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Digital Twin Studio: An Integrated Human-in-the-Loop Framework for 2D Floor Plan to 3D Digital Twin Generation with BIM and VR

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ABSTRACT

The Architecture, Engineering, and Construction (AEC) industry is increasingly adopting digital technologies to address fragmented workflows, inefficient information exchange, and difficulties in communicating complex spatial information. This literature review examines the research foundations for Digital Twin Studio, a proposed human-in-the-loop system that converts a raw two-dimensional (2D) floor plan into a validated, structured three-dimensional (3D) digital representation. The proposed workflow combines automated floor-plan interpretation, optical character recognition (OCR), structured 3D reconstruction, user validation, interior design enrichment, immersive virtual reality (VR), and interoperable Building Information Modelling (BIM)/Industry Foundation Classes (IFC) export. Sixty-three references covering Digital Twin theory, BIM–Digital Twin relationships, computer vision, floor-plan recognition, structured 3D modelling, Scan-to-BIM, BIM–VR integration, VR-based design review, data exchange, and IFC interoperability are synthesized and related to the proposed system architecture. The review indicates that these technological areas are individually well established, but their integration into a single workflow beginning with a raw floor plan and ending with a validated and interoperable digital twin remains comparatively underexplored. Digital Twin Studio is therefore positioned not as a replacement for existing methods, but as an integration-oriented framework that brings established technologies together while retaining meaningful human validation and design control.

Keywords: *Digital Twin, Building Information Modelling (BIM), floor-plan recognition, computer vision, virtual reality, IFC interoperability, Scan-to-BIM, human-in-the-loop systems*

1. INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry has increasingly adopted digital technologies to address fragmented workflows, inefficient information exchange, and the difficulty of communicating complex spatial information. Building Information Modelling (BIM) established a structured digital representation of buildings, while Digital Twin (DT) research extended this idea toward richer, connected, and potentially dynamic representations of physical assets.

Early Digital Twin research emerged largely from manufacturing, where the concept was associated with maintaining a connection between physical and digital systems. Kritzinger et al. (2018) distinguished among a Digital Model, Digital Shadow, and Digital Twin, providing a useful basis for understanding different levels of digital representation. Tao et al. (2019a) described the integration of cyber and physical spaces as a central characteristic of Digital Twin systems, while Tao et al. (2019b) examined the relationship between Digital Twins and Cyber–Physical Systems.

The concept has since been extended into the built environment. Boje et al. (2020) proposed a semantic Construction Digital Twin framework that emphasized BIM, semantic data, the Internet of

Things (IoT), and artificial intelligence (AI) as important enabling technologies. Opoku et al. (2021) found that construction Digital Twin applications were often concentrated within individual lifecycle phases and that design-stage applications were strongly associated with BIM. Jiang et al. (2021) examined Digital Twin applications in civil engineering and discussed the distinction between BIM and Digital Twins.

More recent reviews continue to identify fragmented lifecycle coverage, interoperability, and user involvement as important challenges. AlBalkhy et al. (2024) proposed a four-layer structure for Digital Twins in the built environment and noted that implementation remains at a relatively early stage. Miraj et al. (2025) examined 102 papers and identified organisational, user, and management perspectives as areas requiring greater attention.

These studies provide the conceptual basis for treating Digital Twin Studio as an integrated digital representation rather than simply a 3D visualization application. The proposed system combines structured building information, visualization, user interaction, project information, and downstream deliverables within one workflow.

2. DIGITAL TWIN AND BIM IN THE BUILT ENVIRONMENT

BIM is particularly relevant to Digital Twin Studio because the proposed system must preserve information about architectural elements rather than producing only unstructured geometry. Boje et al. (2020) argued that BIM provides an important foundation for Construction Digital Twins, while additional semantic and dynamic capabilities are required for a broader Digital Twin concept. Opoku et al. (2021) similarly identified BIM as a major technological foundation for Digital Twin applications in construction and design.

Radzi et al. (2023) reviewed the relationship between BIM and Digital Twins and identified several interpretations, including BIM as a subset of Digital Twin, Digital Twin as an extension of BIM, and BIM and Digital Twin as separate but related technologies. Nguyen and Adhikari (2023) further emphasized the role of BIM as an information foundation for integrating Digital Twins into building construction. Baghalzadeh Shishehgarkhaneh et al. (2022), through a large-scale bibliometric analysis, identified BIM/DT, ontology, VR/AR, and AI among the major research clusters in the field.

Lifecycle-oriented studies continue to point toward stronger BIM integration and continuity of information across project stages (Adu-Amankwa et al., 2023; Saif et al., 2024; Nguyen & Adhikari, 2026). Taken together, this literature supports representing Digital Twin Studio through structured entities such as user, project, floor plan, structural data, 3D model, interior design, VR session, walkthrough feedback, IFC export, and project report rather than treating the output simply as a graphical model.

3. AUTOMATED FLOOR-PLAN UNDERSTANDING

A central component of Digital Twin Studio is the conversion of a raw 2D floor plan into structured architectural information. This problem has been widely studied in computer vision. Liu et al. (2017) introduced Raster-to-Vector, which converts rasterized floor plans into vector representations by detecting junctions and aggregating them into primitives such as walls and doors. This is particularly relevant to the first stage of the proposed workflow because a vector or structured representation can subsequently support 3D model generation and architectural manipulation.

Kalervo et al. (2019) introduced the CubiCasa5K dataset, containing 5,000 floor plans with more than 80 annotated object categories, and proposed a multi-task model for automated floor-plan analysis. Zeng et al. (2019) developed DeepFloorplan, using a multi-task network and room-boundary-guided attention to recognize floor-plan elements and room structures. Liu et al. (2018)

developed FloorNet, combining 3D points, top-down representations, and RGB information for floor-plan reconstruction.

These studies demonstrate that architectural drawings can be interpreted computationally rather than requiring every structural element to be manually recreated. For Digital Twin Studio, the corresponding workflow is: raw 2D floor plan → validation and preprocessing → AI/ML detection of walls, doors, windows, rooms, and text labels → human review and correction → confirmed structural data.

4. OCR AND TEXT RECOGNITION FROM FLOOR PLANS

Architectural floor plans contain important textual information, including room names, dimensions, labels, door and window annotations, and material information. Structural recognition alone is therefore insufficient for comprehensive floor-plan understanding.

Schönfelder et al. (2024) investigated deep-learning-based text detection and recognition on architectural floor plans and evaluated multiple object-detection and OCR approaches. Their work supports the inclusion of a dedicated text-recognition stage in Digital Twin Studio. General computer-vision methods also provide relevant methodological foundations. Zhou et al. (2017) introduced EAST as an efficient scene-text detector; Redmon et al. (2016) developed YOLO for real-time object detection; He et al. (2017) introduced Mask R-CNN for instance segmentation; Ronneberger et al. (2015) developed U-Net for dense segmentation; and Chen et al. (2018) developed DeepLab for semantic image segmentation.

Digital Twin Studio does not propose a new OCR algorithm. Instead, it applies established computer-vision methods to the architectural floor-plan domain, with the objective of combining geometric recognition and textual semantics within one structured representation.

5. STRUCTURAL DATA AND 3D RECONSTRUCTION

After detection, Digital Twin Studio converts the recognized elements into confirmed structural data. This human-validated representation is important because automated recognition may contain errors. The proposed workflow therefore follows Detection → User Review → Correction → Confirmed Structural Data rather than transferring AI output directly into the final model.

This approach is consistent with research in structured scene understanding. Ikehata et al. (2015) represented indoor environments through structural elements such as rooms, walls, and objects. FloorNet demonstrated multimodal structural reconstruction (Liu et al., 2018), while Plan2Scene demonstrated the conversion of floor plans into 3D scenes (Vidanapathirana et al., 2021). Structured3D provides photo-realistic structured 3D environments for architectural modelling (Zheng et al., 2020), and Yang et al. (2018) demonstrated automated indoor scene modelling from visual input. House-GAN further showed how architectural layouts can be represented through graphs capturing room types and spatial relationships (Nauata et al., 2020).

Point-cloud research provides an additional technical foundation for structured 3D modelling. PointNet directly processes point clouds for classification and segmentation, while PointNet++ extends this approach by learning hierarchical local features from point sets (Qi et al., 2017a, 2017b). Although Digital Twin Studio begins with a 2D floor plan rather than a point cloud, these studies are relevant to the broader problem of transforming spatial information into structured 3D representations.

6. SCAN-TO-BIM AND AUTOMATED MODEL GENERATION

Although Digital Twin Studio starts from a 2D floor plan rather than a point cloud, its structural conversion is closely related to the broader Scan-to-BIM and automated BIM reconstruction literature. Traditional Scan-to-BIM workflows have often required substantial manual intervention.

Tang et al. (2010) reviewed techniques for automatically reconstructing as-built building information models from laser-scanned point clouds and highlighted the challenge of extracting building components from point-cloud data.

Recent studies show a transition from rigid rule-based workflows toward AI-assisted automation. Queruel et al. (2024) reviewed AI approaches across Scan-to-BIM workflows, while You et al. (2026) examined automated Scan-to-BIM as part of construction digital transformation. Luo et al. (2026) focused on indoor Scan-to-BIM automation from mobile perception to 3D building modelling. Montás-Laracuente et al. (2025) systematically reviewed the use of AI for capturing real-world structures into BIM, and Chen and Luo (2026) reviewed progress and continuing challenges in indoor Scan-to-BIM workflows.

These studies support the broader research premise of raw architectural information → automated interpretation → structured BIM or digital model. Digital Twin Studio differs primarily in its input modality: it begins with a 2D floor plan rather than laser scans.

7. INTERIOR DESIGN AND MODEL ENRICHMENT

Once the structural model has been established, Digital Twin Studio allows the user to enrich it through interior design. Furniture, materials, flooring, lighting, colours, and other design components can be selected within the system. Plan2Scene demonstrates that floor plans can form the basis for 3D scenes with surface textures (Vidanapathirana et al., 2021), while House-GAN demonstrates the importance of spatial relationships in architectural layout generation (Nauata et al., 2020). Structured3D also provides structured architectural scenes containing interior elements (Zheng et al., 2020).

The design stage is intentionally user-controlled. Rather than automatically generating an entire interior, the system allows users to make design decisions and retrieve associated item, price, and texture information from an external catalogue service. This approach is consistent with the human-centred direction identified by Miraj et al. (2025), who emphasized the importance of user and organisational perspectives in Digital Twin research.

8. BIM, VR, AND IMMERSIVE VISUALIZATION

Virtual Reality is a major component of Digital Twin Studio because the system is intended to support spatial exploration rather than static visualization alone. Johansson et al. (2014) investigated the integration of BIM with immersive visualization in the design process, while Hilfert and König (2016) demonstrated a low-cost VR environment for engineering and construction. Zaker and Coloma (2018) proposed a VR-integrated workflow for BIM-enabled collaboration and design review.

Schiavi et al. (2022) reviewed BIM data-flow architectures involving AR/VR technologies across AEC use cases. Safikhani et al. (2022) systematically reviewed immersive VR in BIM and identified its potential to extend the use of building information models. Yigitbas et al. (2023) reviewed BIM and AR/VR research and found particular relevance during architectural and construction visualization. Alizadehsalehi et al. (2020) examined BIM-to-extended-reality workflows in the AEC industry.

The literature therefore supports the proposed sequence of Finalized Model → VR Engine → User Navigation → Walkthrough Feedback. The objective is not merely to display a model but to create an environment in which users can understand space, evaluate design alternatives, and communicate observations.

9. VR FOR DESIGN REVIEW AND USER FEEDBACK

VR is particularly relevant to Digital Twin Studio because the workflow extends beyond visualization to interactive review and feedback. Liu et al. (2020) studied VR-supported design review meetings and found that immersive environments can improve spatial understanding, although they are most effective when combined with other visualization media rather than treated as a complete replacement for conventional drawings.

Van den Berg et al. (2017) investigated pre-meeting VR environments in which clients could navigate a design and provide feedback before formal design meetings. Liu et al. (2014) found that VR could support design communication, evaluation of alternatives, and identification of design issues within an integrated design process. Paes et al. (2017) compared immersive and traditional VR and identified differences in users' spatial perception.

These findings support the inclusion of walkthrough feedback and design review as explicit stages of Digital Twin Studio rather than treating VR as the final visualization layer.

10. BIM–VR DATA EXCHANGE

A critical technical issue is the transfer of 3D and BIM information into the VR environment. Khalili (2021) proposed an XML-based geo-semantic exchange approach between BIM and VR applications using IFC and XML, addressing both geometry and semantic information transfer as well as communication from VR back to BIM.

Johansson et al. (2015) examined real-time visualization of large BIM models and identified performance challenges associated with complex models. Hu et al. (2019) investigated geometric optimization of BIM models to improve storage, transmission, and display performance. Johansson and Roupé (2024) further examined real-world applications of BIM and immersive VR in construction. Together, these studies support the need for a structured data pipeline in which the model is optimized before real-time rendering.

11. BIM INTEROPERABILITY AND IFC

The final stage of Digital Twin Studio includes BIM/IFC export. IFC is important because a digital model becomes more useful when it can be transferred between different BIM platforms rather than remaining locked within a single application. Laakso and Kiviniemi (2012) reviewed the history and development of IFC and identified interoperability among AEC/FM software as a central purpose of the standard. Laakso and Nyman (2014) mapped early IFC research and its relationship to BIM standardization.

Ozturk (2020) identified data loss and communication problems as continuing issues in BIM interoperability. Figueiredo Muller et al. (2019) emphasized that interoperability concerns extend beyond data exchange to processes and guidelines across the BIM lifecycle. Yu et al. (2023) reviewed trends and advances in IFC schema extensions, while Jiang et al. (2019) examined OpenBIM as an approach to information interoperability. Palha et al. (2024) investigated BIM interoperability in residential construction and lifecycle information management.

This literature supports the export-to-BIM/IFC stage of Digital Twin Studio and reinforces the decision to preserve structured information rather than export only a rendered 3D scene.

12. REAL-TIME BIM VISUALIZATION AND PERFORMANCE

Digital Twin Studio ultimately loads the model into a real-time environment. Large BIM models can contain substantial geometric and semantic information, which can affect rendering performance. Johansson et al. (2015) identified performance challenges associated with real-time visualization of detailed BIM models, while Hu et al. (2019) investigated geometric optimization, model simplification, and transmission efficiency.

These findings indicate that the structural model and interior information should be transformed into a representation suitable for real-time rendering. Model optimization is therefore not an isolated technical consideration; it is necessary to maintain responsive VR navigation and interaction within the proposed workflow.

13. HUMAN-IN-THE-LOOP DIGITAL TWIN

A defining feature of Digital Twin Studio is that AI does not have complete authority over the generated model. The proposed workflow follows AI/ML Detection → User Review → User Correction → Confirmed Structural Data. This is important because automated architectural interpretation may contain errors, particularly when floor plans are complex, poorly scanned, or contain ambiguous symbols and annotations.

Miraj et al. (2025) identified user and organisational perspectives as relatively underexplored aspects of Digital Twin research in the AEC sector. Getuli et al. (2020) demonstrated a related human-centred approach in which worker knowledge was incorporated into BIM-based planning through immersive simulations. These findings support positioning the user-review stage as a substantive human-in-the-loop mechanism rather than merely a user-interface feature. Human validation can complement automated interpretation and provide a practical safeguard before the generated model is used for design, visualization, or downstream BIM exchange.

14. OVERALL RESEARCH GAP

The literature demonstrates substantial research activity in each of the technological areas relevant to Digital Twin Studio: Digital Twin theory, BIM–Digital Twin relationships, floor-plan recognition, structured 3D reconstruction, OCR and computer vision, point-cloud processing, Scan-to-BIM, BIM and VR, VR-based design review, BIM–VR data exchange, IFC interoperability, and human-centred construction systems.

However, these areas are often addressed as separate technical problems. Floor-plan research generally concentrates on recognition or reconstruction; BIM research focuses on structured building information; VR research emphasizes visualization, interaction, and design review; IFC research concentrates on interoperability; and Digital Twin research focuses on connected digital representations and lifecycle processes.

Digital Twin Studio brings these research streams together in one proposed workflow: raw 2D floor plan → validation and preprocessing → AI/ML structural detection → OCR and semantic recognition → human review and correction → confirmed structural data → 2D-to-3D reconstruction → interior design and catalogue integration → real-time VR → walkthrough feedback → project versioning → BIM/IFC export and reporting.

The central research gap can therefore be stated as follows: although extensive research has established the feasibility of automated floor-plan interpretation, structured 3D reconstruction, BIM-based VR visualization, and interoperable BIM exchange, there remains an opportunity to integrate these capabilities into a unified, human-in-the-loop workflow that begins with a raw 2D floor plan and produces a validated 3D digital twin, an interactive VR experience, and an interoperable BIM/IFC output.

The contribution of Digital Twin Studio should consequently be framed as an integration-oriented system architecture rather than as a claim to invent floor-plan recognition, BIM, VR, IFC, or Digital Twin technology. Its research value lies in the way established capabilities are connected into a coherent workflow with explicit human validation, design enrichment, immersive review, and standards-based interoperability.

15. CONCLUSION

This literature review synthesized 63 references covering Digital Twin theory, BIM–Digital Twin relationships, computer-vision-based floor-plan recognition, OCR, structured 3D reconstruction, Scan-to-BIM automation, BIM–VR integration and data exchange, VR-based design review, and IFC interoperability. The review indicates that the individual technologies required by Digital Twin Studio have substantial research foundations.

At the same time, the literature points to continuing challenges related to fragmented lifecycle coverage, interoperability, model complexity, and user involvement. Digital Twin Studio is positioned as a response to this integration-oriented opportunity. Its proposed workflow combines automated interpretation with human validation, converts confirmed floor-plan information into structured 3D data, enriches the model through user-controlled interior design, enables immersive VR-based review, and preserves structured information for BIM/IFC exchange.

The human-in-the-loop approach is particularly important because it places architectural judgement alongside automated recognition. Rather than assuming that AI-generated geometry is immediately reliable, the system provides an explicit review and correction stage before the model is finalized. This makes the proposed framework more practical for architectural design workflows, where interpretation, communication, and iterative decision-making remain central to the process.

Table 1

Digital Twin and BIM literature mapped to Digital Twin Studio

Reference	Relevance to Digital Twin Studio
Boje et al. (2020)	Semantic Digital Twin concept
Opoku et al. (2021)	Digital Twin and BIM in construction/design
Jiang et al. (2021)	Distinguishing Digital Twins from BIM
AlBalkhy et al. (2024)	Overall Digital Twin architecture
Radzi et al. (2023)	BIM–Digital Twin relationship
Nguyen & Adhikari (2023)	BIM as an information foundation
Miraj et al. (2025)	User, organisational, AI, and VR perspectives
Baghalzadeh Shishehgarkhaneh et al. (2022)	Lifecycle-oriented BIM/IoT/DT research
Adu-Amankwa et al. (2023)	Digital Twin and lifecycle management
Saif et al. (2024)	Construction Digital Twin taxonomy and lifecycle integration
Nguyen & Adhikari (2026)	Digital Twin maturity and building lifecycle management

Note. The table summarizes the mapping reported in the source literature review.

Table 2

Floor-plan recognition and structured 3D literature

Study	Specific relevance
Liu et al. (2017)	Raster-to-vector architectural representation
Kalervo et al. (2019)	Floor-plan dataset and object recognition
Zeng et al. (2019)	Room, wall, and element recognition
Liu et al. (2018)	Automated floor-plan reconstruction
Zheng et al. (2020)	Structured 3D architectural data

Ikehata et al. (2015)	Structured rooms, walls, and objects
Yang et al. (2018)	Spatial layout reconstruction
Nauata et al. (2020)	Graph-based room relationships
Vidanapathirana et al. (2021)	Floor plan to textured 3D scene

Note. The table summarizes the mapping reported in the source literature review.

Table 3

Digital Twin Studio VR features and supporting literature

Digital Twin Studio feature	Supporting literature
VR walkthrough	Johansson et al. (2014); Hilfert & König (2016); Safikhani et al. (2022); Yigitbas et al. (2023)
Design visualization	Zaker & Coloma (2018); Liu et al. (2014); Liu et al. (2020)
User navigation	Hilfert & König (2016); Paes et al. (2017); Liu et al. (2014)
Walkthrough feedback	Van den Berg et al. (2017); Paes et al. (2017); Liu et al. (2020)
Collaborative review	Zaker & Coloma (2018); Schiavi et al. (2022); Alizadehsalehi et al. (2020)

Note. The table summarizes the mapping reported in the source literature review.

Table 4

Project components mapped to literature

Project component	Literature basis	Contribution
Digital Twin concept	Kritzinger et al. (2018); Tao et al. (2019a, 2019b); Boje et al. (2020); AlBalkhy et al. (2024)	DT definition, architecture, and lifecycle
BIM foundation	Boje et al. (2020); Opoku et al. (2021); Radzi et al. (2023); Nguyen & Adhikari (2023, 2026)	Structured building information
2D floor-plan input	Liu et al. (2017); Kalervo et al. (2019); Zeng et al. (2019); Liu et al. (2018)	Automated floor-plan interpretation
Wall / door / window detection	Zeng et al. (2019); Liu et al. (2018); Zheng et al. (2020)	Structural and object recognition
OCR labels	Schönfelder et al. (2024); Zhou et al. (2017); Redmon et al. (2016); He et al. (2017); Ronneberger et al. (2015); Chen et al. (2018)	Text detection and semantic recognition
Human validation	Miraj et al. (2025); Getuli et al. (2020)	Human-in-the-loop feedback
2D-to-3D reconstruction	Ikehata et al. (2015); Liu et al. (2018); Zheng et al. (2020); Nauata et al. (2020);	Structured spatial reconstruction

	Vidanapathirana et al. (2021)	
Interior design	Zheng et al. (2020); Nauata et al. (2020); Vidanapathirana et al. (2021)	Interior scene and layout enrichment
VR engine and visualization	Johansson et al. (2014, 2015); Hilfert & König (2016); Schiavi et al. (2022); Safikhani et al. (2022)	Immersive visualization and performance
Design review and feedback	Liu et al. (2014, 2020); Van den Berg et al. (2017); Paes et al. (2017)	Immersive spatial evaluation
BIM–VR data flow	Khalili (2021); Johansson et al. (2015); Hu et al. (2019); Johansson & Roupé (2024)	Semantic/geometric data transfer
IFC export	Laakso & Kiviniemi (2012); Ozturk (2020); Figueiredo Muller et al. (2019); Yu et al. (2023); Jiang et al. (2019); Palha et al. (2024)	Interoperability
Overall system integration	The combined literature base	Identifies the integration-oriented research gap

Note. The table summarizes the mapping reported in the source literature review.

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