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The Use Of Blockchain For Legislative Simplification And Tracking

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***Abstract*—This paper explores the potential of blockchain technology in simplifying and tracking legislative processes, addressing the challenges of document management while maintaining the separation of powers. The study examines how blockchain can enhance transparency, security, and efficiency in legislative procedures while preserving constitutional principles. Building upon the analysis of Italy's xLeges system as a case study, the research proposes a multi-level blockchain architecture comprising three interconnected but autonomous layers: a Private Institutional Blockchain for internal deliberations, an Inter-Institutional Coordination Blockchain for document exchange between institutions, and a Public Legislative Blockchain for citizen access to definitive acts. The methodology combines theoretical legal analysis of separation of powers principles with technical evaluation of blockchain capabilities, particularly focused on the implementation of the MOVE programming language for smart contracts and Akoma Ntoso XML standards for legislative document structuring. Results demonstrate that this architecture effectively addresses key requirements of constitutional democracies by ensuring institutional autonomy while enhancing document traceability, implementing selective disclosure mechanisms to balance transparency with necessary confidentiality, and providing immutable verification of legislative processes. The proposed solution offers a blueprint for legislative process modernization applicable beyond the Italian context to other constitutional democracies facing similar challenges.**

***Index Terms*—Blockchain, Legislative simplification, Document tracking, Legal informatics, Separation of powers, Xleges, Akoma Ntoso, Digital transformation, Interoperability of processes, Law-making process, DLT, Smart contract, Move, Deontic operators**

I. Introduction of the Problem

The doctrine of the separation of powers, deeply rooted in the political philosophy of democratic governance, serves as a fundamental safeguard against the potential tyranny that could emerge from the excessive concentration of power within a single branch of government [1]. This doctrine is designed to ensure that the legislative, executive, and judicial branches of government maintain distinct and independent operations, free from intrusions that could disrupt the democratic equilibrium. By compartmentazing governmental powers, the system not only prevents the abuse of power but also establishes a mechanism of checks and balances, where all branches have enough independence to fulfill its constitutional roles while maintaining mutual oversight. Philosophically, the separation of powers is anchored in the rule of law, a principle that insists on the governance of law rather than that of individuals. This rule is paramount for the protection of individual rights and the establishment of a legal framework within which freedom and justice are not merely theoretical ideals but practical realities [2]. The origins of these concepts can be traced back to the Enlightenment era, especially to thinkers like Montesquieu, whose groundbreaking work "The Spirit of the Laws" [3] strongly supports splitting government powers into three parts to prevent dictatorship. Montesquieu's insights have profoundly influenced modern democratic constitutions, embedding the separation of powers as a central column of constitutional design in Italian, European, and Western democracies in general. Within the scope of this doctrine, the management of legislative data presents a complex challenge. Legislative documents, which include drafts, amendments, and ratified laws, form the foundation of the legal framework of any nation. The integrity, security, and accessibility of these documents are crucial for maintaining transparent and effective governance [4]. A centralized database, while potentially efficient for storage and retrieval, poses significant risks by potentially concentrating too much power in the hands of a single entity [5]. Such centralization could distort the balance of power, granting one branch or body disproportionate influence over the legislative process, contravening the principle of separation of powers.

Two innovative aspects characterise this research. First, it addresses the current crisis of rule of law from the perspective of separation of powers, particularly how the executive branch increasingly overshadows the legislative, while simultaneously examining public administration digitalisation. While efficiency drives much of governmental digital transformation, including the recent application of artificial intelligence [6] [7], few studies consider how to balance such efficiency needs with rule of law principles. Second, this research explores how blockchain technology, due to its inherent characteristics, might foster respect for rule of law whilst maintaining digitalisation advantages, an area particularly understudied in the legislative sector [8].

The present research aims to explore the potential of blockchain technology in addressing these fundamental challenges while preserving the essential principles of division of power and, therefore, democratic governance. This paper

is structured to systematically examine the intersection of technological innovation and constitutional safeguards, beginning with an analysis of the X-Leges project as a foundational case study, and offering innovative theoretical solutions and implementations. The Italian legal system serves as a primary reference point, not merely due to its sophisticated constitutional framework, but also because it exemplifies the delicate balance between institutional autonomy and the need for technological modernisation, with a strongly balanced structure that was mainly created after the second WW. Nevertheless, the findings and proposed solutions maintain broad applicability beyond the Italian context, as the underlying principles of democratic governance and the technical challenges of legislative document management are common to many constitutional democracies. Methodologically, this research adopts a theoretical approach that addresses both juridical profiles and technological characteristics of blockchain. The investigation proceeds through several interconnected stages: first, establishing the theoretical framework of separation of powers and rule of law, with particular focus on how this fundamental principle faces challenges in the digital era; secondly, examining the technical foundations of blockchain technology and smart contracts, with particular emphasis on the Move programming language; third, analyzing the current state of legislative document management through the lens of the X-Leges project; and finally, proposing a blockchain-based solution that addresses both the legal and technological requirements of legislative processes. While X-Leges is an Italian project, it demonstrates that certain technological approaches can effectively address issues related to legislative document management across institutional boundaries but taking in first consideration the strict respect for the Roule of law. Blockchain technology not only possesses these capabilities but could potentially enhance them significantly. The replicability of the proposed solutions extends beyond the Italian context precisely because the underlying principles of rule of law apply to all major constitutional democracies, and the technical architecture is designed to be adaptable to various constitutional frameworks whilst maintaining the essential principles of democratic governance. This approach also enhances possibility for multidisciplinary collaboration aimed at developing specific use cases and prototypes in the future.

II. Legal foundations of the separation of powers

In contemporary constitutional jurisprudence, the separation of powers principle emerges as an essential safegard against the concentration of public authority, inextricably linked to the broader concept of the rule of law that serves as the cornerstone of liberal democratic societies. The foundational significance of this principle derives from its capacity to prevent any single branch of government from accumulating excessive power that might threaten individual liberties and democratic governance. This conceptual framework, firstly articulated by thinkers of the Enlightenment era has evolved into a sophisticated doctrine that underpins modern constitutional democracies, particularly evident in Italian, European, and more broadly in many Western legal systems.

The rule of law, as a governing principle, transcends mere procedural requirements to encompass substantive elements that protect fundamental rights and democratic processes. Drawing from an interesting analysis [7], becomes evident that the rule of law serves as both a shield against arbitrary power and a tool that enables real and meaningful participation in democratic governance. The separation of powers, in this context, operates as one of the essential mechanisms through which the rule of law manifests its protective function, creating a system of checks and balances that prevents any single governmental branch from dominating the others. [7] This intricate relationship between the rule of law and the separation of powers becomes particularly salient when examining the challenges posed by modern governance technologies, specifically in the context of algorithmic regulation.

At the European level, the separation of powers finds institutional expression within the Treaties establishing the European Union. Articles 14 and 16 of the Treaty on European Union (TEU) [9] articulate the legislative functions assigned to the European Parliament and the Council of the European Union,embodying a principle of dual legitimacy wherein the Parliament, directly elected by EU citizens, and the Council, composed of representatives of member states' governments, jointly exercise legislative power. The judicial dimension is reinforced by the Court of Justice of the European Union (CJEU), as evidenced in landmark cases such as Costa v. ENEL, which affirmed the supremacy of European law over national laws while simultaneously ensuring that the judiciary maintains its role in balancing power among EU institutions.

In the Italian context, the separation of powers is deeply embedded within the constitutional framework. Article 70 confers legislative power collectively [10] upon the two Houses of Parliament, ensuring a bicameral legislative process. Articles 101 [11] and 104 [12] guarantee judicial independence, establishing that the judiciary operates autonomously and is subject solely to the law, thus creating a strong safeguard to protect against improper control from both executive and legislative powers. This separation is further reinforced by the judiciary's constitutional mandate to uphold the rule of law [13], protecting citizens' rights against potential overreach by other branches of government.

The contemporary challenges to this established framework arise most prominently in the context of algorithmic regulation, which introduces novel dynamics that potentially undermine traditional separations of power. The increasing reliance on algorithmic systems within public administration risks creating an imbalance that favors executive power at the expense of legislative oversight and judicial control. [7] This shift occurs through various mechanisms: first, through the technical complexity that often obscures decision-making processes from meaningful legislative scrutiny; second, through the automation of administrative decisions that may bypass traditional checks and balances; and third, through the creation of *de facto* regulatory frameworks that operate outside

established legislative processes [7].

The interconnectedness of the separation of powers, democratic participation, and transparency underscores the complexity and interdipendence of these principles in democratic governance. Each principle not only supports and enhances the others but also collectively contributes to a robust and resilient constitutional framework. The separation of powers ensures that no single branch of government can dominate or undermine the democratic process, while democratic participation empowers citizens to influence and oversee governmental actions, thereby reinforcing accountability and legitimacy. Judicial system guarantees that laws are applied fairly, and that individuals' rights are protected, thereby upholding the rule of law and preventing arbitrary governance.

This particular balance assumes significance in the context of technological innovation within public administration. The implementation of algorithmic systems, while potentially enhancing efficiency, introduces new challenges to the traditional separation of powers. These systems, often developed and deployed primarily within the executive branch, may concentrate decision-making power in ways that circumvent established legislative and judicial oversight mechanisms. This shift towards automation in administrative processes risks undermining the basic principles of law, not through direct opposition, but by slowly changing how power is balanced between institutions.

III. Technical Foundations of Blockchain Technology

The technological architecture that forms the foundation of blockchain systems represents a sophisticated computational infrastructure with direct relevance to legislative processes. Its inherent capacity to maintain distributed consensus whilst preserving institutional autonomy makes it particularly valuable in legal contexts. This distributed ledger technology operates as a network of interconnected computational nodes implementing decentralised validation mechanisms for transaction processing [14], thereby creating a system that supports the constitutional separation of powers.

The foundational architecture encompases several crucial technological components. First, the distribution mechanism operates through the replication of the ledger across multiple computational nodes. Each node maintains a complete copy of the database, thus implementing a distributed redundancy system that ensures both data persistence and operational autonomy for each participating institution [15]. Within this architecture, the consensus protocol plays a vital role. For legislative applications specifically, the Proof of Authority (PoA) mechanism is particularly relevant, as it assigns transaction validation to specifically authorised nodes. This approach ensures an optimal balance between computational efficiency and institutional control, aligning with legal requirements for authority and trust.

The immutability of the ledger, essential for preserving documentary integrity within legislative processes, is achieved through a data structure known as the Merkle Tree. In this structure, each block contains both transactions and the cryptographic hash of the preceding block, creating a chain of mathematically verifiable references. This immutability is further strengthened through a distributed timestamp system that ensures temporal coherence of transactions across the network,a feature particularly important for legislative document management [16]. The system's security foundation relies on asymmetric cryptography algorithms. These algorithms implement a public and private key system for digital signatures, ensuring both the integrity and institutional provenance of legislative documents. While the public key serves as an address accessible to all participants, the private key remains confidential and enables the creation of signatures that prove document authenticity without revealing the underlying secret key.

In the specific context of legislative applications, the xLeges project [17], discussed further in subsequent sections, could enhance its framework by incorporating smart contracts, especially with the use of MOVE language, with its intrinsic properties explained before. These autonomous programs embedded within blockchain infrastructure can automatically implement document verification procedures and approval workflows in accordance with constitutional requirements. Smart contracts [14] operate through deterministic execution, meaning they consistently produce identical outputs given the same inputs, ensuring predictability in legislative processes. Their execution occurs across all network nodes [15], with each node independently verifying the computation results, thus maintaining the system's distributed nature while ensuring computational consensus.

The system's access management operates through a permissioning framework implementing Role-Based Access Control (RBAC) policies. This approach is particularly relevant for maintaining appropriate separation of legislative powers, as it enables precise control over which entities can participate in the network and what actions they can perform. This ensures that different institutional actors maintain their constitutionally mandated roles while participating in the shared legislative process. For integration with external systems, the architecture employs cryptographically verifiable oracle systems. These oracles serve as trusted bridges between the blockchain and external data sources, implementing verification mechanisms to ensure the authenticity of imported data while remaining a potential off-chain point of vulnerability.

For legislative tracking purposes, the technology employs distributed indexing systems and search mechanisms based on specialised data structures. These enable efficient querying while preserving the immutability and verifiability properties characteristic of blockchain systems, thus ensuring both accessibility and integrity of legislative documents throughout their lifecycle. The indexing systems implement cryptographic commitments allowing for efficient proof of inclusion or exclusion of specific documents within the legislative corpus. The search mechanisms utilise advanced techniques such as zero-knowledge proofs and deontic operators, enabling verification of document authenticity and provenance without revealing

sensitive information about the underlying legislative process.

The implementation of consensus mechanisms requires particular attention to legislative process requirements. The Proof of Authority consensus mechanism, chosen for its appropriateness in institutional contexts, should implement a Byzantine Fault Tolerant protocol capable of maintaining system consistency even with some malfunctioning or compromised nodes. This protocol operates through a leader election process where pre-authorised validator nodes take turns proposing transaction blocks, with validation requiring multiple rounds of cryptographic message exchange. In the legislative ecosystem, this design helps ensure that no single institution can unilaterally control the legislative process while maintaining sufficient efficiency for practical operation.

At the data structure level, the system implements versioning mechanisms that maintain a complete history of legislative documents while enabling efficient access to both current and historical versions. This is achieved through content-addressable storage (where documents are identified by cryptographic hashes of their content) and directed acyclic graphs that maintain relationships between different versions of the same document. The system also employs compression techniques enabling efficient storage of the complete legislative corpus while maintaining accessibility to all document versions. These technical foundations establish a robust infrastructure supporting the complex requirements of legislative processes while maintaining the essential properties of security, immutability, and verifiability that characterise blockchain systems.

IV. X-Leges Project: Overview and Architecture

The current state of the art for this study is profoundly anchored in the xLeges project, an initiative created under the guidance of the Italian government's *Normattiva* program [18]. This project, conceived and implemented with the objective of addressing and mitigating inefficiencies inherent in the legislative process, represents a sophisticated attempt to harness distributed computing principles for the enhancement of legislative workflows, even if in an era preceding the advent of blockchain technology. The project's architecture, operational since 2014, embraced principles of decentralization and inviolability through the innovative utilization of Certified Email (*Posta Elettronica Certificata* - PEC) [19] and document traceability implementation through Uniform Resource Names (URN) [20], establishing a technological framework that would later prove prescient in its anticipation of blockchain-like distributed consensus mechanisms.

The architectural foundation of xLeges manifests particular significance in its implementation of URN and XML standards [21], as mandated by the *Autorità per l'Informatica nella Pubblica Amministrazione* (AIPA) circulars no. 35/2001 [22] and no. 40/2002 [23], along with their subsequent extensions. These standards provided a crucial framework for potential full automation in legislative processes, ensuring consistency, accuracy, and efficiency in document handling and transmission. The XML implementation, specifically tailored for legislative documents, facilitated the structured representation of legal texts while maintaining semantic richness and enabling automated processing. The URN system, meanwhile, established a persistent and location-independent identification mechanism for legislative documents, ensuring reliable reference resolution across different systems and over time. This dual approach to document management established a technical foundation that would prove remarkably forward-thinking in its alignment with contemporary distributed systems principles.

The system's distributed architecture, though predating blockchain technology, implemented several features that would later become hallmarks of distributed ledger systems. In the first instance, the utilization of Certified Email as a transport mechanism established a primitive form of distributed consensus, whereby the legal validity of document transmission was ensured through cryptographic signatures and timestamp authorities. This approach, while differing substantially from blockchain consensus mechanisms, nevertheless established a precedent for distributed validation of legislative documents. Furthermore, the system implemented a sophisticated peer-to-peer architecture for document transmission, enabling direct communication between legislative institutions while maintaining document authenticity and integrity through unique identifiers. The 2022 [24] report [25] from the Council of Ministers emphasized the significant potential of this architectural approach, despite the absence of continued funding for that year. In the 2023 report [26], it is stated that new functionalities for the X-Leges platform are being studied, aiming to update the project with technological advancements and institutional collaboration.

The technical implementation of xLeges demonstrates particular sophistication in its approach to document workflow management. The system implements a complex state machine for tracking legislative documents through various stages of development, from initial drafting through committee review and final approval. The document management system itself implements a sophisticated versioning mechanism, maintaining complete historical records of all document modifications while ensuring the accessibility of both current and historical versions. This approach to version control, though implemented through traditional database technology rather than blockchain's immutable ledger, nevertheless established important precedents for tracking document lineage and maintaining audit trails.

One of the most significant challenges within the existing legislative framework addressed by xLeges concerns the absence of a unified document repository, necessitated by regulatory requirements and legal structure, which exacerbates inefficiencies in document exchange processes. The system's approach to this challenge proves particularly noteworthy in its implementation of a distributed document store, whereby each participating institution maintains its own document repository while the system ensures consistency through sophisticated synchronization mechanisms. This architectural decision, while introducing certain complexities in implementation, aligns remarkably well with contemporary principles of

institutional autonomy and data sovereignty. The synchronization mechanism implements a sophisticated conflict resolution system that maintains document integrity while respecting the authority of different institutions to modify documents within their jurisdiction.

The fragmented nature of the current system makes it particularly challenging to trace the progression and historical trajectory of legislative measures. x-Leges addresses this challenge through the implementation of a sophisticated metadata management system that maintains detailed provenance information for all legislative documents. This system implements a complex graph structure for tracking relationships between documents, enabling the reconstruction of legislative histories and the analysis of document dependencies. The metadata system integrates with the URN-based identification scheme to ensure persistent referenceability of documents and their relationships, while maintaining the flexibility to accommodate evolving legislative processes and institutional structures. This approach to metadata management, while implemented through traditional database technology, establishes important precedents for the tracking and analysis of legislative evolution that remain relevant in contemporary blockchain-based systems.

Additionally, the current infrastructure presents significant challenges in terms of accessibility and transparency of regulatory information. An attempt to resolve this issue [27] was made by *Normattiva*, which proposed and subsequently provided a system to identify the legislation in force as of a user-defined date and to uniquely identify each version (point-in-time [28]). The xLeges system addresses these challenges through the implementation of a sophisticated search and retrieval system that integrates with the metadata management infrastructure to enable complex queries across the legislative corpus. This search system implements advanced text analysis capabilities while maintaining strict access controls to ensure appropriate protection of sensitive information. The system's approach to information accessibility, while constrained by the technological limitations of its *pre-blockchain era*, nevertheless established important principles for balancing transparency with security that remain relevant in contemporary blockchain-based / DLT-based systems. For both institutional operators and citizens, accessing regulatory information remains a daunting task, complicating engagement and transparency. The difficulty in accessing this information limits the ability of stakeholders to participate effectively in the legislative process, undermining the democratic principles of inclusivity and transparency. The infrastructure often leads to the creation of isolated data silos, which impedes effective communication between systems. These silos result in critical information oversight or significant data loss, further complicating the legislative process. The lack of interoperability between different systems presents substantial risks to the continuity and consistency of legislative activities and records, highlighting the necessity for integrated solutions that can bridge these gaps and enhance the overall efficiency and transparency of the legislative process [29].

V. Technological Evolution: From X-Leges to Blockchain Architecture

The transition from X-Leges' distributed architecture to blockchain-based systems represents a fundamental evolution in the technological approach to legislative document management, warranting detailed technical analysis to elucidate both the continuities and discontinuities between these systems. The architectural foundations of X-Leges, though pioneering in their implementation of distributed computing principles, differ substantially from blockchain systems in their fundamental approach to consensus formation and data immutability. In the first instance, X-Leges' utilization of Certified Email (PEC) for document transmission implements a form of distributed validation that, while innovative for its time, relies fundamentally on centralized timestamp authorities and certification providers. This architecture, though effective in ensuring document authenticity, manifests inherent limitations in its scalability and resistance to institutional capture, characteristics that blockchain systems address through their implementation of distributed consensus mechanisms and cryptographic immutability [14].

Despite its substantial advantages, blockchain implementation for legislative processes faces several potential limitations that merit acknowledgment. Scalability concerns may arise as legislative archives grow exponentially, potentially affecting transaction throughput during peak parliamentary activity. The immutability feature, while beneficial for record integrity, could present challenges when legitimate corrections are legally required, necessitating complex governance mechanisms. Additionally, the technological complexity demands specialized expertise often unavailable in legislative institutions, creating knowledge dependencies and maintenance challenges. Beyond technical aspects, significant organizational barriers exist, particularly the introduction of sophisticated technology to public administration staff with predominantly legal backgrounds. This knowledge gap may generate resistance to adoption, requiring extensive training programs and continuous support. Even with well-designed transition strategies from systems like xLeges, implementation could entail periods of procedural inefficiency and institutional resistance. User experience considerations become paramount, as interfaces must mask underlying blockchain complexity while remaining legally precise, a design challenge that adds another layer of implementation difficulty. Furthermore, while decentralization enhances system resilience, it may complicate disaster recovery and system upgrades compared to traditional centralized infrastructures.

The document versioning and tracking mechanisms implemented in X-Leges, while sophisticated in their utilization of URN-based identification and XML standardization, demonstrate particular limitations when compared to blockchain's inherent capacity for immutable record-keeping. Where X-Leges relies on traditional database systems for version control [17], necessitating complex synchronization mechanisms to maintain consistency across distributed repositories,

blockchain architecture inherently maintains an immutable history of all transactions through its chained block structure. This fundamental architectural difference manifests particular significance in the context of legislative documents, where the ability to definitively establish document provenance and maintain an incontrovertible record of modifications assumes paramount importance. The blockchain's implementation of Merkle trees and cryptographic linking between blocks establishes a technically superior mechanism for ensuring document integrity and traceability, while simultaneously eliminating the need for complex synchronization protocols that characterize X-Leges' approach [18] [30]

Moreover, the consensus mechanisms implemented in blockchain systems represent a fundamental advancement over X-Leges' approach to distributed validation. Where X-Leges relies on the legal framework of certified email and institutional trust relationships to establish document validity, blockchain systems implement sophisticated consensus protocols that enable trustless verification of document authenticity and modification history. This transition from institutionally mediated trust to cryptographically enforced consensus represents a paradigmatic shift in approach to document validation, with particular significance in the context of legislative processes where institutional independence and transparency assume critical importance. The implementation of Proof of Authority consensus mechanisms in legislative blockchain applications demonstrates particular sophistication in its ability to balance the requirements of institutional autonomy with the need for efficient consensus formation [31].

The metadata management systems implemented in these architectures demonstrate similarly fundamental differences in approach. X-Leges implements a sophisticated but ultimately centralized approach to metadata management, utilizing traditional database technologies to maintain document relationships and provenance information. In contrast, blockchain systems integrate metadata management directly into their transaction structure, enabling the maintenance of complex document relationships and provenance information without requiring separate database systems. This architectural integration of metadata management represents a significant advancement in system simplicity and reliability, eliminating potential inconsistencies between document storage and metadata systems that can arise in X-Leges' separated approach. The blockchain's implementation of smart contracts further enhances this integration, enabling programmatic enforcement of document workflows and relationship management directly within the distributed ledger system [17].

Access control and permission management represent another domain where these architectures demonstrate fundamental differences in approach. X-Leges implements traditional role-based access control through centralized authentication systems, requiring complex integration with institutional identity management systems. Blockchain systems, on the contrary, implement cryptographic access control through public-private key pairs and smart contract-based permission management, enabling more flexible and granular control over document access while maintaining system security. This transition from institutionally mediated access control to cryptographically enforced permissions represents a significant advancement in system security and flexibility, particularly relevant in the context of legislative processes where complex permission structures must accommodate various institutional roles and responsibilities.

The systems' approaches to search and retrieval functionality manifest similarly fundamental differences. X-Leges implements traditional database-driven search capabilities, requiring complex index maintenance and synchronization across distributed repositories. Blockchain systems, while maintaining immutable records of all transactions, present unique challenges in implementing efficient search capabilities due to their append-only nature. However, contemporary blockchain implementations address these challenges through sophisticated indexing layers and off-chain search systems that maintain efficiency while preserving the security and immutability guarantees of the underlying blockchain. This hybrid approach to search functionality represents a sophisticated balance between competing requirements for search efficiency and data integrity that surpasses X-Leges' traditional database-driven approach.

The implementation of blockchain technology, while offering substantial advantages, introduces several critical considerations that warrant careful examination. Of particular significance is the question of node distribution within permissioned blockchain networks, where the delicate balance between transparency and institutional confidentiality must be meticulously maintained. The very nature of permissioned blockchain architectures necessitates careful consideration of node placement and access control, as certain legislative processes and deliberations must remain internal to specific institutions, protected from external visibility whlie maintaining the system's fundamental integrity. This requirement for *mediated visibility* presents a sophisticated challange in architectural design, wherein the system must simultaneously uphold principles of transparency and maintain essential institutional confidentiality. The implementation of such selective visibility mechanisms demands particular attention to the granular control of access permissions and the establishment of sophisticated cryptographic protocols that can effectively segregate public and private information flows within the same distributed ledger architecture. Moreover, the distribution of nodes within a permissioned blockchain network presents unique challenges in terms of ensuring adequate decentralization while maintaining institutional autonomy. This consideration becomes particularly important in the context of legislative processes, where the separation of powers doctrine necessitates careful attention to the distribution of validating nodes across different institutional entities. The system must be engineered to prevent any single institution from gaining disproportionate influence over the consensus mechanism, while simultaneously ensuring that each participating institution retains appropriate control over its specific domain of responsibility. This complex interplay between transparency requirements and institutional confidentiality manifests particular significance in the con-

text of parliamentary procedures, where certain deliberative processes, such as committee meetings or preliminary draft discussions, must remain confidential until appropriate for public disclosure. The implementation of sophisticated access control mechanisms, potentially leveraging advances in zero-knowledge proof systems and selective disclosure protocols, emerges as a critical consideration in addressing these competing requirements.

VI. Transformative Potential: Blockchain Technology's Contribution to Public Administration and Legislative Processes

The integration of blockchain technology within public sector operations, particularly in legislative processes, represents a paradigmatic shift in the technological architecture of governmental functions. Drawing from a recent comprehensive analysis [14], it becomes evident that blockchain technology offers distinctive advantages that transcend mere technological innovation, establishing instead a novel framework for trust, transparency, and institutional coordination. In the first instance, blockchain's inherent characteristics of immutability and distributed consensus create a technological foundation that enhances the reliability and traceability of public sector operations, particularly in domains where multiple stakeholders must coordinate their activities while maintaining institutional independence. The technological architecture manifests particular significance in legislative contexts, where the integrity and provenance of documents assume primary importance for the functioning of democratic institutions.

The regulatory recognition of blockchain technology's potential has found particular expression in the revised eIDAS Regulation (eIDAS 2), which explicitly acknowledges the legal effects of electronic ledgers. Article 45k of eIDAS 2 [32] establishes that "an electronic ledger shall not be denied legal effect or admissibility as evidence in legal proceedings solely on the grounds that it is in electronic form", while Article 45l establishes specific requirements for qualified electronic ledgers regarding their creation and management by qualified trust service providers. This regulatory framework provides crucial legal reinforcement for blockchain's implementation in public sector applications, particularly as it establishes that qualified electronic ledgers "shall enjoy the presumption of their unique and accurate sequential chronological ordering and of their integrity". Such legal recognition significantly strengthens the case for blockchain adoption in legislative processes as it provides a clear regulatory foundation for the technology's implementation while ensuring its alignment with fundamental legal principles.

When compared to existing systems such as X-Leges, blockchain technology introduces several substantial advancements that merit careful consideration. While X-Leges successfully implemented elements of decentralization through its utilization of Certified Email (PEC) and URN-based identification, blockchain technology extends these capabilities through its implementation of cryptographic immutability and distributed consensus mechanisms. The technological architecture of blockchain enables not merely the secure transmission of documents, as achieved by X-Leges, but rather establishes a comprehensive framework for document versioning, validation, and preservation that inherently maintains document integrity without requiring central coordination. This distinction proves particularly significant in legislative contexts, where the need to maintain document authenticity while enabling multiple stakeholders to participate in the legislative process creates complex requirements for technological systems.

Furthermore, blockchain's implementation of smart contracts enables the automation of complex procedural requirements while maintaining transparency and accountability. This capability extends significantly beyond X-Leges' document management functionalities, enabling the creation of programmable workflows that can enforce procedural requirements while maintaining flexibility for legitimate modifications. Such technological capabilities align particularly well with legislative processes, where procedural compliance assumes fundamental importance for the validity of legislative acts. The implementation of blockchain-based smart contracts can ensure that procedural requirements are met while maintaining the flexibility necessary for democratic deliberation and amendment processes.

The regulatory framework established by eIDAS 2 provides further validation and accountability for blockchain's potential in the legal domain, particularly through its detailed specifications regarding qualified electronic ledgers. Article 45l's requirements regarding the establishment of data record origin, sequential chronological ordering, and integrity preservation align precisely with the technological capabilities of blockchain systems, suggesting a natural convergence between regulatory requirements and technological capabilities. This alignment becomes significant in particular when considering the implementation of blockchain technology in legislative processes, as it demonstrates how the technology's inherent characteristics can satisfy both technical requirements for document management and legal requirements for procedural validity. [32]

VII. Open Problems and Future Research Directions

The implementation of blockchain technology in legislative processes, while offering substantial promise for enhancing institutional coordination and document integrity, nevertheless presents significant challenges that warrant careful consideration and ongoing research attention. In the first instance, one must consider the fundamental challenge of interoperability between different blockchain implementations, particularly in contexts where multiple institutions maintain independent systems. The interoperability challenge manifests through several interconnected dimensions: technical interoperability concerning the ability of different blockchain systems to exchange data and validate transactions; semantic interoperability regarding the shared understanding of exchanged data's meaning and context; and organizational interoperability pertaining to the

alignment of business processes and institutional workflows. These challenges assume particular significance in legislative contexts, where different institutions must maintain their constitutional independence while simultaneously participating in coordinated document management processes.

The technical implementation of blockchain interoperability requires sophisticated solutions that extend beyond mere data exchange protocols. Contemporary approaches to blockchain interoperability have explored various architectural models, including cross-chain communication protocols, relay chains, and sidechains, each presenting distinct advantages and limitations. The selection of appropriate interoperability mechanisms must carefully balance competing requirements for security, efficiency, and institutional autonomy. Moreover, the implementation of interoperability solutions must ensure compliance with regulatory requirements, particularly those established by eIDAS 2 regarding qualified electronic ledgers, smart contracts, electronic notarization and their interaction with other trust services [32]. This regulatory compliance assumes particular importance when considering the integration of blockchain systems with existing legislative infrastructure, including document management systems and electronic signature services, compared to the more *traditional* ecosystem.

The emergence of specialized blockchain programming languages, particularly the Move language, represents a significant development in addressing these challenges. Move, originally developed for the Diem blockchain but now finding broader application, introduces novel programming paradigms specifically designed to enhance security and reliability in blockchain applications. The language's resource-oriented programming model, which treats digital assets as first-class citizens with strict ownership and transfer rules, provides a robust foundation for implementing legislative document management systems. Move's type system implements linear types, ensuring that resources cannot be copied or discarded inadvertently, thereby maintaining document integrity throughout complex workflows. Furthermore, Move's formal verification capabilities enable rigorous analysis of smart contract behavior, a crucial consideration for systems implementing legislative procedures.

Beyond technical considerations, significant challenges persist regarding the governance and administration of blockchain-based legislative systems. The implementation of appropriate access control mechanisms that balance transparency with confidentiality requirements presents particular complexity, especially when considering the need to maintain different levels of access for various stakeholders while ensuring public accountability. This challenge intersects with broader questions regarding the role of blockchain technology in democratic governance and its potential impact on institutional power relationships. The implementation of blockchain-based systems must carefully consider how technological architectures might influence or alter existing institutional balances, particularly in contexts where technology mediates fundamental democratic processes.

A practical prototype could be developed implementing the multi-level blockchain architecture, incorporating a Private Institutional Blockchain for internal parliamentary processes, an Inter-Institutional Coordination Blockchain for document exchange between chambers, and a Public Legislative Blockchain for citizen access. This implementation would utilise the MOVE programming language to create smart contracts modeling critical legislative procedures such as bill unification and inter-chamber transfers, with Akoma Ntoso XML providing standardised document structure. Self-Sovereign Identity mechanisms would manage permissioned access across the three layers, whilst selective disclosure protocols would ensure appropriate confidentiality. A prototype could be directy applied to specific use cases like the management of unified bills (e.g., S.2923-2991-B) and inter-chamber shuttle processes and, additionaly, would serve as a testing enviorment for evaluating both the constitutional viability and operational efficiency of DLT solutions in legislative contexts in both italian end european context.

Research directions for addressing these challenges necessarily involve multiple domains, encompassing technical, legal, and institutional considerations. In the technical domain, ongoing research must address questions of scalability and performance optimization, particularly as legislative systems accumulate increasing volumes of document data over time. The development of efficient consensus mechanisms suitable for institutional contexts, where participants are known and accountable but must maintain independence, represents another crucial area for investigation. Moreover, research into advanced cryptographic techniques for selective disclosure and zero-knowledge proofs may provide valuable tools for managing access control and confidentiality requirements while maintaining system transparency.

From an institutional perspective, research must examine how blockchain implementation affects organizational processes and institutional relationships. This includes investigation of appropriate governance models for blockchain-based legislative systems, mechanisms for dispute resolution, and frameworks for managing system evolution over time. Furthermore, research attention must address questions of long-term sustainability, both in terms of technical maintenance and institutional adoption. The development of appropriate migration strategies for transitioning from existing systems, particularly considering the substantial investment in current infrastructure like X-Leges, represents another crucial area for investigation.

Legal research must continue to examine the implications of blockchain adoption for constitutional principles and administrative law requirements. This includes analysis of how blockchain-based systems align with principles of separation of powers, requirements for democratic accountability, and obligations for administrative transparency. Moreover, research must address questions of legal validity and evidential value for blockchain-based records, particularly in light of evolving regulatory frameworks like eIDAS 2. [32]

The intersection of these research domains suggests the need for interdisciplinary approaches that can address the complex

interplay between technical capabilities, institutional requirements, and legal constraints. Such research might examine, for instance, how Move's resource-oriented programming model could be extended to implement sophisticated access control mechanisms that reflect constitutional requirements for institutional independence while enabling necessary coordination. Similarly, investigation of how blockchain's immutable record-keeping capabilities might be leveraged to enhance democratic accountability while maintaining appropriate confidentiality and the creation of a all-rounded working interdisciplinary prototype represents a promising direction for future research.

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[11] "Costituzione della repubblica italiana, art. 101," 1948, la giustizia è amministrata in nome del popolo. I giudici sono soggetti soltanto alla legge.

[12] "Costituzione della repubblica italiana, art. 104," 1948, la magistratura costituisce un ordine autonomo e indipendente da ogni altro potere.

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