

Design and Analysis of HVAC System for a Residential Building Using BIM Framework - A Review

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Abstract- Heating, Ventilation and Air Conditioning (HVAC) systems comprise spatially interconnected ducts, air terminals, equipment, fittings and accessories that must be coordinated with architectural, structural and other building services. Conventional two-dimensional Computer-Aided Design (CAD) drawings remain useful for drafting, but they can limit spatial understanding and make coordination difficult when multiple services occupy constrained ceiling and shaft zones. Building Information Modeling (BIM) supports the representation of building systems as three-dimensional, information-rich objects and enables model-based coordination and documentation. Published studies indicate that CAD-based duct-model generation can be formalized, BIM coordination benefits from structured information and management processes, and automated clash results still require engineering interpretation. A practical workflow is proposed for the ENEC Staff Accommodation Unit-02 (SAU-02) case study using AutoCAD, Revit MEP and Navisworks. The workflow connects drawing interpretation, HVAC model development, federated coordination, clash classification and resolution, model verification, and documentation. The paper's contribution is an application-oriented synthesis and evaluation framework rather than a new HVAC thermal-design method. Quantitative performance outcomes are not claimed here; they are to be established through project-based model checks and coordination records.

Keywords- Building Information Modeling; CAD-to-BIM; HVAC; Revit MEP; Navisworks; MEP coordination; clash detection; residential building.

I. INTRODUCTION

Heating, ventilation and air conditioning (HVAC) systems contribute to indoor comfort and ventilation and comprise ducts, air terminals, mechanical equipment, fittings and related accessories. Building Information Modeling (BIM) provides a shared digital representation that can support design development, information exchange and construction coordination [3], [4], [14], [15]. For MEP systems, coordination is especially demanding because services compete for limited ceiling, shaft and plant-room space, and decisions must account for installation, access and maintenance [12], [14], [15].

In a conventional 2D workflow, separate drawings communicate geometry and design intent. However, two-dimensional views may not fully communicate

vertical relationships, congested intersections or installation clearances. Research on BIM adoption and project delivery identifies information integration, visualization and coordination as important potential benefits, while also noting that outcomes depend on implementation practices and model quality [4], [16], [17]. Consequently, a coordinated model should be treated as an information-management process rather than simply a 3D visualization exercise [3], [18]. The present review supports an M. Tech CAD/CAM project focused on converting existing CAD information into a coordinated HVAC BIM model for ENEC Staff Accommodation Unit-02. AutoCAD is used to interpret source drawings, Revit MEP to create the HVAC model, and Navisworks to federate discipline models and examine spatial conflicts. The emphasis is the CAD-to-BIM modeling and coordination process, not the

development of a new thermal-load calculation or HVAC sizing method.

II. REVIEW SCOPE AND APPROACH

The review concentrates on four connected themes: (i) BIM applications in HVAC engineering, (ii) conversion of 2D CAD information into BIM objects, (iii) multidisciplinary MEP coordination, and (iv) clash detection, information exchange and model-based documentation. The scope also considers model-based quantity extraction and interoperability because the usefulness of a coordinated HVAC model depends on consistent object information and reliable downstream documentation [19]–[23]. The evidence is interpreted in relation to a practical residential-building workflow. Findings reported by individual studies are attributed to those studies; proposed workflow stages and evaluation parameters are presented as the authors' application to the case study. Project-specific results, clash counts and accuracy percentages are not asserted without completed measurement.

III. LITERATURE REVIEW

1. Bim in Hvac and Mep Engineering

Tang, Zhang and Liang [1] reviewed BIM-based HVAC design from the perspective of automatic and intelligent methods, including links with simulation, optimization and clash filtering. Luo [2] discussed BIM applications in HVAC design. BIM-based HVAC research increasingly considers automation, data exchange and intelligent methods, but this review focuses on geometry-led CAD-to-BIM conversion and coordination rather than thermal-load calculation or system optimization [1], [2], [5]. General BIM literature explains that object-based models can connect geometric representation with non-graphical information and support downstream documentation [3], [4], [16].

Eastman et al. [3] describe BIM as an information-centered approach that can support design, construction and facility-management processes. Azhar [4] discusses the benefits and challenges associated with BIM implementation. Succar [16] presents BIM as a set of interacting technology,

process and policy fields, while Bryde, Broquetas and Volm [17] review project-level benefits reported in BIM case studies. These sources caution against assuming that software alone guarantees better outcomes: information requirements, collaboration practices, skills and quality control are also important [16]– [18], [24].

2. Cad-To-Bim Conversion

CAD-to-BIM conversion requires interpretation of existing drawing geometry, levels, system routes, equipment locations and component relationships. Park et al. [5] formalized a process for generating an air-conditioning duct model using a CAD-to-BIM approach. Related work on existing-building BIM highlights challenges associated with incomplete, inconsistent or differently structured source information [25]. Therefore, the conversion process should preserve drawing intent while checking units, coordinates, elevations, object connectivity and system classification before detailed modeling [5], [25], [26].

The practical implication is that CAD-to-BIM conversion should be managed as a sequence of interpretation, modeling and verification activities rather than a simple file import. In the SAU-02 workflow, the source drawings are interpreted first, the Revit project environment and levels are checked, and HVAC components are modeled with suitable families, sizes, elevations and connectivity. Model geometry is then checked against the available source information

3. Multidisciplinary Mep Coordination

Wang et al. [6] examined BIM-based integration of MEP layout design and constructability. Teo et al. [7] considered BIM technology alongside management strategies, and Wu et al. [8] reviewed the state and future direction of BIM-based coordination research. Earlier work identifies MEP coordination as a knowledge-intensive process that combines trade-specific constraints with construction and maintenance considerations [14], [15]. Coordination approaches can also vary in sequence and team organization; therefore, a federated model should be paired with agreed responsibilities, issue ownership and review cycles [27], [28].

Coordination is both a technical and a management activity. A federated model can expose spatial conflicts, but the usefulness of the review also depends on model versions, coordinate alignment, agreed priorities, ownership of issues and a documented close-out process. Coordination should therefore include the architectural and structural context as well as relevant electrical, plumbing and fire-protection services.

4. Clash Detection and Clash Management

Leite, Akinci and Garrett [9] examined information requirements for automatic clash detection in MEP design coordination. Pärn, Edwards and Sing [10] investigated origins and probabilities of clashes in federated BIM models, while Akponeware and Adamu [11] distinguished clash detection from clash avoidance. Wang and Leite [12] formalized knowledge representation for spatial conflict coordination. More recent work explores logical relationship detection and machine-learning-based relevance filtering, which may help prioritize results but still requires engineering validation [13], [29], [30].

Automated clash tests can identify geometric intersections and clearance problems, but the raw output may contain duplicate, tolerable or non-actionable results. A useful process separates hard clashes, clearance/access issues and intentional or acceptable intersections, then assigns responsibility and records resolution status [9]–[13], [29], [30]. The quality of the results also depends on the model scope, coordinate alignment, object detail and clash rules; a clash count alone is not a sufficient measure of coordination quality [10]–[12], [27].

5. Synthesis of Selected Studies

Study	Focus / method	Relevance to this work
Tang et al. [1]	Review of BIM-based HVAC design and intelligent methods	Frames BIM-enabled HVAC workflows.
Park et al. [5]	CAD-based automated duct BIM generation	Directly relevant to drawing interpretation and model creation.
Wang et al. [6]	BIM integration of MEP layouts and constructability	Supports coordinated layout development.
Teo et al. [7]	Review of MEP coordination technologies and management	Highlights process and team-management needs.
Wu et al. [8]	Critical review and mapping of BIM coordination research	Provides broader research context.
Leite et al. [9]	Information needed for automated clash detection	Supports model-quality checks before clash tests.
Pärn et al. [10]	Analysis of MEP/structural clashes in federated BIM	Supports early spatial-conflict identification.
Akponeware & Adamu [11]	Clash detection versus clash avoidance	Emphasizes prevention and actionable issue review

Overall, the literature supports a connected workflow from source-drawing interpretation to model verification and coordinated documentation. The selected studies differ in scope and method; their findings should not be treated as interchangeable or as proof of a guaranteed productivity gain. Interoperability standards and common information-management practices can help structure exchanges between authoring and coordination environments [31]–[33]. For the present case study, model-derived schedules and quantities should be checked against drawing intent and agreed measurement rules before they are used for documentation or BOQ purposes [19]–[23].

IV. CRITICAL ANALYSIS

Three themes emerge from the reviewed literature. First, CAD-to-BIM conversion can be structured and partially automated, but source-drawing quality and interpretation remain important. Second, BIM-based coordination creates a shared spatial context, yet coordination quality depends on model completeness, common coordinates, suitable tolerances and disciplined issue management. Third, automated clash detection is an identification aid rather than a substitute for engineering judgment. A clash should be assessed against clearance, access, installation sequence and design intent before it is accepted as an actionable issue.

The proposed workflow should be evaluated using transparent project-specific checks: (i) completeness of modeled HVAC components against source drawings, (ii) dimensional/elevation consistency, (iii) number and type of reviewed clashes, (iv) status of issue closure, and (v) agreement between model schedules and checked quantities. These indicators are proposed evaluation measures, not measured findings. BIM-based quantity take-off research shows that model structure, classification and measurement rules influence the reliability of extracted quantities [19]–[23].

V. RESEARCH GAP

The reviewed literature identifies continuing opportunities for practical, end-to-end demonstrations

that connect existing CAD inputs, detailed HVAC BIM modeling, multidisciplinary federation, meaningful clash review and final documentation within one repeatable workflow. In particular, the present case study is intended to address the following application-level gaps:

- Limited project-specific documentation of a complete CAD-to-BIM HVAC workflow for a residential or staff-accommodation building.
- Need to link source-drawing interpretation and Revit MEP model verification with subsequent multidisciplinary coordination.
- Need to classify detected conflicts by significance and record their resolution status rather than report clash counts alone.
- Need to connect the coordinated model to usable plans, sections, schedules and quantity information.
- Limited case-specific evidence from the selected SAU-02 project context; the study will document this workflow without claiming that one case represents all residential projects.

VI. PROBLEM STATEMENT AND OBJECTIVES

Existing 2D CAD drawings provide limited direct spatial visualization of HVAC systems in relation to architectural, structural and other MEP services. Transforming these drawings into a coordinated BIM model requires consistent interpretation of geometry, levels, equipment locations and service routes, followed by structured clash review and documentation. Without these steps, spatial conflicts may remain unresolved until later project stages.

The objectives of the case study are to: (1) interpret the available SAU-02 CAD drawings; (2) develop a 3D HVAC model in Revit

MEP; (3) coordinate the HVAC model with architectural, structural and other relevant service models; (4) identify, classify and review significant clashes in Navisworks; (5) revise the model to address agreed conflicts; (6) generate coordinated drawings, schedules and quantity information; and (7) evaluate model completeness and coordination status using documented parameters.

VII. PROPOSED CAD-TO-BIM METHODOLOGY

- **Source drawing review:** Collect available architectural, structural and HVAC CAD drawings; check units, scales, references and drawing status.
- **CAD interpretation:** Identify levels, spaces, shafts, equipment locations, duct routes, air terminals and relevant dimensions.
- **Revit MEP setup:** Establish project levels, views, families, system settings and coordinate references.
- **HVAC 3D modeling:** Create ducts, fittings, air terminals, mechanical equipment and associated components from the interpreted information.
- **Model verification:** Compare modeled geometry, locations, elevations and component sizes against available source drawings.
- **Multidisciplinary federation:** Link the HVAC model with architectural, structural, electrical, plumbing and fire-protection models where available.
- **Clash detection:** Define suitable Navisworks tests for physical intersections and relevant clearance conflicts.
- **Clash review and resolution:** Classify issues, assign responsibility, revise routes or elevations where appropriate, and record status.
- **Documentation and evaluation:** Generate coordinated plans, sections, schedules and quantity information; assess model completeness and coordination outcomes.

VIII. PROPOSED EVALUATION PARAMETERS

The evaluation should use traceable project records rather than assumed benefits. Suggested parameters are: (i) model completeness—the required HVAC elements represented; (ii) CAD-to-BIM consistency—agreement of selected dimensions, positions and elevations with source drawings; (iii) clash identification—counts by discipline pair and issue category; (iv) clash resolution—resolved, open, accepted or deferred status; (v) documentation consistency—agreement between the coordinated model and generated views/schedules; and (vi)

quantity extraction—availability and consistency of selected model-based quantities.

Where quantitative comparison is possible, the paper should report the measurement method, baseline, sample size and limitations. For example, a clash-resolution ratio may be calculated as resolved significant clashes divided by total significant clashes identified in the defined review, multiplied by 100. The ratio should only be reported after the project review data have been collected and checked.

IX. DISCUSSION

The main value of the proposed workflow is the integration of modeling and coordination activities. Importing or referencing CAD information is only an initial step; reliable outcomes require interpretation, object-based modeling, verification and coordination with other disciplines. Similarly, a clash report becomes useful when it is converted into a controlled list of actionable issues with clear ownership and closure evidence.

For the SAU-02 case study, the practical contribution is a documented workflow that can be repeated on similar residential projects. The expected benefit is improved spatial understanding and more traceable coordination decisions. These benefits should be evaluated through the model checks and issue records described above; they are not presented as measured project outcomes at this review-paper stage.

Limitations and Future Work

This paper is a narrative review combined with a proposed application workflow. It does not present a systematic review protocol, independent expert validation of the SAU-02 model, measured clash statistics or verified time/cost savings. The availability and coordination status of discipline models may also constrain the scope of clash tests. Future work should document the selected model versions, coordination rules, issue categories, sample measurements and before/after model states. A later study may compare manual review with rule-based or automated clash filtering, provided the comparison uses a clearly defined dataset and validation procedure.

X. CONCLUSION

The literature indicates that BIM can support HVAC visualization, information integration, multidisciplinary coordination and model-based documentation. Research on CAD-to-BIM conversion shows that duct-model generation can be formalized, while studies of MEP coordination emphasize model quality, management processes and the need to interpret clash results. Automated detection alone is insufficient: meaningful coordination requires classification, engineering review, resolution tracking and verification.

The proposed SAU-02 case study applies these principles through a workflow connecting AutoCAD drawing interpretation, Revit MEP HVAC modeling, Navisworks coordination, clash review and documentation. Its contribution is practical and application-oriented. The effectiveness of the workflow should be demonstrated using project-specific checks and recorded results rather than assumed numerical improvements.

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