately capture, interpret, and maintain meaningful non-geometric information such as element classification, properties, and relationships, even when source models have incomplete or inconsistent data. A key enhancement lies in enabling partial and context-aware geometry extraction. Instead of processing entire *BEP-PV* volumes, isolating only intersecting regions with structural elements would reduce data overhead and increase the relevance of exchanged information.

Another promising direction is advancing spatial reasoning. Extending IDS or coupling it with external logic to evaluate partial overlaps, proximity thresholds, or containment hierarchies could improve host element identification and better align with real-world coordination needs.

Addressing inconsistent or missing semantic data in source models remains critical. Artificial Intelligence-assisted classification or rule-based enrichment could infer properties or system relationships, enabling more reliable transformations even in incomplete or non-standardized models.

Future work should emphasize real-world integration, broader use cases (e.g., fire safety, clash resolution), and collaboration with industry partners to validate the approach under diverse project conditions.

In summary, refining geometry extraction, enhancing reasoning mechanisms, and enriching semantic interpretation will strengthen the robustness and applicability of pull-based BIM coordination – supporting more automated, efficient, and interdisciplinary workflows.

Data availability statement

The data supporting this study's findings are available at https://gitlab.lrz.de/tweilbach/pfv-ifcopening.git, ensuring that they are Findable, Accessible, Interoperable, and Reusable (FAIR).

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