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Nexus: a knowledge-based decision support system for blockchain adoption in digital health

Nexus: sistema de apoio à decisão baseado em conhecimento para a adoção de blockchain em saúde digital

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ABSTRACT

Introduction: Organizations considering blockchain adoption in digital health must simultaneously assess General Data Protection Regulation (GDPR) and LGPD (Brazil's data protection law) compliance, technical justification, and organizational capacity. No instrument in the consulted literature evaluates this set of dimensions in an integrated way before development begins. **Objective:** To present Nexus, a knowledge-based decision support system, to support the blockchain adoption decision in digital health projects before resources are committed. **Method:** Nexus is specified as a state machine over a 51-node knowledge graph. It checks for fundamental infeasibility through eight veto conditions and, when none are triggered, computes a weighted score across six dimensions. We evaluated Nexus through nine use cases derived from scenarios reported in the literature. **Results:** The instrument detects fundamental infeasibility before any scoring analysis and generates a diagnostic report that guides architectural redesign when applicable. **Conclusion:** Nexus supports decision-making before development begins and before teams commit to infrastructure investment.

Keywords: Blockchain; Expert Systems.

RESUMO

Introdução: Adotar blockchain em um projeto de Saúde Digital é uma decisão multidimensional: envolve compatibilidade com a Lei Geral de Proteção de Dados (LGPD) e o Regulamento Geral sobre a Proteção de Dados (GDPR), justificativa técnica e contexto organizacional. Na literatura consultada, nenhum instrumento avalia esse conjunto de dimensões de forma integrada antes do início do desenvolvimento. **Objetivo:** Apresentar o Nexus, sistema de apoio à decisão baseado em conhecimento, para apoiar a decisão sobre adoção de blockchain em Saúde Digital antes do comprometimento de recursos. **Método:** O Nexus foi especificado como máquina de estados sobre um grafo de conhecimento de 51 nós. O sistema verifica condições de inviabilidade fundamental por meio de oito critérios de veto e, quando nenhum é ativado, calcula pontuação ponderada em seis dimensões. O sistema foi avaliado em nove casos derivados da literatura. **Resultados:** O instrumento detecta inviabilidade fundamental antes de qualquer análise de pontuação e gera diagnóstico que orienta o redesenho quando aplicável. **Conclusão:** O Nexus apoia a decisão antes do início do desenvolvimento e antes de as equipes comprometerem investimento em infraestrutura.

Descritores: Blockchain; Sistemas Especialistas.

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1 INTRODUCTION

Blockchain has emerged as a response to structural challenges in health information systems. The most documented include fragmented clinical records, consent management across multi-institutional environments, the pharmaceutical supply chain traceability, and the absence of interoperability between institutions [1,2]. Its core properties (immutability, decentralization, and auditable traceability) offer a technical answer to these problems; however, organizations that adopt blockchain encounter *trade-offs* that technical analysis alone cannot resolve [3]. The combination of full immutability with personal health data storage directly conflicts with the right to erasure established in the General Data Protection Regulation (GDPR) and in the *Lei Geral de Proteção de Dados* (LGPD), Brazil's data protection law [4-6].

The decision to adopt blockchain in health projects is multidimensional. It requires verifying whether decentralization is technically justified for the case at hand, whether the proposed architectural configuration complies with applicable data protection law, and whether the organization has sufficient implementation capacity [7]. Organizations that adopt blockchain without verifying these dimensions in an integrated manner tend to face unanticipated regulatory conflicts or an oversized infrastructure for the actual problem. Decision-makers must therefore assess feasibility before selecting a platform and committing resources.

Existing instruments address these dimensions partially and in isolation. Balasubramanian *et al.* [7] and Sanda *et al.* [8] propose organizational readiness frameworks that structure the conditions for blockchain adoption, covering technical and organizational aspects. Neither framework, however, incorporates regulatory compliance as an exclusion condition nor produces a project-specific diagnostic. Gaur *et al.* [9] apply multi-criteria decision techniques to blockchain platform selection, presupposing that decision-makers have already chosen to adopt blockchain; this assumption limits their usefulness in the prior feasibility assessment phase.

A review of 47 blockchain adoption frameworks conducted by Almeshal and Alhogail [10] found no instrument in the reviewed set that incorporates regulatory constraints as veto conditions. This gap is consequential in contexts governed by the GDPR and the LGPD, where certain combinations of architectural configuration and data category render blockchain adoption infeasible regardless of any technical scoring.

None of the reviewed works integrates, in a single instrument, adaptive path evaluation, regulatory vetoes as stop conditions, simultaneous coverage of technical, regulatory, and organizational dimensions, and diagnostic report generation. To address this gap, we present Nexus, a knowledge-based decision support system specified as a state machine over a knowledge graph, to support the blockchain adoption decision in digital health projects before resources are committed.

We present three contributions. The first is Nexus, a knowledge-based decision support system specified as a state machine over a 51-node knowledge graph spanning three domains (health, blockchain, and implementation), which integrates technical, regulatory, and organizational assessment in an adaptive decision support process. The second is a two-phase recommendation model. In Phase 1, a hierarchy of eight veto conditions detects fundamental infeasibility before any scoring analysis. In Phase 2, a weighted score across six dimensions (zero to 100 points) determines the final recommendation. The third contribution is the evaluation of Nexus through nine use cases derived from scenarios reported in the literature, covering all three possible outcomes: STRONGLY_RECOMMENDED, PARTIALLY_RECOMMENDED, and NOT_RECOMMENDED.

The remainder of this paper is organized as follows. Section 2 describes the methods, including the theoretical background and Nexus design. Section 3 presents the evaluation results. Section 4 discusses the findings in relation to the literature. Section 5 concludes the paper.

2 METHODS

Nexus rests on three theoretical pillars that inform its design decisions: the state of the art in blockchain applications in health, health data regulation under the GDPR and the LGPD, and the principles of knowledge-based decision support systems, state machines, and knowledge graphs. This section describes these foundations and then details the evaluation workflow and system behavior.

2.1 Theoretical Background

Blockchain in health. Blockchain applications in health focus on scenarios that benefit from immutability, decentralization, and traceability [1]. The most documented use cases in the literature include consent management in multicenter clinical trials, pharmaceutical supply chain traceability, remote patient monitoring, and clinical record interoperability across institutions [2,3,11]. Organizations that adopt blockchain, however, face tensions: scalability, ongoing operational cost, and, most critically, the incompatibility between blockchain's native immutability and the erasure rights established in data protection legislation [12].

Health data regulation. Health data constitutes a special category under both the GDPR (Art. 9) and the LGPD (Art. 11), requiring specific legal bases for

processing and reinforced protection measures [4,5]. The right to erasure, established in GDPR Art. 17 and LGPD Art. 18, directly conflicts with the immutability of blockchains that store personal data *on-chain*. In 2025, the European Data Protection Board (EDPB) published guidelines recognizing *off-chain* storage with cryptographic key deletion as an accepted mitigation strategy for reconciling blockchain with the right to erasure [6]. This conflict and its mitigation directly ground the regulatory infeasibility conditions incorporated into Nexus's recommendation model.

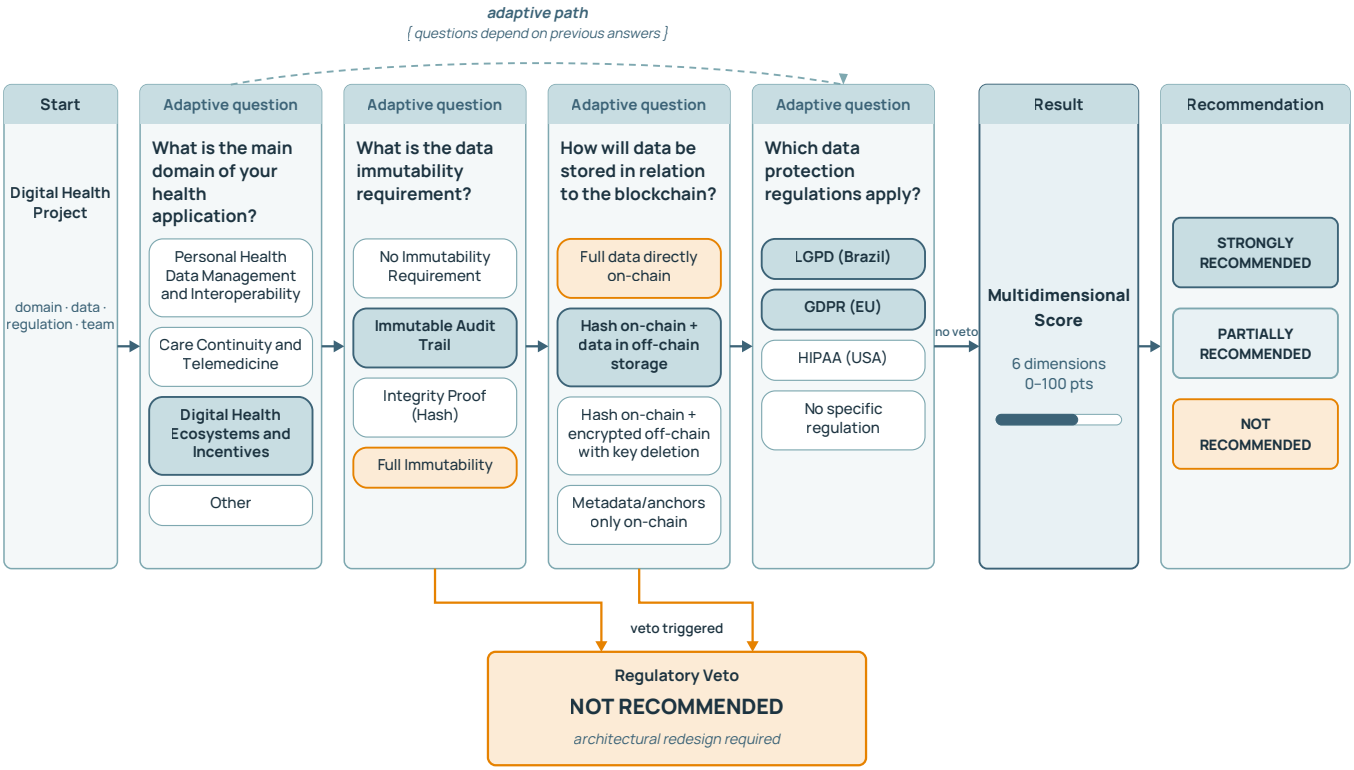
Knowledge-based decision support systems, state machines, and knowledge graphs. Knowledge-based decision support systems encode domain knowledge through explicit representations and support decisions [13]. When developers represent this knowledge as a graph and specify the evaluation process as an Extended Finite State Machine (EFSM), the system enables adaptive, formally verifiable navigation: state transitions depend on the user's immediate response and on variables accumulated throughout the session. By tracking these variables, the system ensures that the evaluation path reflects the specific context of the project under assessment [14]. The choice of symbolic logic over machine learning reflects the nature of the decision: in health contexts, decision-makers value traceability in the decision-making process as much as the outcome, and they prefer interpretable models over black-box approaches when decisions carry direct regulatory and organizational implications.

2.2 Nexus Design

Evaluation workflow. Nexus evaluates adaptive questions derived from the knowledge graph, as illustrated in Figure 1. Each response determines the next question; the resulting path adapts to the specific context of the project under assessment. In Phase 1, Nexus checks regulatory veto conditions before any scoring: when the proposed configuration conflicts with applicable legal obligations, the process terminates with a diagnostic report identifying the infeasibility condition and, where applicable, the redesign strategy that would remove it. When no veto is triggered, Phase 2 computes a multidimensional score that determines the final recommendation.

Knowledge graph. Nexus uses an EFSM, in which the knowledge graph defines the state topology and adaptive transitions of the evaluation process. Each node corresponds to a machine state. Transitions depend on both the user's immediate responses and the variables accumulated throughout the session; by tracking these variables, Nexus ensures that the evaluation path reflects the specific context of the project under assessment. The graph contains 51 nodes organized into three domains: health, blockchain, and implementation. The composition of each domain is grounded in the domain literature.

Figure 1. Nexus evaluation workflow: adaptive sequence of knowledge graph questions, with regulatory veto detection as a stop condition and the generation of the score and final recommendation.



Source: Prepared by the authors (2026).

Table 1. Phase 1 veto conditions of the Nexus recommendation model.

Veto	Category	Detected Condition
V1	Regulatory	Full immutability + on-chain storage + compliance obligation under the right to erasure (GDPR/LGPD Arts. 17/18)
V2	Regulatory	Violation of the data minimization principle: the volume or nature of on-chain data exceeds what is necessary (GDPR Art. 5)
V3	Technical	Absence of a genuine need for decentralization
V4	Technical	Real-time requirements incompatible with the consensus mechanism latency
V5	Regulatory	Re-identification risk of pseudonymized data in public or semi-public networks
V6	Operational	Insufficient implementation capacity for a minimum proof of concept
V7	Regulatory	Irreconcilable incompatibility with multiple GDPR principles simultaneously (Arts. 5, 17, and 25)
V8	Technical	Cosmetic decentralization: all nodes under control of the same entity

Source: Prepared by the authors (2026).

Table 2. Phase 2 scoring dimensions of the Nexus recommendation model.

Dim.	Description	Weight
D1	Technical Justification	30 points
D2	Regulatory Compliance	20 points
D3	Technical Platform Adequacy	20 points
D4	Privacy Mechanisms	15 points
D5	Implementation Capacity	7 points
D6	Interoperability and Integration	8 points
	Total	100 points

Source: Prepared by the authors (2026).

The health domain covers clinical context, data category, sensitivity, and legal compliance. Questions about the data category are motivated by the distinct legal regimes that the GDPR and the LGPD impose on health data as a special category: the correct identification of the data category determines which veto conditions may be triggered [4,5]. Questions about immutability and storage are motivated by the EDPB (2025) finding that the combination of full immutability, on-chain storage, and GDPR compliance obligations is the most frequent cause of regulatory infeasibility [6].

The blockchain domain covers network type, consensus mechanism, storage model, and privacy mechanisms. The distinction between public, consortium, and private networks is motivated by the documented trade-off between decentralization and access control: public networks maximize decentralization but lose the ability to restrict participants, which is incompatible with health data subject to the GDPR [3]. Questions about the consensus mechanism are motivated by the latency incompatibility between *Proof of Work* and applications with real-time requirements. The question about off-chain storage follows directly from the EDPB (2025) guidelines.

The implementation domain covers team expertise, available budget, and timeline. Its inclusion is motivated by Balasubramanian *et al.* [7], who report that organizational readiness is a necessary condition for successful blockchain adoption: projects with insufficient capacity tend to fail regardless of technical feasibility.

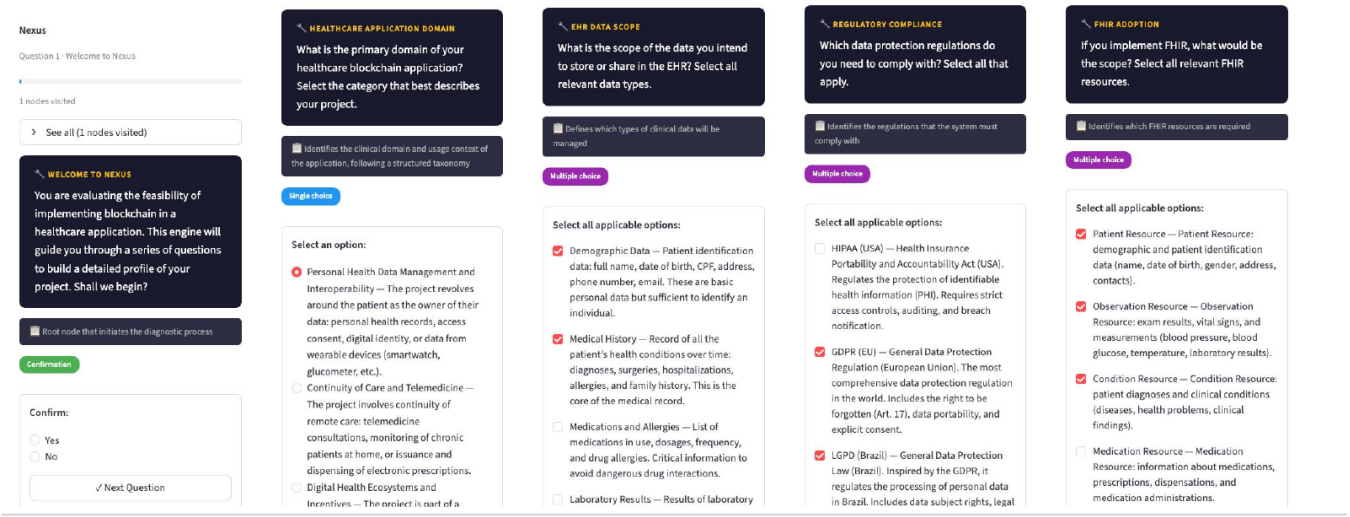
Navigation through the graph adapts to the user's responses. In contexts of low data sensitivity, the system skips questions about the right to erasure. When the team has sufficient technical expertise, the system does not visit states related to organizational capacity. By adapting the path in this way, Nexus reduces cognitive load and improves the precision of the semantic model it constructs.

Recommendation model. The recommendation model operates in two sequential phases.

In Phase 1, Nexus applies a hierarchy of eight veto conditions that represent fundamental infeasibility, each grounded in an explicit regulatory or technical rationale (Table 1). Nexus draws this veto logic from the elimination criteria of the ELECTRE method [15]: certain conditions are sufficiently restrictive to make scoring analysis irrelevant.

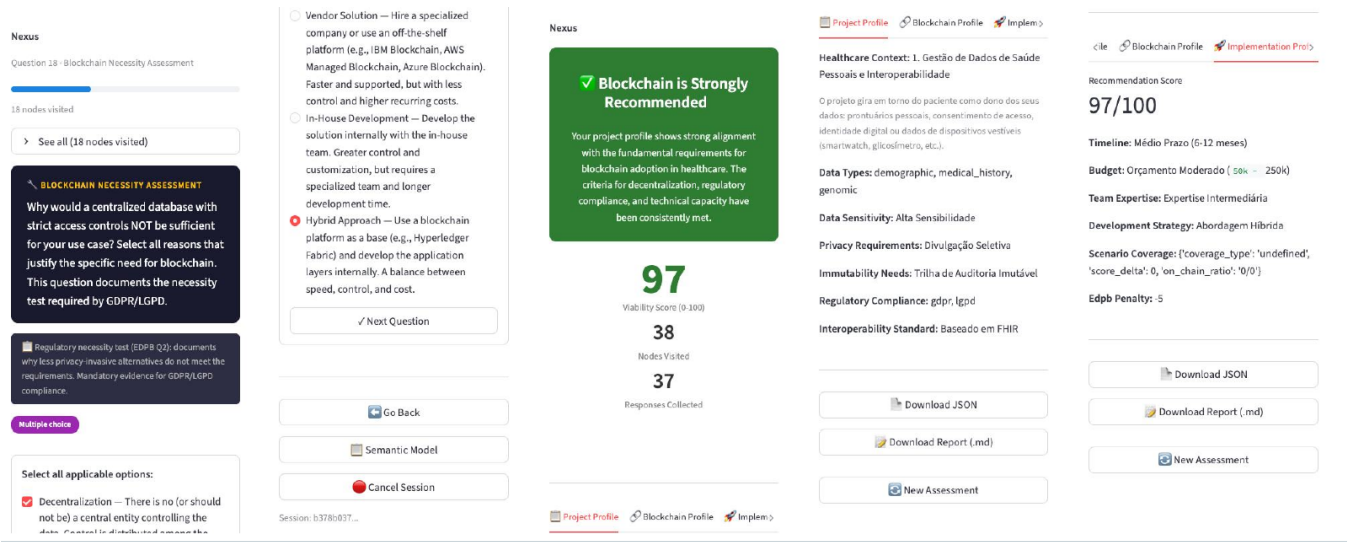
When no veto is triggered, Phase 2 computes a weighted score from zero to 100 points across six dimensions (Table 2). The combined weight of D1 and D3 (50 points) reflects the stronger discriminating power of technical justification and platform adequacy. Nexus classifies the outcome into three levels: STRONGLY_RECOMMENDED (score ≥ 70), PARTIALLY_RECOMMENDED (score between 40 and 69), or NOT_RECOMMENDED (score < 40, with no active veto).

Figure 2. Nexus web interface: welcome screen and adaptive question sequence, including application domain (single choice), electronic health record data scope, regulatory compliance (GDPR and LGPD), and interoperability standards.



Source: Prepared by the authors (2026).

Figure 3. Nexus web interface: blockchain necessity question in progress (18 nodes visited), session navigation controls (go back, view semantic model, and cancel), evaluation result (Blockchain Strongly Recommended, score 97/100), and diagnostic report with project profile, blockchain configuration, and implementation capacity.



Source: Prepared by the authors (2026).

Diagnostic report. Nexus does more than assign a recommendation label. The diagnostic report identifies the triggered veto and the specific condition that activated it, provides total and per-dimension scores when Phase 2 runs, presents textual justifications with auditable references, and recommends a mitigation strategy to remove the blocking condition for cases classified as NOT_RECOMMENDED by veto. In health contexts, decision-makers value traceability in the decision-making process as much as the outcome: when V1 produces an infeasibility result, Nexus also prescribes the specific architectural redesign needed to resolve the conflict and enable reassessment [16].

Implementation. The Nexus prototype was implemented in Python and provides three interfaces: a command-line interface for integration into automated workflows, a REST API for integration with external systems, and a web interface. The system operates in Portuguese and English. Figures 2 and 3 illustrate the web interface: the welcome screen with the adaptive question sequence, and the evaluation result with the detailed diagnostic report.

3 RESULTS

We evaluated Nexus through nine use cases derived from scenarios reported in the blockchain adoption in health literature [1]. Each use case specifies the clinical context, the blockchain configuration under consideration, and the institution's organizational profile. Nexus automatically processes each case, adaptively navigates the knowledge graph, and produces a recommendation with the corresponding diagnostic report. Researchers typically evaluate knowledge-based systems through use cases with previously known expected outcomes because this approach focuses on model behavior across

representative domain configurations and does not require human participants. For this reason, the study does not require ethics committee approval. The cases are organized into three groups, corresponding to the model's three possible outcomes.

Table 3. Results of the nine use cases evaluated by Nexus. Legend: "—" in Score: Phase 1 vetoes prevent Phase 2 execution. "—" in Active Veto: no veto was triggered. STRONG. = STRONGLY; PART. = PARTIALLY; REC. = RECOMMENDED

Use Case	Group	Active Veto	Score	Recommendation
UC1: Multicenter consent management [17]	STRONG.	—	97	STRONG. REC.
UC2: Pharmaceutical traceability [18]	STRONG.	—	90	STRONG. REC.
UC3: Remote monitoring in consortium [11]	STRONG.	—	94	STRONG. REC.
UC4: Preventive incentives (tokenomics) [19]	PART.	—	52	PART. REC.
UC5: Telemedicine in rural areas [20]	PART.	—	59	PART. REC.
UC6: Epidemiological surveillance [3]	PART.	—	57	PART. REC.
UC7: Electronic health record under the GDPR [4,6]	NOT	V1	—	NOT REC. (Veto)
UC8: Mental health on a public blockchain [21]	NOT	V2, V3	—	NOT REC. (Veto)
UC9: Genomic database [22]	NOT	V1	—	NOT REC. (Veto)

Source: Prepared by the authors (2026).

Use Case 1: Consent Management in a Multicenter Clinical Trial. An international clinical trial with 25 hospitals in ten countries faces a consent synchronization problem. When a participant revokes consent at one site, the revocation does not propagate in real time to the others, creating a regulatory risk [17]. Nexus assesses a case with moderate data sensitivity, off-chain storage with cryptographic key deletion (the condition that deactivates V1), a permissioned private network with Proof of Authority consensus, and technical expertise distributed across the consortium. None of the eight veto conditions is triggered. In Phase 2, D1 (Technical Justification) and D2 (Regulatory Compliance) contribute the highest scores. Final score: 97/100. Recommendation: STRONGLY_RECOMMENDED.

Use Case 7: Electronic Health Record with Full Immutability under the GDPR. A university hospital in Germany plans a blockchain-based electronic health record with full immutability for research integrity and audit purposes, under a GDPR compliance obligation [4,6]. Nexus detects the combination of full immutability, on-chain storage of personal data, and a compliance obligation under GDPR Art. 17 (right to erasure). This configuration triggers Veto 1 (V1): the conflict between immutability and the right to erasure is irreconcilable without architectural redesign. Nexus returns *Not Recommended* without executing Phase 2. The diagnostic report identifies V1 and specifies the mitigation that would remove the veto: adopting off-chain storage with cryptographic key deletion and resubmitting the project for evaluation.

Table 3 presents a summary of the nine evaluated cases, including the active veto, the score obtained, and the resulting recommendation.

The nine evaluated cases cover all three possible model outcomes. Nexus correctly classified all cases into their expected groups. The three cases with high technical adequacy and full regulatory compliance received a *Strongly Recommended* rating. The three cases with governance limitations, insufficient implementation capacity, or partial technical justification received a *Partially Recommended* rating. Phase 1 blocked the three cases with a fundamental conflict. In UC4, UC5, and UC6, the absence of a veto did not produce a high score because D1 (Technical Justification) and D3 (Technical Platform Adequacy) received reduced scores, reflecting scenarios in which decentralization lacks full justification or centralized governance limits the expected benefits. Regulatory vetoes V1 (conflict with the right to erasure) and V2 (data minimization violation) were triggered in the three infeasible cases, indicating that storage strategy and the GDPR/LGPD compliance model are the decisive feasibility factors in regulated health contexts.

4 DISCUSSION

The evaluation covered all three possible outcomes of the recommendation model. The full-feasibility cases (UC1, UC2, and UC3) scored between 90 and 97, reflecting strong technical justification and the absence of regulatory conflicts. The partial-feasibility cases (UC4, UC5, and UC6) scored between 52 and 59. In these scenarios, technical justification for blockchain use and platform adequacy were the limiting factors in projects where decentralization is not fully justified for the context. The infeasibility cases, however, reveal the patterns with the greatest practical implications for decision-makers evaluating blockchain adoption in digital health projects under the GDPR and the LGPD.

The three cases blocked in Phase 1 present two qualitatively distinct types of infeasibility. UC7 and UC9 were blocked by the combination of full immutability, on-chain storage, and compliance obligations under

the right to erasure established in GDPR Art. 17 and LGPD Art. 18. This combination creates an architectural conflict, not an inadequacy in the use case itself. In both cases, off-chain storage with cryptographic key deletion would remove the infeasibility condition, a mitigation strategy that the EDPB (2025) recognizes as an accepted approach [6]. UC8 presents a different type of infeasibility. The combination of mental health data on a public blockchain with no genuine need for decentralization shows that the premise for blockchain use is incorrect for the context, and no architectural redesign resolves the infeasibility. This distinction has direct practical implications: in the first type, the project may proceed after redesigning the storage strategy. In the second type, decision-makers must review the adoption premise itself before making any architectural decision.

Use Case 7 illustrates the role of regulatory stop conditions in a feasibility evaluation. The project describes a university hospital with a legitimate research audit objective, a qualified technical team, and a clinical justification (a profile that an organizational readiness instrument would assess positively). Regulatory compliance is not absent from the project. It is the stated objective. The conflict emerges because full record immutability is incompatible with the obligation to erase personal data under the GDPR and the LGPD. An instrument without a regulatory stop condition lacks the mechanism to detect this conflict before scoring, regardless of its coverage in other dimensions.

The pattern observed in UC7 and UC9 points to a specific consequence. In digital health projects subject to the GDPR and LGPD, the decisive architectural question is not which blockchain platform to adopt, but how the system will store data in relation to applicable legal obligations. In regulatory feasibility terms, the choice between on-chain and off-chain storage precedes platform selection, consensus mechanism, and governance model. The Nexus diagnostic report for UC7 does not end with a refusal. It specifies the redesign needed to remove the veto condition and make the project feasible. In health contexts, where traceability is as relevant as the decision itself, distinguishing between infeasibility in the current configuration and feasibility through redesign has direct practical value for technical teams and compliance committees.

4.1 Limitations

Three limitations bound the scope of the reported results. We validated Nexus using cases derived from the literature rather than real health blockchain adoption projects, so the findings may not generalize to scenarios beyond the consulted literature. The knowledge graph covers only a subset of possible configurations. Regulatory contexts beyond the scope of the GDPR and LGPD may require an extended veto set, since the current model does not cover jurisdictions without equivalent data protection legislation. Finally, we did not evaluate the system with real users, so we have not yet empirically studied the usability and interpretability of the diagnostic report for health IT managers and technical teams.

5 CONCLUSION

We present Nexus, a knowledge-based decision support system specified as a state machine over a knowledge graph to support blockchain adoption decisions in digital health projects. We evaluated Nexus through nine use cases derived from the literature. The results indicate that the system detects regulatory infeasibility before technical analysis begins in scenarios where the architectural configuration conflicts with the GDPR and LGPD, and distinguishes full from partial adequacy in the remaining cases. Nexus supports decision-making before development begins and before teams commit to infrastructure investment.

The central finding of the evaluation is that regulatory infeasibility has structure. The blocked scenarios fall into two types with distinct practical implications. In the first type, infeasibility stems from an architectural conflict between full immutability and the obligation to erase personal data under the GDPR and the LGPD. The diagnostic report specifies the redesign that would remove the conflict, positioning Nexus as a project support tool, not merely a screening gate. In the second type, the premise for blockchain use is incorrect for the context, with no architectural redesign that resolves the infeasibility. For Brazilian institutions under the LGPD, where the right to erasure of personal health data is a current legal obligation, this distinction has immediate practical value.

No instrument in the consulted literature integrates adaptive path evaluation, regulatory vetoes as stop conditions, and actionable diagnostic report generation in a single process. Nexus represents a first step in a research agenda on decision support systems for emerging technologies in digital health.

Three directions stand out for future work. A usability study with health managers and IT teams would assess the interpretability of the diagnostic report under real-use conditions. The knowledge graph would benefit from scenarios drawn from real blockchain adoption projects beyond the cases derived from the literature, improving representativeness. A reasoning agent based on language models would extend the system's ability to handle ambiguous inputs and generate personalized recommendations.

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Use of artificial intelligence. Generative AI tools were used to support scientific text revision, including grammatical, orthographic, stylistic, and fluency review, coherence and clarity verification, and translation assistance. The tools used were Grammarly, Claude Opus, and GPT-5.4.

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EDITORIAL NOTES

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This article was double-blind peer reviewed by specialists in the field. The editorial team used artificial intelligence tools, under human supervision, in the initial screening, in checking the text, references and numbers and, when needed, in redrawing figures, charts and tables, which the authors approved in the proof. The tools and safeguards are described in the journal's Policy on the use of artificial intelligence. Editorial decisions were made by people.