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Designing Efficient Business Processes in the Metaverse with EffABPMN2MV: A Model-Driven Framework for Collaborative Software Design, AI-Driven Documentation, and Stakeholder Rights Management

Masoud. Rezaei[1], Abbas. Mirzaei[2*], Babak. Nouri-Moghaddam[2], Ramin. Karimi[3], Rahman. AliMohammadzadeh[1]

[1] Department of Computer Engineering, NT.C., Islamic Azad University, Tehran, Iran
[2] Department of Computer Engineering, Ard.C., Islamic Azad University, Ardabil, Iran
[3] Department of Computer Engineering, Sh. Q.C., Islamic Azad University, Shahr-e-Qods, Iran

*** Corresponding author email address**: a.mirzaei@iau.ac.ir

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A B S T R A C T

Business process management (BPM) faces three persistent structural challenges: (1) the exclusion of non-technical stakeholders from process design due to the complexity of BPMN 2.0 notation; (2) the fragmentation among requirements engineering, user interface design, and process modeling; and (3) the absence of a transparent mechanism for managing stakeholder intellectual property (IP) rights. This paper introduces EffABPMN2MV — a ten-layer collaborative design ecosystem operating within an immersive metaverse environment. The framework comprises three integrated components: (i) EffABPMN2MV-ML, a modeling language that maps metaverse UI interactions to BPMN 2.0 elements; (ii) EffABPMN2MV-Tools, a GPT-4-powered AI engine that automatically generates four standardized software deliverables; and (iii) EffABPMN2MV-SCB, a Hyperledger Fabric smart contract subsystem that immutably records stakeholder contributions and allocates LNT participation tokens. A controlled experiment with two parallel nine-member teams (Group A: EffABPMN2MV; Group B: Scrum) and an independent expert panel (n=15) was conducted using a banking loan application case study. EffABPMN2MV reduced documentation time by 58.3% ($t=4.82$, $p<.001$, Cohen's $d=2.28$), improved document quality by 21.4% ($d=1.65$), enhanced stakeholder experience ($d=2.27$), and raised legal transparency from 2.58 to 4.61 out of 5.0 ($d=3.47$). All effects were statistically significant ($p<.001$) with large effect sizes ($d>1.0$). EffABPMN2MV represents a theoretically grounded and empirically validated contribution to BPM, collaborative software design, and blockchain-enabled information systems.

Keywords: *EffABPMN2MV; BPMN 2.0; Metaverse; Blockchain; Collaborative software design*

1. Introduction

Business process management has become one of the central foundations of contemporary organizational design because it provides the conceptual, methodological, and technical means through which organizations identify, model, analyze, automate, monitor, and continuously improve their operational processes. In digitally intensive environments, business processes are no longer limited to internal administrative routines; rather, they represent socio-technical configurations through which customers, managers, analysts, developers, regulators, and intelligent systems interact across organizational boundaries. Within this context, business process modeling functions as a bridge between organizational strategy and information system implementation, enabling business requirements to be translated into executable or semi-executable representations that guide software development and operational governance. However, despite the maturity of business process management as a field, the practical modeling of business processes remains highly dependent on technical experts, specialized notations, and fragmented documentation practices. This creates a persistent gap between those who understand the business problem and those who can formally represent it in technical models (Dumas et al., 2018; Weske, 2019).

The Business Process Model and Notation, widely known as BPMN, has become the dominant standard for representing business processes because it offers a formal yet visually interpretable notation for events, activities, gateways, flows, pools, lanes, and message exchanges. BPMN 2.0 has been standardized as a comprehensive modeling language and is widely used in process analysis, workflow automation, system design, and enterprise architecture (Object Management, 2014). Its strength lies in its ability to create a common modeling grammar for business analysts, system architects, and software developers. Nevertheless, this same formal richness also creates a barrier for non-technical stakeholders. Customers, frontline employees, domain managers, and policy owners often possess critical knowledge about process expectations, exceptions, risks, and user needs, but they may not be able to express this knowledge directly through BPMN symbols and modeling conventions. As a result, process modeling frequently becomes an expert-mediated activity in which stakeholder knowledge is translated indirectly by analysts. This indirect translation may reduce accuracy, weaken stakeholder ownership, and produce documentation that only partially reflects the actual business context (Chinosi & Trombetta, 2012; Weske, 2019).

The limitations of conventional BPMN-based modeling are not merely notational; they are also methodological and organizational. In many software design projects, requirements are collected in one tool, user interface prototypes are created in another tool, user stories are managed in agile project management platforms, and process models are maintained separately by business analysts. This fragmentation reduces traceability between the business process, user interface behavior, software requirements, user stories, acceptance criteria, and final development tasks. Model-driven engineering has long argued that higher-level models should serve as primary artifacts from which lower-level software representations, documentation, and implementation structures can be systematically derived (Schmidt, 2006). However, in practice, many model-driven approaches remain highly technical and insufficiently participatory. The challenge, therefore, is not only to create formal models, but to create an integrated modeling ecosystem in which non-technical stakeholders can participate meaningfully while technical consistency, documentation quality, and process traceability are preserved.

A further challenge concerns the visual and cognitive accessibility of modeling languages. The effectiveness of a notation depends not only on its formal expressiveness but also on its cognitive fit with the users who must interpret and manipulate it. Moody’s principles for visual notation design emphasize perceptual discriminability, semantic transparency, complexity management, and cognitive effectiveness as essential conditions for usable modeling languages (Moody, 2009). From this perspective, conventional BPMN can be considered powerful but not always cognitively transparent for non-expert stakeholders. A promising solution is to use familiar user interface metaphors, such as forms, buttons, dashboards, approval panels, digital signature areas, progress trackers, and interaction screens, as participatory modeling objects. These objects can then be formally mapped to BPMN elements in the background. Such an approach preserves the rigor of BPMN while allowing stakeholders to work with visual objects that are closer to their everyday digital experience.

The emergence of metaverse technologies creates a new opportunity to redesign the participation model of business process design. The metaverse can be understood as an immersive, shared, persistent, and interactive digital environment in which users are represented through avatars and can collaborate with digital objects and other participants in real time. In business contexts, metaverse environments are increasingly discussed as platforms for collaborative innovation, simulation, training, prototyping, and value co-creation (Latino et al., 2024). Unlike conventional video conferencing or screen-based collaboration tools, metaverse environments can provide spatial co-presence, embodied interaction, shared artifacts, and multimodal participation. These features are directly relevant to business process modeling because process design is inherently collaborative and benefits from real-time negotiation among stakeholders with different roles, knowledge bases, and decision rights.

Recent research on metaverse user experience has highlighted that immersive environments can support new forms of organizational collaboration when they are designed around user-centered interaction, shared meaning-making, and task-specific digital affordances (Gandhi et al., 2024). However, the metaverse has not yet been fully operationalized as a structured environment for BPMN-based process modeling and software design documentation. Much of the existing work treats the metaverse as a general collaboration or innovation space rather than as a formal modeling infrastructure. At the same time, metaverse environments introduce new security, identity, privacy, and governance concerns, particularly when organizational decisions, user data, process designs, and intellectual contributions are created in immersive digital spaces (Wang et al., 2023). Therefore, any metaverse-based business process design framework must address not only collaboration and usability, but also auditability, contribution traceability, access control, and rights management.

Artificial intelligence, particularly large language models, adds another transformative layer to the redesign of business process documentation. AI-based systems can now generate, validate, summarize, and transform structured and semi-structured information into formal documentation formats. In the BPM domain, recent work has explored the capacity of artificial intelligence to generate and validate BPMN diagrams from textual descriptions, showing that structured input can improve the reliability of AI-generated process outputs (Asllani, 2024). This is especially important for software design because a major source of inefficiency is the manual conversion of stakeholder discussions into software requirements specifications, user stories, process models, and design documentation. If stakeholder interactions can be captured as structured design data, AI engines can potentially generate standardized deliverables more rapidly and consistently than manual documentation processes.

The growing interaction between AI agents and smart contracts also suggests that automation is moving beyond documentation toward autonomous coordination, validation, and execution of agreement-based actions. AI agents can interpret operational data, recommend decisions, trigger workflows, and interact with smart contract logic, while smart contracts can formalize predefined conditions for automatic execution (Yodaplus, 2025). This convergence is especially relevant to collaborative software design because design activities generate not only technical outputs but also contribution claims, approval records, responsibility assignments, and potential intellectual property interests. In such settings, AI can support documentation and analysis, while blockchain and smart contracts can support accountability and rights allocation.

Blockchain technology provides a complementary infrastructure for trust, transparency, and immutable recording of digital transactions. Since the introduction of peer-to-peer electronic cash, blockchain has been recognized as a mechanism for creating distributed records without reliance on a single trusted intermediary (Nakamoto, 2009). Smart contracts extend this logic by formalizing and securing relationships through code-based execution of predefined conditions (Szabo, 1997). Contemporary definitions of smart contracts commonly emphasize their function as self-executing agreements whose terms are represented in computer code and executed on blockchain or distributed ledger infrastructures (Wikipedia, 2025). Although the legal and philosophical status of "code as law" remains contested, the concept has become increasingly important in discussions of digital governance, automation, and legal enforceability (Yusuf & Martinez, 2025). These issues are especially significant in collaborative design environments where multiple stakeholders contribute ideas, requirements, approvals, and design decisions that may later generate economic or intellectual value.

In business process management, blockchain has already been explored as a mechanism for monitoring, executing, and securing collaborative processes. Early work showed that blockchain could support untrusted business process monitoring and execution by creating a tamper-resistant record of process-related events (Weber et al., 2016). Subsequent studies examined dynamic role binding in blockchain-based collaborative business processes, demonstrating how distributed ledger mechanisms can support flexible participation and role assignment across organizational boundaries (Lopez-Pintado et al., 2019). Broader reviews of blockchain applications have also identified intellectual property rights, auditability, traceability, and trusted automation as major application domains (Casino et al., 2019). These developments indicate that blockchain can support business process governance, but much of the prior work has focused on process execution or security rather than on the recording of stakeholder design contributions during the earlier stages of process modeling and software specification.

More recent blockchain-related BPM research has attempted to connect process modeling with blockchain deployment and security requirements. SecBPMN2BC, for example, extends BPMN-based process design toward secure blockchain implementation, showing that BPMN can be adapted for blockchain-oriented systems (Kopke et al., 2023). However, such approaches generally preserve an expert-centric modeling structure and do not directly solve the problem of non-technical stakeholder participation in process design. Similarly, Hyperledger Fabric has been introduced as a permissioned blockchain operating system suitable for enterprise environments, offering modularity, identity management, privacy, and controlled participation (Androulaki et al., 2018). These characteristics make it particularly appropriate for organizational contexts such as banking, where permissioned access, traceable transactions, and governance control are essential. In the banking industry specifically, the future of smart contracts is increasingly shaped by drivers related to regulation, trust, security, operational efficiency, digital transformation, and institutional readiness (Adeli & Maleki, 2026). Legal and dispute-resolution scholarship has likewise emphasized that smart contracts and technology-assisted review may reshape evidentiary practices, contractual governance, and dispute management in complex industries (Ru, 2026).

Despite these developments, a major gap remains at the intersection of BPMN, metaverse collaboration, AI-driven documentation, and blockchain-based rights management. Existing BPMN approaches provide formal modeling power but limited stakeholder accessibility. Existing metaverse research provides immersive collaboration but rarely connects this collaboration to formal process modeling and standardized software deliverables. Existing AI documentation research demonstrates the potential of automated generation but often depends on textual inputs rather than structured multi-stakeholder design activities. Existing blockchain-based BPM research provides auditability and execution mechanisms but rarely focuses on the attribution of stakeholder contributions during collaborative design. Finally, existing smart contract studies emphasize automation and enforceability but do not sufficiently address how contribution data can be generated, normalized, and linked to process design artifacts in real time. This fragmentation creates the need for an integrated model-driven framework that can unify participatory process modeling, metaverse-based collaboration, AI-generated documentation, and transparent stakeholder rights management.

Design science research provides an appropriate methodological foundation for addressing this gap because it focuses on the creation and evaluation of purposeful artifacts that solve identified organizational and technological problems. The design science research methodology emphasizes problem identification, objective definition, artifact design and development, demonstration, evaluation, and communication (Peffers et al., 2007). In the context of business process design, this means that the research contribution should not be limited to theoretical argumentation; it should also produce an operational framework that can be demonstrated and empirically evaluated. A design science approach is especially suitable for EffABPMN2MV because the framework is intended to function simultaneously as a modeling language, a collaborative environment, an AI documentation engine, and a blockchain-based governance mechanism.

Accordingly, EffABPMN2MV is proposed as a ten-layer model-driven framework for designing efficient business processes in the metaverse. Its architecture integrates a Design Domain, a Collaboration Domain, and a Governance Domain. The Design Domain supports process modeling, UI/UX linkage, requirements management, and user story development. The Collaboration Domain enables real-time metaverse-based stakeholder participation and AI-generated deliverables. The Governance Domain records stakeholder actions through blockchain audit mechanisms, executes smart contract and participation token logic, tracks contributions, and supports business workflow monitoring. Through its Design Capsule concept, each process activity is linked to its BPMN element, user interface element, requirement, user story, stakeholder contribution, AI analysis, blockchain audit record, smart contract logic, and token information. This structure is intended to eliminate the separation between business need, process model, software documentation, and stakeholder rights attribution.

The aim of this study was to design and evaluate EffABPMN2MV as a ten-layer model-driven framework for collaborative business process design in the metaverse, integrating BPMN-based modeling, AI-driven software documentation, and blockchain-based stakeholder rights management.

2. Methods and Materials

2.1. Study Design and Sample

This study was conducted using a design science research approach combined with a controlled comparative evaluation. The research was organized around the development, demonstration, and empirical assessment of EffABPMN2MV as a model-driven framework for designing efficient business processes in a metaverse-based collaborative environment. The methodological logic followed the Design Science Research Methodology, in which the research problem was first identified through the analysis of persistent limitations in conventional business process management, including the limited participation of non-technical stakeholders, the fragmentation between business process modeling, requirements engineering, user interface design, and documentation, and the absence of a transparent mechanism for recording stakeholder contributions and intellectual property rights. Based on these identified problems, EffABPMN2MV was designed as a ten-layer ecosystem composed of three integrated domains: the Design Domain, the Collaboration Domain, and the Governance Domain. In the design phase, the framework was specified through the EffABPMN2MV-ML modeling language, the EffABPMN2MV-Tools AI-driven documentation engine, and the EffABPMN2MV-SCB blockchain-based contribution and rights management subsystem. The empirical part of the study was then conducted to compare the performance of the proposed framework with a conventional Scrum-based software design process.

The study used a banking loan application process as the demonstration and evaluation case. This case was selected because it involves multiple stakeholders, contains both technical and non-technical decision points, requires traceable documentation, and includes approval, validation, contract, and execution stages that are suitable for evaluating process modeling, documentation quality, stakeholder collaboration, and rights transparency. The modeled process included nine main stages: process initiation, application submission, credit validation, collateral assessment, credit review, contract generation, digital signature, loan disbursement, and process completion. In addition, the approval workflow involved five organizational decision roles, including the loan officer, deputy manager, branch manager, credit manager, and credit committee. This structure provided a sufficiently complex but controlled context for testing the capability of EffABPMN2MV to integrate process modeling, user interface design, requirements documentation, user stories, AI-generated outputs, and blockchain-based contribution tracking.

The final evaluation sample consisted of 33 participants. Eighteen participants were assigned to two parallel project teams, with nine members in each team. Group A, consisting of nine participants, used the EffABPMN2MV framework in a simulated metaverse environment developed with Unreal Engine. Group B, also consisting of nine participants, used a conventional Scrum-based workflow supported by Jira, Figma, and Confluence. Both teams had identical role composition in order to control for functional differences between the two groups. Each team included two customers, one loan officer, one deputy manager, one branch manager, one business analyst, one UI/UX designer, one software developer, and one project manager. The independent evaluation panel consisted of 15 experts who assessed the outputs produced by both groups. Therefore, the main study sample included 18 experimental participants and 15 expert evaluators. In addition, the questionnaire was pilot-tested with five participants before the main evaluation, and these five individuals were not included in the final statistical comparison. Thus, 38 individuals were involved across the pilot and main phases, while the final reported evaluation was based on 33 participants.

The two experimental groups were designed to be comparable in demographic and professional characteristics. In Group A, the mean age was 31.4 years with a standard deviation of 4.2 years; the group included six male and three female participants, and the mean work experience was 6.8 years with a standard deviation of 2.4 years. In Group B, the mean age was 32.1 years with a standard deviation of 3.9 years; the group also included six male and three female participants, and the mean work experience was 7.1 years with a standard deviation of 2.8 years. The expert panel had a higher level of professional experience, with a mean age of 38.6 years and a standard deviation of 6.1 years; it included 11 male and four female experts, with a mean work experience of 14.3 years and a standard deviation of 5.7 years. Familiarity with BPMN was lower in the two project teams than in the expert panel, which was methodologically appropriate because the study aimed to evaluate whether EffABPMN2MV could support participation by stakeholders who were not necessarily expert BPMN modelers.

2.2. Data Collection

The first data collection tool was the EffABPMN2MV framework artifact itself. The framework was used both as the intervention environment for Group A and as the main object of design science evaluation. EffABPMN2MV was structured around a ten-layer architecture. The Design Domain included the Process Layer, UI/UX Layer, Requirements Layer, and User Story Layer. The Collaboration Domain included the Stakeholder Collaboration Layer and the AI-Generated Deliverables Layer. The Governance Domain included the Blockchain Audit Layer, Smart Contract and Participation Token Layer, Contribution Tracking Layer, and Business Workflow Layer. This ten-layer architecture was not treated merely as a descriptive model; rather, it functioned as the primary methodological structure through which data were generated, organized, and evaluated. Each layer produced traceable design evidence, ranging from process elements and interface components to requirements, user stories, stakeholder interactions, AI-generated documents, blockchain audit records, contribution scores, and workflow monitoring outputs.

The second tool was the Design Capsule protocol. In this study, each business process activity was represented as a Design Capsule, which served as the main unit of data capture and integration. A Design Capsule linked the BPMN process element to its corresponding user interface element, requirement description, user story, stakeholder contribution, AI analysis, blockchain audit record, smart contract and token logic, and participation token information. This structure enabled vertical traceability from business intent to software design documentation and governance evidence. During the metaverse-based design sessions, stakeholder actions such as placing process elements, completing forms, adding requirements, commenting on design decisions, approving or rejecting artifacts, and adding user stories were captured as structured activity records. These records were then used to generate design outputs and to evaluate stakeholder participation, documentation quality, and governance transparency.

The third tool was the metaverse-based collaborative workspace used by Group A. This environment was implemented as a simulated immersive workspace in Unreal Engine and was designed to allow stakeholders to interact with process elements, interface components, shared design objects, and collaborative artifacts through familiar visual metaphors. The environment supported real-time collaboration, shared artifacts, virtual workspace interaction, and role-based participation. Instead of requiring non-technical participants to directly manipulate BPMN notation, the system allowed them to work with recognizable UI components such as forms, buttons, dashboards, approval panels, digital signature panels, and workflow connectors. These elements were then mapped to BPMN 2.0 concepts through the EffABPMN2MV-ML modeling language. This tool was central to evaluating whether the framework could reduce the cognitive barrier of BPMN-based process design and improve stakeholder inclusion.

The fourth tool was the conventional Scrum-based software design environment used by Group B. This environment consisted of Jira for task and workflow management, Figma for user interface design, and Confluence for documentation. Group B followed a traditional collaborative software design process in which requirements, UI design, process documentation, and user stories were produced through separate tools and coordinated through Scrum practices. This group served as the comparison condition against which EffABPMN2MV was evaluated. Both Group A and Group B worked on the same banking loan application case and were required to produce the same core deliverables, including a BPMN process model, a software requirements specification document, a UI/UX design package, and a user stories document with acceptance criteria.

The fifth tool was the EffABPMN2MV-Tools AI documentation engine. This component collected structured activity data from the metaverse workspace and transformed them into standardized software deliverables. The engine followed a three-stage pipeline. In the first stage, stakeholder activities were parsed and serialized into structured activity logs. In the second stage, collaboration scores were calculated based on weighted activity categories, including process element definition, requirement entry, design approval, and user story addition. In the third stage, the structured activity data were processed through GPT-4-based engineered prompts to generate standardized documentation. The outputs included BPMN 2.0 XML, a software requirements specification document, a UI/UX design package, and a user stories document. These generated artifacts were later assessed by participants and by the expert panel.

The sixth tool was the EffABPMN2MV-SCB blockchain and smart contract subsystem. This subsystem was implemented conceptually around Hyperledger Fabric and was used to record stakeholder actions as immutable contribution records. The recorded events included process element placement, requirement and annotation entry, approval actions, and user story additions. The subsystem also supported the calculation of participation tokens, referred to as LNT tokens, based on the relative contribution of each stakeholder. This mechanism was used to evaluate legal transparency, contribution traceability, and intellectual property rights management. The blockchain audit log provided objective system-generated evidence that complemented the subjective questionnaire data and expert evaluations.

The seventh tool was a structured Likert-scale evaluation questionnaire. The questionnaire contained 27 items scored on a five-point scale and measured four main dimensions: design speed, document quality, stakeholder experience, and legal transparency. Design speed assessed the perceived and observed efficiency of producing standard software design deliverables. Document quality assessed the clarity, completeness, standard compliance, and usefulness of the produced BPMN model, requirements document, UI/UX package, and user stories. Stakeholder experience assessed ease of participation, perceived inclusiveness, collaboration quality, and usability of the design process. Legal transparency assessed the perceived clarity, fairness, traceability, and reliability of contribution recording and rights allocation. The questionnaire was pilot-tested with five participants before the main study. Internal consistency was acceptable across all four dimensions, with Cronbach's alpha values of 0.89 for design speed, 0.91 for document quality, 0.87 for stakeholder experience, and 0.88 for legal transparency.

The eighth tool was the expert assessment protocol. The outputs of both groups were evaluated through self-assessment, cross-assessment, and independent expert assessment. The expert panel consisted of 15 evaluators who reviewed the deliverables produced by both teams. The expert evaluation focused on the quality of the BPMN process model, compliance and completeness of the software requirements specification, clarity and usability of the UI/UX package, quality of user stories and acceptance criteria, overall traceability between artifacts, and transparency of contribution and rights management. The expert panel evaluation was conducted independently and blindly in order to reduce bias. Inter-rater agreement among the expert panel members was assessed using Krippendorff's alpha, which was 0.84 and indicated acceptable agreement.

2.3. Data Analysis

Data analysis was conducted in two consecutive levels because the study included both artifact design and empirical evaluation. At the first level, the EffABPMN2MV model was analyzed as a design science artifact. This analysis focused on the internal coherence of the proposed ten-layer architecture, the consistency of the three-domain structure, the logical completeness of the Design Capsule, the alignment between metaverse UI elements and BPMN 2.0 process elements, and the traceability of outputs across process modeling, user interface design, requirements engineering, user stories, AI-generated documentation, and blockchain-based contribution tracking. This artifact-level analysis was necessary because the first major finding of the study concerns the proposed ten-layer EffABPMN2MV model itself. Therefore, the framework architecture, Design Capsule structure, ecosystem model, process model, modeling language, AI documentation engine, and smart contract-based governance subsystem were treated as primary design outputs before the comparative statistical results were interpreted.

At the second level, quantitative data from the controlled comparison were analyzed. Descriptive statistics, including means and standard deviations, were calculated for all main evaluation dimensions. The time required to produce the four core deliverables was compared between the EffABPMN2MV group and the Scrum group. Percentage reduction in documentation time was calculated by comparing the mean completion time of Group A with that of Group B. Questionnaire scores and expert ratings were normalized using Delphi-based normalization so that all ratings could be interpreted on a common five-point scale. A composite evaluation index was then calculated by averaging the normalized scores across the four major dimensions of design speed, document quality, stakeholder experience, and legal transparency.

Inferential analysis was conducted using independent-samples two-tailed t-tests to compare the EffABPMN2MV group and the Scrum group across the four main evaluation dimensions. The significance level was set at 0.05. In addition to statistical significance, effect size was calculated using Cohen's d in order to determine the practical magnitude of differences between the two groups. Cohen's d was calculated by dividing the absolute difference between the two group means by the pooled standard deviation. Effect sizes were interpreted as indicators of the strength of the framework's impact on efficiency, documentation quality, stakeholder experience, and legal transparency. Internal consistency of the questionnaire was assessed using Cronbach's alpha, and agreement among expert evaluators was assessed using Krippendorff's alpha. The blockchain audit records were analyzed descriptively by examining the number and distribution of recorded transactions, the frequency of different contribution types, and the resulting distribution of participation tokens among stakeholders. This combination of artifact analysis, descriptive statistics, inferential testing, effect-size estimation, reliability assessment, expert agreement analysis, and blockchain audit validation provided a comprehensive basis for evaluating the technical, collaborative, and governance performance of EffABPMN2MV.

3. Findings and Results

The findings of the study are presented in two complementary parts. First, the structural and design findings of the EffABPMN2MV framework are reported, because the main output of the study was the development of a ten-layer model-driven architecture for business process design in the metaverse. Second, the empirical evaluation findings are presented to compare the performance of EffABPMN2MV with a conventional Scrum-based software design process in terms of design speed, document quality, stakeholder experience, legal transparency, and blockchain-based contribution validation.

The first major finding of the study was the development of the EffABPMN2MV ten-layer architecture. The model organizes the collaborative business process design lifecycle into three interconnected domains: the Design Domain, the Collaboration Domain, and the Governance Domain. The Design Domain includes the layers responsible for process modeling, UI/UX design, requirements management, and user story development. The Collaboration Domain supports real-time stakeholder participation and AI-generated documentation. The Governance Domain provides blockchain-based auditability, smart contract execution, contribution tracking, participation token allocation, and business workflow monitoring. This architecture shows that business process design in the metaverse can be structured as an integrated model-driven ecosystem rather than as a fragmented set of independent modeling, design, documentation, and governance activities.

Table 1

EffABPMN2MV Ten-Layer Architecture

Domain	Layer	Layer Title	Main Function in the Framework
Design Domain	Layer 1	Process Layer	Models business processes using extended BPMN elements within the metaverse environment and establishes the process logic of the system.
Design Domain	Layer 2	UI/UX Layer	Links each process activity to corresponding interface screens, interaction elements, forms, dashboards, approval panels, and user experience artifacts.
Design Domain	Layer 3	Requirements Layer	Captures and manages functional and non-functional requirements related to each business process activity.
Design Domain	Layer 4	User Story Layer	Converts stakeholder needs and process activities into user stories and acceptance criteria for software development.
Collaboration Domain	Layer 5	Stakeholder Collaboration Layer	Enables real-time participation of customers, managers, analysts, designers, developers, and other stakeholders in the metaverse workspace.
Collaboration Domain	Layer 6	AI-Generated Deliverables Layer	Uses AI-driven processing to generate standardized software deliverables from structured design data and stakeholder activities.
Governance Domain	Layer 7	Blockchain Audit Layer	Records stakeholder actions, decisions, approvals, and design changes as immutable blockchain audit records.
Governance Domain	Layer 8	Smart Contract and Participation Token Layer	Executes smart contract logic and allocates participation tokens according to recorded stakeholder contributions.
Governance Domain	Layer 9	Contribution Tracking Layer	Measures and evaluates stakeholder contributions across process modeling, requirement entry, design approval, and user story development.
Governance Domain	Layer 10	Business Workflow Layer	Supports end-to-end business workflow execution, monitoring, and continuity from design to implementation.

Figure 1

EffABPMN2MV Ten-Layer Architecture — Design, Collaboration, and Governance domains

The second structural finding was the formation of the Design Capsule as the central unit of traceability in the EffABPMN2MV framework. Each Design Capsule integrates nine dimensions: the BPMN process element, the related UI element, the requirement, the user story, stakeholder contributions, AI analysis, blockchain audit record, smart contract and token logic, and participation token information. This finding indicates that the framework can preserve vertical traceability from the original business need to technical documentation and stakeholder rights management. In contrast to conventional approaches in which process models, requirements, user interface files, user stories, and contribution records are often produced in separate tools, the Design Capsule provides a unified artifact that connects all relevant design and governance information.

The framework also produced a formal modeling language, EffABPMN2MV-ML, which maps familiar metaverse user interface elements to BPMN 2.0 elements. This mapping was an important finding because it operationalizes non-expert participation in business process modeling. Instead of asking non-technical stakeholders to directly use abstract BPMN symbols, the framework allows them to interact with familiar components such as entry screens, forms, dashboards, decision buttons, digital signature panels, AI widgets, token transfer widgets, progress trackers, organization pools, and connector arrows. These metaverse-side elements are then translated into BPMN-compatible process elements.

Table 2

Primary Mapping of Metaverse UI Elements to BPMN 2.0 in EffABPMN2MV-ML

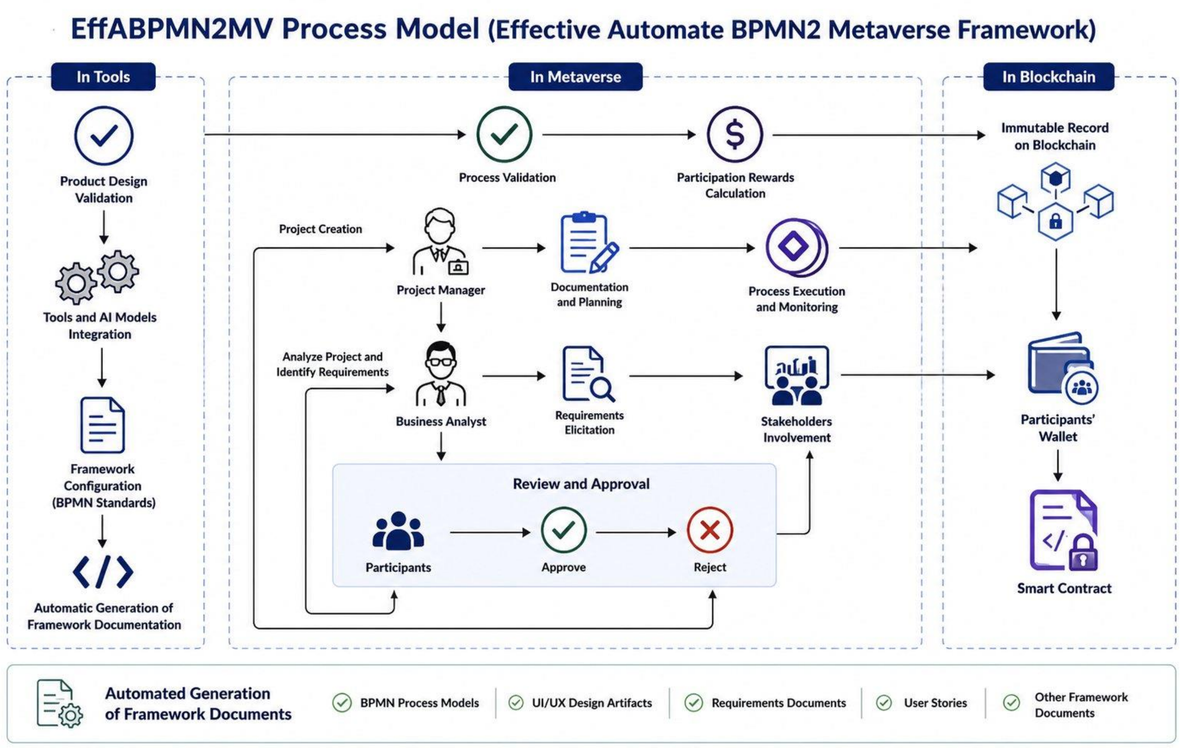
Code	Metaverse UI Element	BPMN 2.0 Equivalent	Mapping Rule
E01	Login or Entry Screen	Start Event	User entry into the metaverse workspace triggers the beginning of the business process.
E02	Exit or Completion Screen	End Event	Completion of the workspace interaction or exit from a completed process zone indicates process termination.

E03	Smart Contract Trigger	Message Start Event	Invocation of smart contract logic initiates a blockchain-related process event.
T01	Input Form	User Task	Completion of a data-entry form by an avatar is interpreted as a user task.
T02	Review Dashboard	User Task / Review Task	Review and approval screens are mapped to specialized user tasks.
T03	Digital Signature Panel	Manual Task	Off-chain confirmation or signature activity is mapped to a manual task.
T06	AI Analysis Widget	Service Task	Automated AI analysis, validation, or recommendation is mapped to a service task.
T08	Token Transfer Widget	Blockchain-Integrated Service Task	Blockchain-based token transfer is interpreted as a service task integrated with the governance subsystem.
G01	Binary Decision Buttons	Exclusive Gateway	Mutually exclusive decisions such as approve/reject generate an XOR gateway.
G03	Parallel Progress Tracker	Parallel Gateway	Simultaneous active activities are represented as AND-gateway logic.
S01	Organization Pool	Pool	A distinct organizational participant or unit is represented as a BPMN pool.
C01	Connector Arrow	Sequence Flow	Directed connections between UI components represent execution order within the same process boundary.

The process model of EffABPMN2MV further showed how the framework operates across three execution domains: Tools, Metaverse, and Blockchain. In the Tools domain, product design validation, AI model integration, BPMN-standard configuration, and automatic framework documentation are performed. In the Metaverse domain, the project manager creates the project, defines the team, and coordinates collaborative process design; the business analyst elicits and analyzes requirements; participants review and approve artifacts; and the process is executed and monitored after approval. In the Blockchain domain, all relevant events are recorded immutably, participation rewards are calculated, participant wallets are updated, and smart contracts execute the defined ownership and reward logic.

Figure 2

EffABPMN2MV Process Model — workflow across the Tools, Metaverse, and Blockchain domains



The AI documentation engine generated four standard software deliverables from stakeholder activities and Design Capsules: a BPMN 2.0 process model, a software requirements specification document, a UI/UX design package, and a user stories document with acceptance criteria. The activity parsing mechanism recorded element placement, form completion, annotation entry, design approval, and user story additions. These activities were then scored through a weighted contribution mechanism in which process element definition, requirement entry, design approval, and user story addition were assigned different weights. The structured data were subsequently processed through AI-based prompts to generate standardized documentation. This finding shows that the framework can reduce manual documentation work by converting collaborative metaverse interactions into formal software design outputs.

In the empirical evaluation, Group A used EffABPMN2MV in a simulated metaverse environment, while Group B used a conventional Scrum-based workflow supported by Jira, Figma, and Confluence. Each group consisted of nine participants with identical role composition, including two customers, one loan officer, one deputy manager, one branch manager, one business analyst, one UI/UX designer, one developer, and one project manager. The outputs of both groups were assessed through self-assessment, cross-assessment, and blind expert evaluation by a 15-member expert panel. Although the demographic information had originally been organized in tabular form, it is reported here narratively to preserve the focus of the findings section on the three main tables. Group A had a mean age of 31.4 years and mean work experience of 6.8 years, while Group B had a mean age of 32.1 years and mean work experience of 7.1 years. The expert panel had a mean age of 38.6 years and mean work experience of 14.3 years. BPMN familiarity was low in the two project teams and high in the expert panel, which was appropriate for evaluating both non-expert participation and expert judgment of the final deliverables.

The quantitative findings showed that EffABPMN2MV outperformed the Scrum-based comparison condition across all evaluation dimensions. The most visible difference was found in design speed. Group A completed all four standard deliverables in 3.8 ± 0.6 hours, whereas Group B required 9.2 ± 1.3 hours. This indicates a 58.3% reduction in documentation and design completion time. The difference was statistically significant and had a large effect size. The improvement can be attributed to the integration of process modeling, UI/UX design, requirements capture, and user story generation within a single metaverse-based design environment, as well as the automated generation of deliverables by the AI documentation engine.

Document quality was also higher in the EffABPMN2MV group. The expert-rated quality score for Group A was 4.21 ± 0.38, compared with 3.47 ± 0.51 for Group B. The difference represented a 21.4% improvement in documentation quality. The strongest sub-dimensional improvement was observed in the software requirements specification, where Group A achieved stronger compliance with structured documentation expectations. BPMN conformance was also higher in Group A because the framework generated process structures from formal mappings between metaverse UI components and BPMN 2.0 elements, thereby reducing manual notation errors.

Stakeholder experience was significantly better in the EffABPMN2MV condition. Group A achieved a mean score of 4.38 ± 0.42, while Group B achieved a mean score of 3.11 ± 0.67. Non-technical participants in Group A, especially customers and managerial participants, reported greater inclusiveness and ease of participation. This finding supports the central assumption of the framework: using familiar UI metaphors in a metaverse workspace can reduce the cognitive barrier associated with BPMN and allow non-technical stakeholders to contribute more directly to process design.

The strongest difference was observed in legal transparency. Group A achieved a score of 4.61 ± 0.31, compared with 2.58 ± 0.74 for Group B. The expert panel specifically endorsed the LNT participation token mechanism as a practical and innovative approach for recording stakeholder contributions and supporting intellectual property rights management. This finding demonstrates the value of the blockchain and smart contract subsystem as a governance mechanism, not merely as a technical add-on. By recording each design action as an immutable transaction, the framework provided transparent evidence for contribution attribution and rights allocation.

Table 3

Evaluation Results of EffABPMN2MV Compared with Scrum

Evaluation Dimension	EffABPMN2MV Mean	Scrum Mean	Main Empirical Difference	t	p	Cohen's d
Design Speed	4.47 ± 0.38	2.01 ± 0.61	58.3% reduction in time required to produce deliverables	4.82	< .001	2.28
Document Quality	4.26 ± 0.41	3.47 ± 0.52	21.4% improvement in expert-rated documentation quality	4.14	< .001	1.65
Stakeholder Experience	4.45 ± 0.42	3.11 ± 0.67	Higher inclusiveness, usability, and collaborative participation	5.01	< .001	2.27
Legal Transparency	4.62 ± 0.31	2.58 ± 0.74	Stronger contribution traceability and rights-management transparency	7.24	< .001	3.47
Composite Index	4.45 ± 0.36	2.79 ± 0.63	Overall superiority of EffABPMN2MV across all evaluation dimensions	6.74	< .001	2.61

The blockchain audit validation further supported the governance-related findings. The Hyperledger Fabric audit log recorded 1,247 transactions across nine blocks during the case study, with an average of 138.6 recorded transactions per participant. The transaction distribution showed that 34.2% of the recorded actions were related to element placement, 28.7% to requirement or annotation entry, 19.3% to approval actions, and 17.8% to user story additions. Participation token allocation ranged from 6% for the least active participant to 12% for the most active participant. All 15 experts rated the audit log as sufficient evidence for intellectual property attribution, with a mean score of 4.61 out of 5.0. These results indicate that the blockchain subsystem successfully captured different forms of stakeholder contribution and translated them into an auditable basis for participation-based rights allocation.

Overall, the findings demonstrate that EffABPMN2MV produced both a coherent model-driven architecture and statistically significant empirical advantages over a conventional Scrum-based process. The ten-layer architecture established the structural foundation of the framework, the Design Capsule enabled integrated traceability, the modeling language connected metaverse UI interactions to BPMN 2.0, the AI engine automated software documentation, and the blockchain subsystem provided transparent stakeholder rights management. Empirically, the framework improved design speed, document quality, stakeholder experience, and legal transparency, with all differences reaching statistical significance and all reported effect sizes falling in the large range.

4. Discussion and Conclusion

The findings of this study demonstrate that EffABPMN2MV provides both a conceptual and empirical response to persistent limitations in conventional business process management and collaborative software design. The first major result was the development of a ten-layer architecture organized into the Design, Collaboration, and Governance domains. This architecture is important because it moves business process design beyond isolated BPMN modeling and positions it as an integrated socio-technical ecosystem in which process logic, UI/UX design, requirements, user stories, stakeholder participation, AI-generated documentation, blockchain auditability, smart contract logic, contribution tracking, and workflow monitoring are structurally connected. This finding is consistent with the broader logic of business process management, which emphasizes that process models must support organizational analysis, technical specification, and operational improvement rather than function merely as static diagrams (Dumas et al., 2018; Weske, 2019). It also extends the BPMN tradition by addressing one of its major practical weaknesses: although BPMN 2.0 provides a mature standard for representing business processes, its formal notation remains difficult for non-technical stakeholders to manipulate directly (Chinosi & Trombetta, 2012; Object Management, 2014). Therefore, the ten-layer architecture of EffABPMN2MV can be interpreted as an attempt to preserve the formal rigor of BPMN while redistributing process design participation across a broader stakeholder network.

The finding related to the Design Capsule is particularly significant because it addresses the fragmentation that commonly occurs between business process modeling, interface design, requirements engineering, user stories, and governance records. In conventional software development, these artifacts are often produced and maintained in separate environments, creating discontinuity between business intent and implementation specifications. The Design Capsule integrates each process element with its associated

UI element, requirement, user story, stakeholder contribution, AI analysis, blockchain record, smart contract logic, and token information. This supports the central assumption of model-driven engineering that models should act as primary artifacts from which downstream software representations and documentation can be generated (Schmidt, 2006). However, EffABPMN2MV advances this assumption by making the model not only technically generative but also participatory and auditable. This is an important distinction because many model-driven approaches remain expert-centered, whereas the present framework uses metaverse interaction and UI-based metaphors to involve stakeholders who may not understand formal modeling notation.

The results also showed that the EffABPMN2MV-ML modeling language successfully mapped familiar metaverse UI elements to BPMN 2.0 constructs. This finding supports the theoretical relevance of visual notation principles in software engineering. According to the physics of notations, modeling languages become more usable when symbols are semantically transparent, visually discriminable, cognitively manageable, and meaningfully aligned with user expectations (Moody, 2009). The use of entry screens, forms, dashboards, approval buttons, digital signature panels, AI widgets, token transfer widgets, and progress trackers as modeling metaphors reduces the representational distance between stakeholder experience and formal process logic. This explains why stakeholder experience scores were significantly higher in the EffABPMN2MV group than in the Scrum group. The finding suggests that non-expert participation in BPM is not simply a matter of inviting stakeholders into modeling sessions; rather, it requires redesigning the symbolic interface of process modeling so that stakeholders can act meaningfully without first becoming BPMN specialists.

The empirical results further confirmed the efficiency advantage of the proposed framework. The EffABPMN2MV group completed the required software deliverables in 3.8 ± 0.6 hours, while the Scrum group required 9.2 ± 1.3 hours, representing a 58.3% reduction in documentation and design completion time. This difference was statistically significant and had a large effect size. This result can be explained by the integration of process modeling, UI/UX design, requirements capture, user story formulation, and documentation generation within a unified environment. In traditional Scrum-based work, teams often move between separate tools and manually translate stakeholder discussions into design artifacts. EffABPMN2MV reduced this translation burden by capturing design activities as structured data and processing them through the AI documentation engine. This result aligns with recent evidence that artificial intelligence can support BPMN generation and validation when the input structure is sufficiently organized (Asllani, 2024). It also reflects the broader automation potential of AI agents in structured digital workflows, especially when AI systems are connected to rule-based or contract-based mechanisms (Yodaplus, 2025).

The improvement in document quality provides additional support for the value of structured AI-assisted documentation. The EffABPMN2MV group achieved higher expert-rated quality scores than the Scrum group, with a 21.4% improvement in documentation quality and stronger performance in BPMN conformance and software requirements specification structure. This suggests that AI-generated documentation becomes more reliable when it does not rely only on unstructured text but instead receives structured inputs from mapped process elements, requirements, user stories, and stakeholder actions. In this sense, the contribution of EffABPMN2MV is not merely the use of GPT-based generation, but the design of an upstream data structure that makes generation more coherent. This supports the broader model-driven engineering argument that automation quality depends on the quality and formal organization of source models (Schmidt, 2006). It also addresses a known limitation of BPMN practice: manual modeling can produce notation errors, incomplete logic, and inconsistent alignment between process models and other design documents (Dumas et al., 2018; Weske, 2019).

The stakeholder experience findings are also theoretically meaningful. The EffABPMN2MV group achieved substantially higher scores on collaboration, inclusiveness, and ease of participation. Non-technical participants, particularly customers and managerial roles, reported greater ability to engage with the design process. This finding is consistent with emerging studies on metaverse-based organizational collaboration, which argue that immersive environments can support shared presence, prototyping, simulation, and collaborative experience design (Gandhi et al., 2024; Latino et al., 2024). However, the present study extends this literature by showing how metaverse collaboration can be operationalized for a formal BPM and software design task. Previous metaverse research has generally emphasized user experience, business model innovation, and immersive collaboration, but EffABPMN2MV connects these capabilities to BPMN modeling, AI documentation, and blockchain governance. Therefore, the findings suggest that the metaverse can function not only as a communication medium but also as a structured modeling environment.

The strongest empirical advantage was observed in legal transparency. The EffABPMN2MV group scored 4.61 ± 0.31 compared with 2.58 ± 0.74 in the Scrum group, and the effect size was very large. This result indicates that the blockchain and smart contract subsystem was perceived as a highly effective mechanism for recording stakeholder contributions and supporting rights attribution. This finding aligns with the foundational logic of blockchain as a tamper-resistant record system introduced in peer-to-peer digital transaction contexts (Nakamoto, 2009). It is also consistent with the concept of smart contracts as mechanisms for formalizing and securing digital relationships through executable rules (Szabo, 1997). Contemporary descriptions of smart contracts emphasize their capacity to automate agreement-based actions through encoded conditions (Wikipedia, 2025), while legal scholarship continues to examine their enforceability and their implications for the philosophy of code as law (Yusuf & Martinez, 2025). In the context of this study, the key contribution is that smart contracts are not used only to automate transactions after a process has been designed; they are used to make the design process itself auditable, attributable, and more transparent.

The blockchain audit validation strengthened this interpretation. The Hyperledger Fabric audit log recorded 1,247 transactions across nine blocks, including element placement, requirement and annotation entry, approval actions, and user story additions. This transaction distribution demonstrates that the framework captured multiple forms of design contribution rather than only final approvals. Prior research has shown that blockchain can support monitoring and execution of business processes in low-trust or multi-party contexts (Weber et al., 2016). Other work has examined dynamic role binding in blockchain-based collaborative business processes (Lopez-Pintado et al., 2019), while systematic reviews have identified traceability, intellectual property management, and transparency as important blockchain application areas (Casino et al., 2019). EffABPMN2MV builds on these contributions but redirects the blockchain function toward participation governance and intellectual contribution attribution during design. This differs from blockchain-based BPM frameworks that primarily focus on process execution, such as approaches that translate or secure BPMN models for blockchain-supported processes (Kopke et al., 2023).

The selection of Hyperledger Fabric as the governance infrastructure is also coherent with the organizational and banking orientation of the study. Hyperledger Fabric is designed as a permissioned blockchain infrastructure, making it more suitable than open public blockchains for enterprise contexts requiring identity control, confidentiality, modularity, and restricted participation (Androulaki et al., 2018). The banking loan application case used in this study required precisely these characteristics because it involved regulated data, hierarchical decision roles, approval procedures, and contribution accountability. This aligns with recent banking-focused research suggesting that smart contracts in the banking industry are shaped by technological, regulatory, institutional, and operational drivers (Adeli & Maleki, 2026). It also resonates with legal and dispute-resolution discussions in which smart contracts and technology-assisted review are increasingly viewed as tools for improving evidentiary transparency, reducing ambiguity, and supporting more structured dispute handling (Ru, 2026). In this regard, EffABPMN2MV provides a practical design pathway for connecting banking process design to transparent contribution records and rights-management mechanisms.

Overall, the findings indicate that EffABPMN2MV contributes to BPM research in three major ways. First, it introduces a participatory BPMN modeling architecture that reduces the dependence of process design on technical specialists while maintaining BPMN compatibility. Second, it connects metaverse-based collaboration with model-driven engineering and AI-generated documentation, thereby improving both speed and quality. Third, it introduces a blockchain-based governance layer for recording design contributions and supporting transparent stakeholder rights management. These contributions are consistent with the design science research logic, which emphasizes the creation and evaluation of artifacts that address relevant organizational problems (Peffers et al., 2007). The statistically significant results across speed, document quality, stakeholder experience, legal transparency, and the composite index suggest that EffABPMN2MV is not only conceptually coherent but also empirically promising. The framework therefore extends prior work on BPMN, metaverse collaboration, AI documentation, blockchain-based process management, and smart contracts by integrating them into a single model-driven ecosystem.

This study has several limitations that should be considered when interpreting the findings. First, the empirical evaluation was conducted in a simulated metaverse environment rather than in a fully deployed production-grade VR/AR infrastructure, and real-world immersive implementation may introduce additional usability, hardware, network, security, and accessibility constraints. Second, although the sample size was appropriate for a controlled design science evaluation, the two project teams included only nine participants each, and the expert panel included 15 evaluators; therefore, broader generalization requires replication with larger and more diverse organizational samples. Third, the case study focused on a banking loan application process, which provided a structured and governance-sensitive context, but the findings may differ in less regulated, more creative, or highly dynamic industries. Fourth, the AI-generated documentation depended on the quality of structured inputs and prompt engineering, meaning that output quality may vary across domains, languages, and documentation standards. Fifth, the blockchain and smart contract components were evaluated primarily in terms of auditability and perceived transparency, while long-term legal enforceability, organizational adoption costs, and integration with existing enterprise systems require further validation.

Future studies should evaluate EffABPMN2MV in real organizational settings and over longer project cycles to determine whether the reported advantages remain stable during full implementation, maintenance, change management, and post-deployment process improvement. Future research should also test the framework in different sectors, such as healthcare, insurance, e-government, logistics, education, and manufacturing, because each domain has distinct process structures, stakeholder profiles, compliance requirements, and documentation standards. Another important direction is to compare different AI models and prompting strategies in order to determine which configurations produce the most accurate BPMN models, requirements specifications, UI documentation, and user stories. Future studies should also examine the legal, ethical, and organizational implications of contribution tokenization, particularly in relation to intellectual property disputes, employee ownership, contractual recognition, and cross-jurisdictional enforceability. In addition, future work should develop maturity models, adoption frameworks, and interoperability standards for integrating EffABPMN2MV with enterprise architecture tools, agile platforms, cloud services, identity management systems, and production-grade metaverse environments.

Organizations seeking to implement EffABPMN2MV should begin with a limited pilot project involving a process that is important, multi-stakeholder, and sufficiently structured, but not so mission-critical that experimentation creates operational risk. Before deployment, organizations should define clear participation rules, stakeholder roles, data governance policies, documentation standards, token-allocation criteria, and approval procedures. Training should be provided not only for technical users but also for customers, managers, analysts, and domain experts so that all participants understand how their actions in the metaverse environment are translated into process models, documentation artifacts, and contribution records. Implementation teams should also ensure that AI-generated outputs are reviewed by qualified analysts before being used as official project documentation. Finally, organizations should treat the blockchain layer as a governance mechanism rather than a purely technical feature; its value depends on transparent rules, institutional acceptance, privacy safeguards, and alignment with legal and managerial policies.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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