AI-Agent Application for Semantic Data Enrichment in Ventilation Systems Using National Nomenclature for IFC and GS1-Based Product Information

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Abstract

This study investigates the potential of AI agent systems to automate information management within the mechanical, electrical, and plumbing (MEP) construction process. Currently, building information model (BIM) data is often exchanged manually via 2D drawings and Excel spreadsheets, leading to significant discontinuities in information flow across the design, procurement, and construction phases. Based on a systematic identification of these discontinuities, a simulation was developed to evaluate the feasibility of AI agent–based automation. The results demonstrate that AI agents can effectively enrich and transform a machine-readable engineering bill of materials (E-BOM) into a structured manufacturing bill of materials (M-BOM). Owing to the standardized structure of Finnish MEP data, the solution is not limited to a single case but can be generalized across different MEP domains, enabling broader automation of data flows. These findings suggest that AI agents offer substantial potential as next-generation solutions for automating information workflows in construction.

Keywords

AI agents, semantic enrichment, BIM, IFC, MEP, E-BOM, M-BOM, GS1-standards

1. Introduction

The construction industry significantly lags behind other sectors in both digitalisation [1], [2] and industrialisation [3], resulting in fragmented information scattered across systems and files. These silos are reinforced by disjointed business models [4], which hinder the transfer of innovations from more digitised fields. Unlike manufacturing, construction still lacks industrial-grade data-transfer standards and interfaces; consequently, information is exchanged mainly through files rather than interoperable services [5], [6]. Compared with the integrated process automation achieved in manufacturing [7], construction automation remains largely impractical because design and production have diverged over the past 30 years [8]. The enduring "islands of automation" first illustrated by Hannus et al. [9] underscore that, although BIM has become routine, design software still cannot feed reliable data downstream to production machinery.

BIM authoring tools—architectural, structural and MEP—are therefore used primarily for design-phase coordination [10] rather than for product-lifecycle management. They lack explicit concepts and interfaces for an Engineering Bill of Materials (E-BOM) and a Manufacturing Bill of Materials (M-BOM) [7] and have limited integration to enterprise-resource-planning (ERP) systems [11]. This

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means that BIM-models do not function as a continuous source of information downstream in the process. Instead, 2D drawings are produced from the models for quantity calculations during procurement and for execution planning on-site [6]. This causes manual labour and notably, the use of BIM models also depends on file-based exchange between organisations and companies [10], and current BIM systems are not designed to support bidirectional, real-time, and continuous data transfer throughout the design, procurement, and construction processes [12].

The whole built-environment sector faces increasing pressure to improve efficiency and cut carbon emissions while accurately reporting on these reductions [5]. Environmental regulations [13] further raise the bar, adding design and product-development requirements that will be untenable without better data automation. These demands call for digital information flows robust enough to support lifecycle carbon-assessment standards [14].

Recent breakthroughs in AI research have lowered the barrier to adoption across industries, also in the field of construction [15]. Beyond large language models, AI agents and multi-agent platforms now offer lightweight, goal-driven software "teammates" that can search for, combine and transform data with minimal human scripting [16].

Yet putting these capabilities to work in construction product-data enrichment is difficult. BIM files follow the IFC standard, whose design-centric schema was never meant to carry product data seamlessly through the supply chain. To enable downstream data use, design information must first be extracted from IFC models into an external platform in a machine-readable format suitable for enrichment. Only then can it be reliably transformed into product-level bill of materials data. This process requires partial standardization of design-phase nomenclature for each supply chain and product family [6], which paradoxically increases the complexity of conventional enrichment algorithms [6].

This study tackles that complexity by deploying an AI-agent platform to bridge researcher-identified digital discontinuities in ventilation-system design and supply-chain data. Our purpose is twofold: (i) to demonstrate how AI agents can enrich BIM-based Engineering Bills of Materials (E-BOMs) into Manufacturing Bills of Materials (M-BOMs) that support product-selection decisions, and (ii) to propose ways to simplify the underlying enrichment logic. The work is guided by two research questions:

1. What digital discontinuities exist in 2D- and BIM-based ventilation-system design and supply-chain management, and how do professionals currently handle them?
2. How can an AI-agent platform bridge these discontinuities and deliver a continuous, machine-readable data flow?

The remainder of the paper is organised as follows. Section 2 outlines the theoretical background, including the Finnish MEP data context, AI agents, the E-BOM to M-BOM transformation, and a detailed description of the ventilation system workflow across design, procurement, and installation. Section 3 presents the case data and multi-agent workflow. Section 4 reports the results, Section 5 discusses implications, Section 6 addresses limitations and future research, and Section 7 concludes.

2. Theoretical background

2.1. The importance of digitalisation, machine reading, and data flow in manufacturing and construction

When comparing the state of the industry with manufacturing or the food industry, the disparity becomes highly evident from both a manufacturing theory and modelling perspective. Manufacturing has successfully conceptualised its production model [17] and has developed the GS1 standard family [18], [19] along with the PEPPOL standard. The PEPPOL enables supply chain transaction data to be transferred from file- and email-based exchange into electronic order-delivery messaging

[20], [21]. The fight against climate change, alongside accelerating EU regulations, has driven other industries towards digitalisation. As a result, the automated processing of process and product data has become standard practice like in food industry. In the retail sector, machine-based data processing is closely linked to the consumer market. Consumers can track real-time purchase pricing, the proportion of domestic products, and carbon footprint data. Even the retailers report this information via mobile applications straight to customers. However, the construction industry has yet to implement such advancements at construction sites. The sector lacks essential digital management solutions for inbound and on-site logistics, machine-readable supply chain data, automated processing of design data, and seamless data exchange between systems.

2.2. Digitalisation of the construction supply chain in Finland

In Finland, the construction industry has aimed to solve the challenges of digitalisation through collaboration between the public and private sectors and research institutions. This has resulted in the development of a built environment digital interoperability platform, the national standardisation of data content, and the digitalisation of supply chains [6], [22]. The ongoing development has already transformed available construction-related data into a structured format, facilitating new applications for both software robotics and artificial intelligence.

At the national level, the digitalisation efforts of the construction supply chain have already produced concrete results by integrating concrete element manufacturers, designers, and construction companies. This has led to the first pilot implementations of GS1-standard RFID usage, enabling tracking from manufacturing to the construction site, through the structural phase, and into the completed building in an Engineer-to-Order (ETO) supply chain [23]. Additionally, the construction industry, together with the building product industry and universities, has developed a national data flow architecture for building services products [6] and also for the mentioned ETO supply chain products [5].

In this research, the data flow of the building services supply chain has been further modelled to validate the data flow architecture at the bill of materials level for ventilation systems. The study has demonstrated that BIM model data content can be linked to procurement, supply chain management, production planning, and management, covering site logistics and manufacturing [24]. Furthermore, the research has shown that the application of machine processing in the design process of ventilation systems enables CO_2 calculations based on GS1/GTIN identification using Linked Building Data (LBD), a graph-based framework that publishes BIM entities, product classes and properties as semantically rich, interlinkable data [25], [26]. LBD supplies the common semantics that let our AI agents retrieve BIM-based E-BOM data and enrich it into an M-BOM, seamlessly linking design, procurement and manufacturing.

2.3. AI agents: the next generation of process automation

The adoption of large language models (LLMs) is rapidly expanding in the construction industry, where they are applied to enhance design, automate documentation, and improve project coordination [15]. In addition, AI agents mark a step change in both artificial intelligence development and industrial digitalisation due to their potential to automate entire workflows, not just isolated tasks. An agent can plan, execute and monitor a process, adapt to objectives and learn continuously from feedback. By calling external data sources and tools on demand, agents enhance complex-task execution and improve information flow between systems and stakeholders [27], [28], [29]. When several autonomous agents share an environment and coordinate through predefined protocols, they act as a collaborative AI-agent framework [30], [31], [32]. Such coordination is well suited to distributed problems in which a larger goal is decomposed into smaller subtasks that individual agents perform in parallel. One of the key capabilities of AI agents is data retrieval and enrichment, enabling them to autonomously access, interpret, and structure information across diverse systems [16].

The rapid evolution of generative AI has made agent technology central to current innovation [33]. Gartner predicts that AI agents will be the most important strategic technology trend by 2025 [34]. Major vendors have already released orchestration frameworks—Microsoft's AutoGen Studio [35], Google's Agentspace [36], Amazon's Bedrock Agents [37] and OpenAI's Swarm [38]—to simplify building and deploying cooperating agents.

The ability of AI agents to operate as "human-like" digital workers is now recognised in software development [39], data analytics [40], research [41] and team-based knowledge work [42] . In construction, their potential is emerging in BIM data interfaces [39], [40], [41], [42]. Integrating agents with BIM models is especially promising because BIM standards are maturing at the same time that agent technologies are advancing [43], [45], [46]. Nevertheless, empirical studies that apply agent frameworks in construction remain scarce.

Deploying AI agents within the rule-bound processes of construction demands careful tailoring so that each agent performs its task inside clear constraints, and so that inter-agent collaboration, roles and data flows are coherently orchestrated. This research addresses that gap by examining how an AI-agent platform can bridge digital discontinuities in 2D- and BIM-based ventilation-system design and supply-chain management.

2.4. Engineering Bill of Materials (E-BOM) and Manufacturing Bill of Materials (M-BOM)

Material flow management is a key function of Enterprise Resource Planning (ERP) systems, which include a separate Material Resource/Requirements Planning (MRP) module. In manufacturing, materials are managed in factories using a Warehouse Management System (WMS) integrated into the ERP system. The WMS oversees material reception, internal transfers, inventory balance tracking, movement of materials to worksite, and the transfer of finished products between worksites until shipment within the supply chain. These functions together form a digitalised material flow system, covering inbound, internal, and outbound logistics within factories.

Manufacturing and assembly operations, which are guided by ERP/MRP and WMS, rely on production planning that defines the components and materials required for assembly at the article level. During product development, it is often impractical to specify suppliers for all components due to factors such as supplier availability at the time of production. Therefore, product development generates an initial component hierarchy known as the Engineering Bill of Materials (E-BOM), which engineers use to present the product structure. As the process moves from development to production planning, E-BOM data must be enriched with supplier-specific details, identifying the exact articles and suppliers for each component. The result is the Manufacturing Bill of Materials (M-BOM), which defines the components, materials, and work sequence required for production [47].

A similar approach can be applied in the construction industry, where designers use generic components and materials at the BIM modelling stage (E-BOM), while procurement selects specific suppliers and articles for these components and materials (M-BOM) [6].

2.5. Ventilation system workflow: from design to installation

2.5.1. Ventilation system design process

Building services design involves segmenting the design into distinct system components. Consequently, due to the use of specialised design and calculation tools, data becomes fragmented across multiple sources and is compiled into various files alongside the primary 2D and 3D design plans. From the designer's perspective, the design phase has two main objectives: 1) ensuring the system is dimensioned correctly according to spatial requirements, and 2) modelling the system holistically to prevent conflicts with other systems or structural components.

These requirements significantly impact the structure and content of the data. In MEP design, systems are not modelled from the perspective of procurement, construction, or installation. Ventilation system models, for instance, lack detailed product information and essential installation components such as suspension accessories and support brackets.

In the case studies examined in this research, the designer's BIM model incorporates IFC data, identifiers, coordinate-based location data, and geometric information. According to the E-BOM definition used in manufacturing, this data is incomplete. However, for ventilation systems, it provides sufficient information to identify components, determine quantities, and, to some extent, establish locations. The designer exports a 2D drawing from the model, but this output loses its structured data format, consisting only of schematic symbols and floor plan geometry. Additionally, system identifiers are added manually, leading to the loss of quantity, geometric, and location data.

2.5.2. Ventilation system procurement process

The designer provides structured design files to the main contractor's procurement team, which then forwards them to subcontractors as part of the request for quotation (RFQ) process. In the studied cases, subcontractors estimate material quantities using either a software-based or manual approach.

In the software-based method, the subcontractor traces duct routes over a PDF using CAD software to calculate duct lengths by diameter and identify components, generating an Excel-based parts list. Alternatively, in the manual method, the estimator prints the floor plan and marks duct lengths and component counts directly on paper.

At this stage, location data remains unstructured, as wholesalers' web platforms do not support its integration into the order-delivery process. Once quantity estimation is complete, the estimator assigns ventilation ducts and components to suppliers, calculates costs, or requests additional quotations.

In this study, the subcontractor who won the bid used a wholesaler's web application for ordering, basing quantities on warehouse availability. Duct components were delivered during the structural phase and distributed across floors accordingly.

2.5.3. Ventilation system installation process

In the studied projects, the subcontractor had agreed with the installers on the scope of work, which was defined according to the industry's collective labour agreement. The primary tasks of the installer included: 1) performing execution planning based on 2D drawings, 2) horizontally transporting components and materials, 3) installation, and 4) participating in a model inspection review with the site supervisor. At the construction site, the installer first transported the necessary materials and components to the installation location based on calculations from the 2D drawing. If a material shortage was identified, additional materials were ordered. For the installation, the installer measured the duct lengths from the drawings, cut the ducts accordingly, and measured and drilled attachment points in the ceiling for the supports. The ducts and prefabricated parts were installed at support intervals, and the apartment's ventilation distribution was completed one duct at a time – either from the vertical ventilation shaft to the prefabricated bathroom and its ducting or a later-installed terminal device. The installer connected the duct components to the prefabricated parts by drilling holes for riveting and securing them together. Some connections were further reinforced with sealing tape. Before the suspended ceiling was built, the main contractor's site supervisor inspected the installations, requested corrections if necessary, or approved them for coverage.

3. Materials and methods

3.1. Case data: HVAC system components for multi-storey residential construction

To identify the discontinuities of data flow, this study examines the design, tendering, material delivery, and installation processes of building services subcontracting. Discontinuities were identified where data is not transferred in a machine-readable format. Among these, the enrichment of E-BOM data into M-BOM data was selected as the process to be simulated using a multi-agent platform. The selected case study focused on multi-storey residential construction, allowing the utilisation of a BIM model for building services, created as an example within the digital building permit process in Finland under the Rava3PRO project [22], [48].

This study utilises the standardisation of BIM data content through the national HVAC product component classification [50]. The ventilation system was chosen for simulation, as its product range is the most standardised compared to other MEP systems. Additionally, its modelling approach and BIM data content are the most comprehensive, providing the best representation of the implemented system at the product level. The classification published in 2023 has also been implemented as part of the Magicad software suite in Revit/Autocad environments. Furthermore, it has been implemented in the Cadmatic design software and published in the buildingSMART Data Dictionary (bSDD) [51]. Experiences from using the classification indicate that it is semantically functional and logically well-structured. The nomenclature has already been applied in several dozen projects, and its adoption is expanding systematically as main contractors enter into design contracts for new projects. The logic of information hierarchy within the classification is consistent, and for this reason, semantic enrichment operates according to the same principles across all system types covered by the nomenclature. As a result, the data hierarchy of the HVAC product group is representative of the building as a whole.

Standardised and structured BIM E-BOM data serves as the primary dataset for the research. This study focuses on building services, as the national interoperability platform [49], launched in 2023, includes a machine-readable classification system, [50], [53] and a country-specific database for the Revit design software, published under an open license [51].

3.2. Multi-agent workflow for E-BOM to M-BOM enrichment

The study evaluated a multi-agent workflow that enriches a ventilation-system Engineering Bill of Materials (E-BOM) into a floor-level Manufacturing Bill of Materials (M-BOM) and then refines it into location-specific lists for installers. The MEP design model's IFC data were first converted to a machine-readable form. A Python environment was configured on Ubuntu Linux, together with IfcOpenShell [52], which supports object-oriented scripting for IFC. The extraction script defined the system components and PropertySets required by the use-case and filtered IfcPipeFitting objects, the target class for HVAC piping [49], [50] ,[51], [53]. It also captured the product-type codes stored in the demonstration model's PropertySet; these codes—maintained in the Finnish interoperability platform [22]—serve as primary keys for later enrichment. Executing the script produced a structured, HVAC-specific E-BOM in JSON, chosen for its flexible schema, native Python support and seamless ingestion by AI-agent frameworks. Figure 1 illustrates the extraction sequence, which follows the template introduced by Alhava et al. at LDAC 2025 [24].

To automate quantity take-off for subcontractors and installers, several open-source AI-agent frameworks were screened against three early-stage requirements: (i) a visual, intuitive GUI, (ii) low-code workflow modelling, and (iii) rich data-input nodes. Financial constraints limited the choice to fully open-source tools. Langflow satisfied all criteria and was adopted [54]. Its drag-and-drop interface lets users combine Python snippets, database/API queries, mathematical nodes and language-model prompts into a single agent chain.

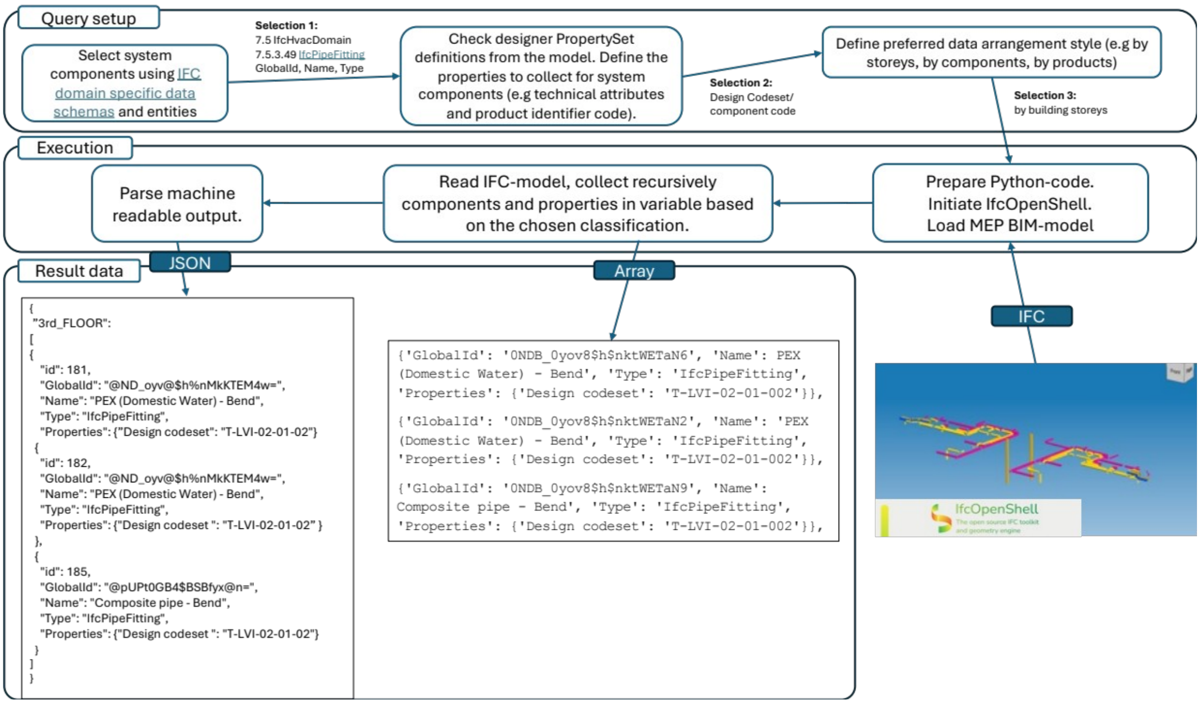

Figure 1: Data enrichment process-steps to extract E-BOM from BIM-model

Pre-tests showed that reliable product matching demands a domain-tuned language model. A small Finnish LLM (Poro/Viking) was therefore deployed via Ollama, which hosts fine-tuned models and supplies semantic search functions for catalogue look-ups. Using Langflow's basic template, the research team mapped each task required to generate the M-BOM (Figure 2) and confirmed that the JSON parts list could circulate through the agent chain without additional coding.

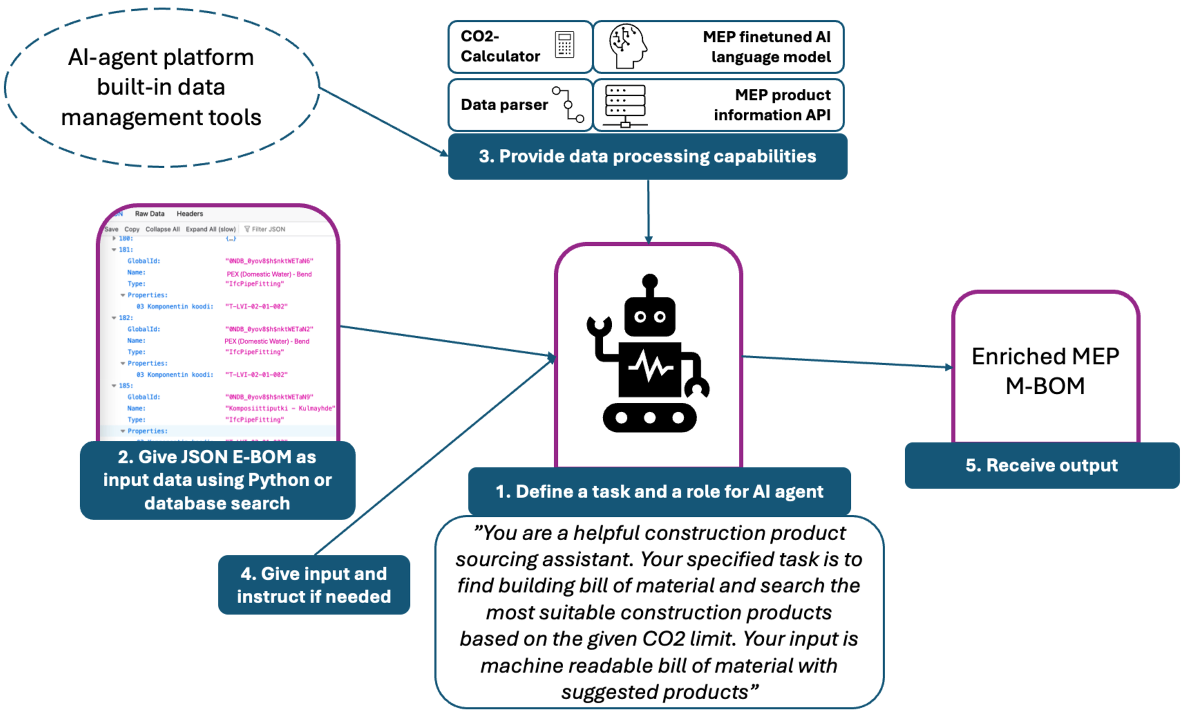

Figure 2: AI-agent process-flow example for MEP M-BOM

An AI agent dedicated to product selection was configured to ensure that chosen components meet CO_2 constraints. Langflow already contained the necessary data-fetch and enrichment blocks, so only minor parameter tuning was required. The complete toolchain comprised (i) the local Finnish

LLM served via Ollama, (ii) an API-based product database or web-scraper for ventilation items, (iii) a CO_2 computation module, (iv) a data parser for agent I/O, and (v) the IfcOpenShell routines that regenerate the E-BOM list. Sample inputs and outputs generated inside Langflow verified smooth data exchange across the chain and confirmed that the multi-agent environment was ready for performance testing.

4. Results

The simulation confirmed that current ventilation workflows still rely on manual extraction of BIM information, so design, procurement, supply-chain management and on-site execution fail to exploit the model's data. Information on ventilation components is exchanged as 2D draw-ings; part types are re-identified and quantities recalculated by hand. The study uncovered five critical recurring digital discontinuities distributed across project phases, roles and software tool:

1. Tendering phase: manual quantity estimation by the subcontractor's cost estimator (using a quantity estimation software or Excel).
2. Material procurement and ordering phase: refinement of product quantities and selection of required installation materials by the subcontractor's cost estimator (Excel or quantity estimation software). Orders placed through a wholesaler's web-shop tool (Excel-based import file).
3. Call-off stage: project engineers, site managers, or team leaders adjust product quantities based on updated designs and previous calculations from the procurement phase (Excel-based import file).
4. Reception and logistics: materials are stored in the basement without precise quantity records; apartment-level calculations and material picking for daily logistics rely on hand-written notes on graph paper or 2D drawings.
5. Installation phase: execution plans are developed from 2D drawings, followed by manual material calculations (notes on graph paper or 2D drawings).

Existing AI-agent platforms proved capable of modelling these fragmented processes, querying external product catalogues and performing real-time CO_2 calculations. The simulation handled all five discontinuities within a single agent chain, confirming that one workflow can span design, procurement, logistics and installation without manual re-entry. When supplied with the machine-readable Engineering Bill of Materials, the agents automatically produced a structured, supplier-ready Manufacturing Bill of Materials. Because the agents worked directly on the JSON E-BOM extracted from the BIM model, the data remained fully machine-readable throughout the transformation.

To deploy such a platform successfully, process owners must (i) *describe the target task in plain language for the agent*, (ii) *supply standardised E-BOM input*, (iii) *connect product-data APIs for enrichment*, (iv) *provide a supporting LLM, prompt templates and calculation routines*, and (v) *designate a downstream recipient*—which may itself be another agent. In practice, the entire workflow hinged on the presence of the product-type codes issued by the Finnish interoperability platform; without these identifiers the agents could not resolve catalogue entries or attach CO_2 data, underscoring that reliable automation is attainable when the BIM model already contains well-formed technical attributes and design classifications and when those classifications conform to a shared, sector-wide standard. Thus, structuring IFC-based BIM models into machine-readable formats is essential for AI-driven processes. While training a domain-specific language model for product search would enhance this process, such a model was not yet available during the study.

A further result is that the Finnish data-standardisation scheme underpinning our workflow applies uniformly across all MEP domains, thereby enabling system-level automation of data flows throughout the building-services supply chain. The hierarchy we implemented for ventilation components matches the structure used for, for example, heating radiators, under-floor heating loops, domestic water lines and sanitary drainage. Because the same Finnish design codes and product identifiers govern every technical system, the identical agent workflow can be reused across the full range of MEP applications, not just ventilation.

In addition, the AI-agent platforms used in this study provide advanced capabilities—such as web-based document searches, vector-database queries, and mathematical computations—that traditional construction software typically lacks. Beyond data enrichment, AI agents support multimodal searches across diverse project sources, converting heterogeneous information into machine-readable formats. Their ability to coordinate multiple agents toward a single objective further enhances the efficiency of automation workflows.

Testing showed that the agent chain replaced every manual hand-off with an automated step, effectively "digitising" each of the five documented discontinuities. Once the BIM model contained the Finnish product-type codes and other standardised attributes, the workflow moved data continuously from design to procurement and site execution—no 2D take-offs or spreadsheets were required. Two concrete observations were recorded: (i) standardised BIM data served directly as the source for quantity take-off, and (ii) the agents enriched that data into supplier-specific M-BOMs that were passed downstream without re-entry. In addition, the platform wrote order-to-delivery information back to the model, a task that is currently handled in disconnected files. These results illustrate how AI agents, coupled with shared data standards, can close the data gap between design and execution.

5. Discussion

The use of AI agents in a small-scale test yielded highly encouraging results, demonstrating that the digitalisation of discontinuities in the construction industry can be achieved by following the same actions of individual people involved in the process. The great potential of AI-agents lies in the future when we can teach AI systems how the same products behave within the same supply chain types. In this scenario, AI-agents will be able to act proactively and provide users with recommendations when certain products or technical attributes appear, for example, in a ventilation design model. This will also facilitate compliance with sustainability reporting and environmental requirements, as real-time compliance monitoring and calculations will be embedded in the product selection process. A key insight from this study is that investing in standardisation pays off, as it enables precisely this kind of agent-based data enrichment and seamless information flow across design, procurement, and installation. While the paper does not claim universal empirical coverage, it demonstrates how digitally mature environments can already leverage AI agents effectively—and provides a blueprint that less mature contexts can adopt incrementally.

The successful integration of AI-enriched building services component lists into business operations also requires the incorporation of AI technology into the company's enterprise architecture. The core principle is to separate data management perspectives into 1) presentation layer, 2) application layer (business logic), 3) persistence layer (data storage), and 4) database layer (technology and database infrastructure). Integrating AI functionalities into enterprise architecture is essential to ensure that AI agent platforms align with business and expert needs within the organisation. Since AI agent platforms are still in the development phase, the platform should be implemented in separate technical development environment (sandbox). This sandbox must align with the company's enterprise architecture including the existing systems and data sources the people are using. To support the simulated AI-driven product selection process, integrations are required with ERP-systems (procurement data), financial systems (contract pricing), project banks (project documentation), project scheduling software, quality management systems, and security and access control systems.

The starting point of this research was that existing construction industry information systems could be utilised despite their limitations. During the study, it was identified that the automation of data processing provided by AI-agents simplifies the algorithms needed for data extraction and transformation while also making vast product data repositories accessible within design models. Our initial hypothesis was confirmed: AI-agents significantly increase the level of automation in data processing at the enterprise level compared to traditional algorithm development. With AI-agents, we can bridge the missing link in BIM-based information modelling, enabling data connectivity, if BIM data can first be extracted into a suitable format for AI agents (e.g., structured component lists).

6. Limitations and future research

The study's limitations can be summarized into four key areas. First, the experiment focused on a single ventilation system's design, procurement, and installation, limiting the generalizability of findings to the broader building services or construction industry. Expanding the research to multiple system types and projects is necessary.

Second, the AI-agent system remains a prototype with incomplete integrations, and its ability to optimize product selection based on carbon footprint, cost, or installation efficiency is still limited. Further development requires structured databases, high-quality data, a trained language model, and a unified architecture for AI model selection and fine-tuning.

Third, ensuring semantic consistency in product data processing requires linking structured data to graph or vector databases while maintaining robust authentication and agent permissions. Additionally, user interfaces and monitoring tools must allow users to track system functions, manage exceptions, and facilitate feedback loops between AI agents and human users. Practical implementation challenges, such as pricing models and system integration (e.g., SaaS solutions), need further exploration before systemic multi-agent adoption in construction digitalization.

Fourth, orchestrating multiple agents warrants dedicated research as a systemic solution for construction data flow. How to coordinate many specialised agents, resolve conflicts and maintain global objectives in a live project environment remains an open question. Equally critical is establishing governance mechanisms—such as clear performance metrics and human-in-the-loop override protocols—to ensure that autonomous agent swarms act transparently and reliably across the project lifecycle.

Future research should also expand testing across multiple construction projects and building services domains (e.g., HVAC, plumbing, electrical). Developing broader, standardized product and CO_2 databases would improve AI-driven product selection and optimization. Additionally, refining the technical reliability and orchestration of multiple AI agents could transform data management and exchange in the construction industry.

Despite the study's limited scope, the successful enrichment of building services data demonstrates the feasibility and value of machine-based data processing in supply chain management. AI-agent tasks must be carefully defined, with models trained for specific functions to ensure effectiveness. A key future research area is the development of a specialized language model for product selection and carbon footprint data interpretation.

Finally, identifying and addressing supply chain discontinuities through a multi-agent platform presents new opportunities for digitalization. Future studies should also explore material flow management, emphasizing product identification and traceability using GS1/GTIN-standardized data, markings, and barcodes, which are widely used in other industries.

7. Conclusion

The study modelled the construction process by analysing the design, procurement, supply chain management, and subcontracting processes related to ventilation systems and mapping the associated data flows. The findings confirmed previous observations regarding building services systems, particularly that ventilation system design data is transmitted as 2D drawings, and that BIM is only used in the design phase. The entire downstream process relies on 2D drawings in PDF or paper format for data exchange.

By examining the data flows, five critical discontinuities were identified, from which data enrichment from E-BOM to M-BOM was selected for the multi-agent analysis. Based on process analysis, a data processing simulation was conducted using a multi-agent platform. The results included standardisation of design data within the building services information model, transformation of design model data into a structured format, as well as enrichment of BIM data using a multi-agent platform.

The study demonstrated that the AI agent platform's functionalities support the enrichment of IFC-based building services models using multi-agent system tools. Additionally, the study found that enriching linked data with AI agents requires integrating AI-agents into a company's enterprise architecture and processes, which is essential for establishing necessary system and process integrations. To develop AI-agents, it is crucial to establish a dedicated development environment (sandbox) that replicates the company's existing architecture and work environment, ensuring seamless adoption.

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Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT-4o and Grammarly to check grammar and spelling. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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