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CREATING A THREAT MODELING PROTOCOL FOR NON-HIERARCHICAL ORGANIZATIONS

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Abstract

This research explores the development of a threat modeling protocol specifically designed for non-hierarchical organizations. Grounded in analyses of distributed governance frameworks and security methodologies, the study presents an innovative approach that treats horizontality as a strategic asset. Leveraging tools such as attack trees, STRIDE, PASTA, and COLBAC, the protocol aims to integrate cybersecurity with democratic participation, addressing the unique challenges of decentralized structures. This work fills a gap in the literature by providing practical guidelines to identify, mitigate, and prevent threats in contexts where distributed trust and collaboration are essential.

Keywords: threat modeling, horizontal organizations, distributed governance, collaborative security, decentralized trust

Resumo

A pesquisa explora a criação de um protocolo de modelagem de ameaças projetado especificamente para organizações não-hierárquicas. Com base em análises de frameworks de governança distribuída e metodologias de segurança, o estudo desenvolve uma abordagem inovadora que considera a horizontalidade como um ativo estratégico. Utilizando ferramentas como árvores de ataque, STRIDE, PASTA e COLBAC, o protocolo busca integrar segurança cibernética e participação democrática, abordando desafios únicos de estruturas descentralizadas. Este trabalho contribui para preencher lacunas na literatura ao oferecer diretrizes práticas para identificar, mitigar e prevenir ameaças em contextos onde a confiança distribuída e a colaboração são fundamentais.

Palavras-chave: modelagem de ameaças, organizações horizontais, governança distribuída, segurança colaborativa, confiança descentralizada

Contents

Acronyms

ABC   Asset-Based Cryptocurrency *(pp. 18–21, 28)*

COLBAC Collective based access control system *(pp. 10, 17, 18, 20, 21, 28)*
CoReTM Collaborative and Remote Threat Modeling *(p. 17)*

DAC   Discretionary Access Control *(p. 17)*
DFDs   Diagramas de Fluxo de Dados *(p. 12)*
DREAD   Damage, Reproducibility, Exploitability, Affected users, Discoverability *(p. 13)*

hTMM   Hybrid Threat Modeling Method *(p. 17)*

MAC   Mandatory Access Control *(p. 17)*

PASTA   Process for Attack Simulation and Threat Analysis *(pp. 1, 13–15, 20)*
PGP   Pretty Good Privacy *(pp. 19, 20)*
PnGs   Personae Non Gratae *(pp. 16, 17)*
PTM   Participatory Threat Modeling *(pp. 17, 21)*

RBAC   Role-Based Access Control *(p. 17)*

STRIDE Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege *(pp. 1, 2, 7, 8, 12–14, 17, 18, 20, 21, 24, 25, 28)*

WoT   Web of Trust *(pp. 19, 20)*

Introduction

1.1 Threat Modeling: Relevance and Challenges

Threat modeling is an essential discipline in information security, whose main function is to identify, classify and mitigate vulnerabilities in technological systems before they can be exploited by adversaries [38, 51]. In a context where systems become increasingly complex and integrated, threat modeling stands out as a critical tool for anticipating risks and establishing effective security measures [45, 36].

Traditional models such as Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege (STRIDE), attack trees, and iterative methodologies such as Process for Attack Simulation and Threat Analysis (PASTA) have been widely applied in hierarchical contexts [34, 35, 47]. These approaches focus on linear, hierarchical data flows, but face significant challenges when applied to horizontal organizations, where the distribution of power and responsibilities fundamentally alters risk dynamics [40, 9].

Horizontal organizational structures, characterized by the absence of a formal hierarchy, face particular challenges in threat modeling [9]. The lack of centralization can make it difficult to implement role-based access controls (RBAC) and other systems that rely on hierarchical structures [9]. Furthermore, the temporary centralization of organizational secrets, such as passwords or encryption keys, often leads to conflicts known as "password wars" during leadership transitions [19].

Additionally, digital tools often promote implicit centralization of power, creating the phenomenon of the "digital vanguard," where individuals control critical resources such as communication platforms [10]. This is exacerbated by attacks specific to horizontal systems, such as identity spoofing (Sybil attacks) and quorum manipulation, which exploit the dependency on participatory processes [46, 7].

The challenges highlighted indicate the need for adaptations in threat modeling methods for horizontal contexts [9]. In addition to technical limitations, such as the difficulty of integrating collaborative cryptography [1], the need for participatory tools that respect democratic dynamics and promote resilience is also highlighted [6].

1.2 Horizontal Security in Times of Interconnection

In today's interconnected world, horizontal organizations challenge the assumption that security depends on a clear chain of command [11, 42]. The absence of a formal hierarchy can become a strategic asset by hindering centralized attacks and enabling a reconfiguration of trust management, promoting organizational resilience [42, 9]. In distributed trust systems, such as those used in blockchain-based organizations, security is promoted by collaborative mechanisms that replace formal leaders with participatory processes and solutions oriented towards transparency and consensus [33, 1].

Traditional threat analysis methodologies such as STRIDE and attack trees provide valuable insights but face limitations in decentralized environments, highlighting the need for approaches better suited to the specificities of horizontal structures [14, 36]. Less hierarchical contexts require adapted approaches that understand the complexity of horizontal trust and the potential associated risks [9].

In this sense, technologies such as collaborative cryptography [9, 1] and threat modeling approaches that adopt the global perspective of the organization can promote a more realistic understanding of security in decentralized structures. Horizontality, often seen as a challenge, should be explored as a strategic asset capable of diluting single points of failure and strengthening organizational resilience [42].

1.3 Organizational Governance: A Historical Perspective

Organizational governance reflects the social, economic, and technological structures of each era. From the earliest human groups to the complex organizations of contemporary times, the ways of organizing power and decision-making have been shaped to respond to specific contexts [11]. The hierarchical model, widely adopted, emerged as a solution to demands for control and efficiency. However, history also records experiments that challenged this logic, suggesting the possibility of new approaches to the management and coordination of activities [15, 50].

Even in systems considered pioneers in horizontality, such as Athenian democracy, governance faced significant limitations related to inclusion and practical applicability, highlighting weaknesses in the operationalization of equal participation [2]. As the Industrial Revolution progressed, hierarchical centralization intensified to cope with organizational growth and complexity [50]. Additionally, experiences such as cooperatives and the 19th century labor movement outlined alternatives to absolute centralization, while modern technologies offer decentralized structures that challenge traditional paradigms of control [15, 42].

Innovations such as blockchain open up new possibilities for decentralization, yet face challenges in equitable distribution of power and resources, as evidenced by the concentration of miners on public networks [17].

These historical and technological evolutions not only shape governance structures, but also introduce unique challenges in threat modeling [49, 41]. Critical analysis of these attempts allows us to identify vulnerabilities and strengths that underpin the construction of security protocols in horizontal organizations [9].

1.4   Security Protocol for Non-Hierarchical Organizations

This research proposes a security protocol that integrates horizontality as a strategic element, going beyond the simple adaptation of traditional methodologies [9]. The main objective is to demonstrate how decentralization, when structured in a way that is coherent with organizational principles, can strengthen resilience against complex threats, mitigating single points of failure and distributing responsibilities equitably [38]. The protocol aims to balance operational efficiency and democratic participation, ensuring that security measures do not compromise decision-making agility or the inclusion of members in critical processes [33]. To this end, it relies on collaborative approaches, such as cryptography adapted to horizontal contexts [9], and on threat modeling methodologies that consider participatory dynamics [43].

The integration between security and governance is addressed through guidelines that harmonize technical requirements with organizational principles [43]. The protocol foresees the application of transparent and auditable consensus mechanisms, inspired by distributed reputation models [33], to validate access policies and mitigate risks such as Sybil attacks [46]. In addition, it incorporates modular structures that allow adaptation to different levels of horizontality, from fully decentralized networks to organizations with more hierarchical structures [9]. This flexibility is essential to respond to dynamic threats without compromising the autonomy of members and to cover the largest number of organizations.

To strengthen resilience, the protocol combines technical and social layers: cryptographic techniques protect against external threats, while radical transparency structures and periodic reviews by rotating committees prevent internal fraud [42]. The traceability of decisions via immutable records ensures that vulnerabilities are identified and corrected collaboratively, in line with studies on failures in distributed systems [33]. By incorporating lessons from historical cases and methodological innovations, the protocol offers a practical framework for organizations that seek security without giving up their horizontal identity, paving the way for detailed analyses in subsequent chapters.

1.5   Defining the Scope of Research

The diversity of horizontal organizations ranges from informal collectives to complex digital networks, each with its own dynamics [42]. To ensure analytical focus, this study is limited to structures that operate under strict principles of horizontality, characterized

by: (1) absence of formal hierarchies or permanent centralization of power; (2) decision-making processes based on consensus or broad participation; and (3) explicit mechanisms for distributing responsibilities and resources [9]. This delimitation excludes hybrid or partially decentralized models, where the coexistence of hierarchical and horizontal structures introduces additional variables that make it difficult to evaluate the proposed protocol in isolation [11].

The choice to analyze organizations such as worker cooperatives and community networks is justified by their empirical relevance: these models have robust documentation on operational challenges [15], in addition to explicitly adopting principles of self-management and radical transparency [42]. These characteristics allow testing the protocol in contexts where security depends directly on collective coordination, without intermediaries or central authorities [38].

Although digital platforms and decentralized social networks [18] represent equally relevant cases, their dynamic nature and dependence on heterogeneous technical infrastructures would require methodological adaptations beyond the current scope. Future studies could explore these variations, using the protocol developed here as a basis for comparative analyses in less controlled environments.

1.6   Expected Contributions

The research will deliver a threat modeling protocol specific to horizontal organizations, integrating the principles of distributed governance, collective participation, and transparency [9]. This protocol will be designed to identify, assess, and mitigate threats in decentralized structures, providing practical guidelines adapted to the particularities of these organizations. In addition, it will be accompanied by an evaluation method to validate its effectiveness and its application in real cases.

The protocol is expected to demonstrate how horizontality can be a strategic asset, reinforcing organizational security and resilience in the face of complex threats. In addition to contributing to theoretical advancement on security in decentralized structures, the research seeks to offer a practical solution that strengthens autonomy and promotes the integration between security and democratic governance.

1.7   Structure of the Thesis

After the introduction, the Background chapter presents the fundamentals of threat modeling and security in horizontal structures. The Related Work chapter analyzes previous studies, identifying relevant gaps and opportunities.

The Design chapter outlines the proposed protocol, its methodologies, and evaluation criteria. The Work Plan chapter describes the research steps and schedule, ensuring

the structured and viable execution of the project. Finally, the Conclusion chapter summarizes the results, discusses limitations, and proposes future directions, highlighting horizontality as a strategic asset for organizational security.

The first chapter presented the context that support this research, identifying challenges faced by non-hierarchical organizations in the area of digital security and threat modeling. The structural particularities of these organizations were described, highlighting the need for specific methods for risk analysis and mitigation. Having defined the objectives, intended contributions and structure of this research, Chapter 2 will address the essential concepts that underpin the study, including threat modeling, the conceptual differences between horizontal organizations and organizations without explicit leadership, and the role of democratic centralism as an organizational principle.

Background

2.1 Foundations of Threat Modeling

Threat modeling is a central component of cybersecurity, as it allows the identification of valuable assets, analysis of potential attack vectors, and establishment of controls capable of mitigating risks. This practice goes beyond technical factors, incorporating organizational and human elements that shape security in diverse contexts, especially in horizontal structures, where internal processes and trust relationships become even more critical due to the absence of formal hierarchies [9]. In a scenario of rapid technological evolution and constant diversification of threats, a broad and flexible approach gains relevance, meeting the particularities of changing contexts [38].

Studies such as [28], [29], and [45] demonstrate the need for structured, yet adaptable, methods to keep up with changing environments. Adopting the adversary perspective [25] is crucial to anticipate complex scenarios and strengthen resilience in decentralized environments, where the multiplicity of actors and the distribution of power require a holistic analysis of threats. In this type of context, threat modeling needs to reflect the distribution of power and the multiplicity of actors, including potential internal, external and hybrid threats [36].

In addition, Microsoft's experience, documented in [37], emphasizes the importance of involving diverse stakeholders and applying collaborative tools. These elements become crucial when decision-making is democratic or decentralized, since identifying and mitigating risks requires collective engagement and strategic flexibility, connecting the threat modeling exercise to organizational dynamics [43].

2.1.1 Conceptual Definitions

Threat modeling can be understood as a systematic protection effort that considers both technical vulnerabilities and social and organizational factors. By adopting a holistic view, as suggested by [28] and [29], security analysis is not restricted to infrastructure, but incorporates internal practices, information flows, and the organization's culture. In non-hierarchical contexts, the absence of clear lines of authority and the participatory

nature make an analysis that considers the distribution of responsibilities and the reliance on collective mitigation mechanisms essential [9].

In turn, [45] emphasizes that there is no single solution for threat modeling. In this sense, threat modeling becomes an iterative process, adapting to structural changes and incorporating innovations such as participatory decision-making tools and collaborative security practices [6, 43].

2.1.2 Main Methodologies

Widely discussed methodologies such as Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege (STRIDE), attack trees, and scenario-based frameworks [40] provide a tested starting point, but they often fail to capture the complexity of horizontal structures.

The documentation [36] provides an overview of existing methods, cautioning that the effectiveness of each approach depends on the context. For example, STRIDE and attack trees are useful for identifying straightforward attack vectors, but the lack of formal hierarchies intensifies the need to explore complex scenarios such as insider threats coupled with external attacks, as well as flaws in distributed authentication, consensus, and governance mechanisms, as suggested in [9, 35, 20].

Integrating diverse approaches, such as collaborative cryptography practices [1] and hybrid approaches [48], enables horizontal organizations to identify less obvious risk patterns and strengthen their collective resilience. This integration becomes crucial in distributed structures, where the absence of a 'center' turns security into a collective effort, and resilience emerges from the continuous interaction between members, systems and decentralized governance mechanisms [33].

2.2 Taxonomy of Organizational Structures

Understanding the relationship between organizational form and security is essential to adjust threat modeling to the reality of each institution [11]. While hierarchical structures rely on central decision points for control and coordination, these same points can become critical vulnerabilities [38]. Horizontal or cooperative organizations can disperse vulnerabilities and increase resilience through decentralized governance, although they can also create multiple entry points that require collaborative control [9]. Analysis of this taxonomy, as [15, 21], provides a basis for identifying how the distribution of power in different organizational forms affects the effectiveness of security measures, including the ability to respond to internal and external threats.

2.2.1 Traditional Hierarchical Structures

Hierarchical organizations have clear lines of authority, which facilitates control but can concentrate vulnerabilities in critical areas [34]. These organizations are characterized by a

well-defined chain of command, where decisions flow from the top down. Classic examples include large multinational corporations, where the board of directors establishes policies that are implemented by layers of managers, supervisors, and employees. On the other hand, in small businesses, such as family offices, the hierarchy may be less formal but still based on a clear, centralized command structure [15].

In large organizations, such as banks or automotive manufacturers, hierarchy allows for efficient allocation of resources and tight control over operations. For example, IT departments in these environments often use security frameworks such as STRIDE for threat modeling, focusing on protecting critical assets and centralized access management [34, 51]. Centralization facilitates rapid incident response, but it also creates single points of failure, such as vulnerabilities in key servers or administrative credentials [49, 27].

In contrast, small businesses face different challenges. In these contexts, lack of resources may lead to fewer hierarchical layers, but decisions are still centered on a single owner or manager [50]. This reduces organizational complexity but increases reliance on specific individuals, making them prime targets for attacks [15]. Furthermore, the lack of dedicated security teams can limit the ability to implement sophisticated frameworks such as STRIDE, requiring more streamlined solutions.

The difference between large and small organizations also impacts threat modeling [15, 36]. In larger organizations, hierarchical structures allow for detailed segmentations to identify and mitigate risks at specific levels of the organization. However, this segmentation can lead to communication gaps between departments, making it difficult to implement integrated solutions [51]. On the other hand, smaller organizations have greater flexibility to quickly adapt their security strategies, although they often lack the resources to implement robust solutions [50].

Therefore, while hierarchical organizations offer advantages in terms of control and clarity, they also introduce specific challenges for threat modeling. These challenges vary significantly with the size and complexity of the organization, requiring adaptations to traditional frameworks to meet the specific needs of each type of hierarchy.

2.2.2 Horizontal Organizations

Horizontal organizations are distinguished by their rejection of traditional hierarchies, prioritizing distributed decision-making processes and equitable participation of all members. This model contrasts directly with hierarchical structures, which centralize power at higher levels, perpetuating inequalities in access to information and organizational control [11, 31].

Horizontality is both a tool and an objective in itself [9]. In Argentine social movements, as analyzed by Marina Sitrin, horizontality has emerged as an essential mechanism for establishing relationships based on trust and consensus, overcoming traditional forms of organization. Neighborhood assemblies and collectives of unemployed workers exemplify how horizontality can be applied to self-management and collective planning [42].

In the field of cybernetics, the COLBAC protocol demonstrates the relevance of horizontality in digital security systems, promoting collaborative access control that reduces the centralization of power. This model avoids the vulnerabilities created by the dependence on single owners of passwords or permissions, reinforcing the coherence between organizational practices and technological tools [9].

In addition, historical examples, such as Athenian democracy, illustrate that horizontal structures can be complemented by temporary centralization mechanisms in times of crisis, ensuring flexibility and efficiency without compromising the basic principles of distributed governance [2].

Despite the challenges, such as the risk of domination by more influential voices or the management of conflicts in collective spaces, horizontal organizations demonstrate that, with adequate mechanisms, it is possible to promote autonomy, inclusive participation and efficiency in decentralized structures [10].

2.2.3 Leaderless Organizational Models

The discourse of leaderless organizations hides an additional complexity, where the absence of a formal hierarchy does not necessarily imply genuine horizontality [10]. Critical studies highlight how these organizations often replicate veiled power dynamics and informal centralizations [10, 42].

Marina Sitrin, in her analysis of horizontal movements in Argentina, points out that although horizontality is declared as an objective, many movements face significant challenges in sustaining truly participatory practices. The lack of formal hierarchy often leads to informal power structures, where dominant voices assume leadership roles without oversight or clear collective responsibility [42].

In the digital context, movements such as Occupy Wall Street demonstrate that the absence of recognizable leadership does not eliminate internal conflicts [10]. Studies of social media teams in these movements reveal that account management, as on Twitter, was often marked by struggles for control, illustrating how power and influence can consolidate even in supposedly horizontal structures [10].

Furthermore, research on worker cooperatives in the United States indicates that these organizations, although often seen as non-hierarchical alternatives, tend to develop informal leaders who influence decisions in significant ways, challenging the narrative of absolute horizontality [50].

Technologies used by these organizations also carry political implications [49, 41]. Langdon Winner argues that technical artifacts can perpetuate existing power structures, even when employed in decentralized contexts [49]. For example, digital platforms, often designed for individual use, create challenges in building effective collective governance, exacerbating latent inequalities [49, 27].

These examples highlight that while the idea of formal leadershiplessness is appealing, its practical execution often results in informal forms of hierarchy [42, 10]. Thus,

the success of these organizations depends on the ability to identify and mitigate hidden power dynamics, promoting clear mechanisms of collective governance and mutual accountability that truly sustain the desired horizontality [9].

2.3 Democratic Centralism

In the midst of increasingly challenging scenarios in terms of organizational coordination, whether in the management of large corporations or in the maintenance of decentralized networks such as blockchain, the need arises to reconcile efficiency in decision-making with the active participation of all those involved [49]. Democratic centralism, formulated to meet the demands of revolutionary movements, maintains its relevance by proposing a dynamic balance between collective deliberation and centralized execution [31]. This approach has proven to be relevant both in political and social contexts and in contemporary technological scenarios [9].

2.3.1 Fundamental Principles and Theoretical Origins

Democratic centralism is based on the idea that opinion gathering and deliberation (democracy) must be harmonized with the ability to implement decisions in a unified manner (centralism) [44]. This system was originally conceived as a response to the need for organization in contexts of high structural complexity [52, 31].

Its initial formulation, associated with the Communist Party of the Soviet Union, inspired the adoption of the model by different groups around the world [31]. In China, for example, the practices of democratic centralism demonstrate remarkable resilience, being reconfigured as political and social situations change [44].

2.3.2 Contemporary Models of Application

The transposition of the precepts of democratic centralism to modern contexts has been observed in different organizational and technological structures [49, 9]. One example is the Collective based access control system (COLBAC) protocol, which adapts the bases of democratic centralism to a collaborative access control environment, enabling participatory decisions combined with cohesive implementation [9].

Trade unions and social organizations have also integrated principles of democratic centralism [8]. The General Confederation of Portuguese Workers, for example, combines collective deliberation and periods of strategic centralization to provide effective responses to organizational challenges [8].

2.3.3 Implications and Potentials for Governance

The influence of democratic centralism transcends the limits of political parties and can be extended to diverse scenarios that require both broad participation and efficient execution

[44, 5]. Horizontal or distributed organizations can use this model to reconcile the voice of their members with the need to make centralized decisions at critical moments [52, 44].

In this sense, the application of elements of democratic centralism in digital platforms highlights how historical concepts can be reappropriated to meet contemporary governance demands [9].

Chapter 2 presented the theoretical foundations related to threat modeling, addressing structured and flexible methods needed to deal with decentralized organizational contexts. Approaches that incorporate adversarial perspectives were discussed and emphasized the importance of considering social and organizational factors, in addition to technical vulnerabilities, highlighting especially the relevance of collaboration between different actors in the process. Building on these fundamental concepts, Chapter 3 will analyze related works, describing in detail traditional threat modeling approaches, such as STRIDE, and exploring their applications and limitations in decentralized and collaborative environments.

RELATED WORK

The references discussed in this chapter were chosen based on an initial selection suggested by the advisor of this work, Professor Kevin Gallagher. As a starting point, the professor provided three fundamental articles related to his research area: COLBAC, ABCcrypto and PGP's Web of Trust. In particular, the work on COLBAC is directly linked to Professor Gallagher's academic production, offering a solid and highly relevant basis for the development of this research. Based on these initial references, traditional and emerging methods for threat modeling were explored, aiming to establish a comprehensive overview that would allow a critical analysis of the applicability of these methods to the specific context of non-hierarchical organizations.

3.1 Traditional Approaches to Threat Modeling

3.1.1 STRIDE

Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege (STRIDE), developed by Microsoft, is a systematic threat modeling methodology designed to identify potential vulnerabilities in software systems [34]. The acronym STRIDE stands for six main categories of threats [38]. Each of these categories reflects a specific violation of desired security properties such as authenticity, integrity, non-repudiation, confidentiality, availability, and authorization [34].

Applying STRIDE begins with the creation of Diagramas de Fluxo de Dados (DFDs) to map the movement of information within the system [12]. DFDs help identify elements such as external entities, processes, data flows, and data stores. For each element in the diagram, the six STRIDE threat categories are analyzed to identify potential vulnerabilities [38].

Each threat in STRIDE has a clear definition and practical examples to aid in identification and mitigation. For example:

1. **Spoofing:** Threats that involve falsification of the identity of users or processes, compromising authenticity.

2. **Tampering:** Manipulation of data in transit, in storage, or in memory, affecting integrity.

3. **Repudiation:** Scenarios where users deny actions performed, often due to the lack of adequate logging mechanisms.

4. **Information Disclosure:** Exposure of sensitive information to unauthorized parties, compromising confidentiality.

5. **Denial of Service:** Attacks that overload system resources, impairing availability.

6. **Elevation of Privilege:** Cases where a malicious actor obtains privileges above those authorized, compromising authorization.

The STRIDE methodology can be adapted to different contexts. For example, in cyber-physical systems, it is possible to assess threats related to hardware and software components, such as failures in synchronization or communication [20]. In addition, variants such as STRIDE-per-Element and STRIDE-per-Interaction offer more focused approaches to identify threats in specific elements or in interactions between components [38].

Although widely used, STRIDE has limitations. It relies heavily on analyst experience and may not capture emerging threats in decentralized systems or dynamic environments [13]. Therefore, it is often complemented with other frameworks, such as Damage, Reproducibility, Exploitability, Affected users, Discoverability (DREAD), to prioritize threats based on impact and probability [22].

In summary, STRIDE provides a solid foundation for threat identification, but its effective application requires integration with other methodologies and adaptations to meet the specific needs of modern, decentralized systems [12].

3.1.1.1 STRIDE Complementary Models

Several complementary models have been derived from or used in conjunction with STRIDE to improve its effectiveness and adaptability in different contexts [32]. Notable among these is the DREAD model, which complements STRIDE by providing a quantitative approach to threat prioritization [22]. DREAD uses five main categories: Damage Potential, Reproducibility, Exploitability, Affected Users, and Discoverability, allowing analysts to assign values and create scores to rank threats according to their severity [32, 22].

The combined use of STRIDE and DREAD can improve risk assessment in more complex systems. However, the inherent subjectivity in assigning values in DREAD can compromise the consistency of [22] analyses. To mitigate these limitations, some organizations have integrated STRIDE with more comprehensive frameworks, such as Process for Attack Simulation and Threat Analysis (PASTA), which takes an iterative approach to identifying and prioritizing threats [32].

Additionally, the use of attack trees has proven effective in complementing STRIDE, allowing teams to visually represent complex threat scenarios and identify multiple attack paths [24]. This integration is particularly useful in horizontal organizations, where the lack of centralization increases the need for collaborative threat mapping [38].

3.1.2 Attack Trees

Attack trees, introduced by Bruce Schneier [35], provide a hierarchical framework for threat modeling, where the attack objective is represented by the root node, and the sub-objectives and steps required to achieve it are arranged in child nodes. Each node can be detailed with logical operators such as AND and OR, representing conditions that must be met either together or alternatively [24].

A key advantage of attack trees is their ability to decompose complex threats into smaller, more manageable components, enabling systematic analysis [17]. This methodology makes it easier to identify multiple attack paths, allowing organizations to prioritize countermeasures based on metrics such as cost, impact, and likelihood [16].

Practical applications of attack trees include their use in wireless sensor networks to assess location privacy risks [16], as well as in energy theft detection in advanced metering infrastructures such as smart grids [17]. In both cases, the approach enables organizations to map specific threat scenarios and design effective countermeasures.

In addition, studies such as [24] highlight the reuse of subtrees to increase efficiency in complex systems. This practice allows shared elements across different scenarios to be modeled once and incorporated into future analyses, saving time and resources.

Although broadly applicable, attack trees present challenges related to the effort required for their initial construction and the complexity in large-scale systems [35, 17]. Collaboration between stakeholders, including technical and operational experts, is essential to ensure that threat representation is accurate and comprehensive [17].

Attack trees also stand out as complementary tools to methodologies such as STRIDE and can be used both to identify threats and to organize those already discovered [24, 51]. Furthermore, reusing existing trees, such as those focused on fraud or elections, saves time and provides a solid foundation for analysis [24]. Despite their versatility, effective use of trees depends on clear representations of AND/OR nodes and continuous evaluation to avoid oversights or gaps [38].

3.2 Emerging Methodologies

3.2.1 PASTA

PASTA is a risk-centric threat modeling methodology designed to integrate security throughout the software development lifecycle. Proposed by Tony UcedaVelez and Marco M. Morana [47], the framework consists of seven sequential stages that allow for in-depth and iterative analysis of threats and vulnerabilities.

The main goal of PASTA is to align security concerns with business objectives, ensuring that mitigation measures address both technical risks and organizational impacts. The methodology promotes a risk-oriented approach by integrating attack simulations to evaluate the effectiveness of proposed countermeasures [47].

1. **Definition of the Objectives (DO):** In this initial stage, the security requirements, risk profile, and potential business impacts are defined.

2. **Definition of the Technical Scope (DTS):** This stage details the technical aspects, such as users, software components, third-party infrastructure, and external dependencies.

3. **Application Decomposition and Analysis (ADA):** The application is broken down into basic functional elements to identify data flows, user types, and existing security controls.

4. **Threat Analysis (TA):** Identification of potential threats based on the analyzed elements and assets, considering the most likely attack vectors.

5. **Weakness and Vulnerability Analysis (WVA):** At this stage, threats are associated with specific vulnerabilities, evaluating the effectiveness of existing controls and identifying weaknesses.

6. **Attack Modeling and Simulation (AMS):** Performing simulations to determine the most likely attack paths, using attack trees and other models to explore risk scenarios.

7. **Risk Analysis and Management (RAM):** Identifying technical and business impacts, proposing measures to mitigate priority risks [47].

PASTA stands out for its flexibility and analytical depth, making it particularly effective in dynamic and distributed environments [51]. The methodology encourages collaboration between stakeholders from different areas, promoting a unified understanding of risks and organizational priorities [43]. In addition, the integration of attack simulations allows organizations to test the effectiveness of their security strategies under realistic conditions, improving their resilience against emerging threats [47].

One of the most relevant aspects of PASTA is its compatibility with horizontal organizations. The collaborative approach of the methodology, which involves multiple stakeholders at all stages of the process, is aligned with the principles of distributed governance [9]. In non-hierarchical structures, where responsibility for security is shared, PASTA offers a structured framework to identify and mitigate risks in a participatory and efficient way.

3.2.2 Security Cards

Security Cards are a tool designed to facilitate brainstorming of security threats, using a deck of cards that address different aspects of potential attacks [6]. Created by Tamara Denning, Batya Friedman, and Tadayoshi Kohno, the cards cover four main dimensions: adversary motivations, adversary capabilities, adversary methods, and human impact [4]. This approach aims to foster creativity and collaboration among stakeholders, encouraging a more holistic and comprehensive analysis of threats [39].

Each card provides examples and scenarios related to its dimension, helping teams explore vulnerabilities that might otherwise be missed by traditional methods [6]. For example, in the "Human Impact" dimension, cards can highlight how security breaches can affect privacy, emotional or financial well-being, providing a more user-centric perspective [4].

Security Cards have been used in a variety of applications, such as protecting biometric systems against presentation attacks [23, 4]. Their flexible structure allows them to be adapted to different organizational contexts, including decentralized environments [43]. In horizontal organizations, Security Cards facilitate the participation of multiple stakeholders, promoting distributed governance and reinforcing collaboration [39].

Despite their potential, the methodology can generate a high number of false positives, which requires additional effort to filter relevant threats [4]. However, their emphasis on creativity and inclusion of multiple perspectives makes Security Cards a valuable tool for exploring emerging threats and strengthening organizational resilience [39].

3.2.3 Personae Non Grata

Personae Non Gratae (PnGs) represent an innovative approach to threat modeling, notable for their focus on malicious users and undesirable behaviors [3]. Inspired by traditional user experience design personas, PnGs help anticipate how adversaries might exploit vulnerabilities in a system, providing a detailed adversarial perspective [26].

PnGs are created through techniques such as crowd-sourcing, allowing different stakeholders to contribute insights to threat identification [26]. This collaborative approach increases the breadth and diversity of attacker profiles considered, allowing for more robust modeling that is adapted to different contexts [3].

One of the main advantages of PnGs is their ability to capture specific attacker motivations, capabilities, and behaviors [26]. For example, a PnG might describe an adversary who uses phishing to obtain credentials or exploits security flaws in financial transactions [3]. This level of detail helps in prioritizing countermeasures and allocating security resources [26].

In addition, PnGs are particularly effective in contexts where internal and external threats overlap [3]. In flat organizations, where governance is distributed and responsibility is shared, PnGs help map potential risks that may arise from internal actors, such as employees, or external actors, such as competitors [3].

Despite its benefits, implementing PnGs requires significant effort to ensure that profiles are accurate and relevant [26]. However, when integrated with other methodologies such as attack trees or STRIDE, PnGs provide an additional layer of analysis, making them an indispensable tool for organizations seeking to comprehensively understand and mitigate threats [26].

3.3 Hybrid and Collaborative Approaches

Hybrid and collaborative approaches seek to integrate different methodologies to create adaptable and effective frameworks in different contexts [25, 48]. Among these, Hybrid Threat Modeling Method (hTMM) stands out, combining elements of different frameworks for a comprehensive risk analysis. It is particularly useful in scenarios involving multiple stakeholders and requiring alignment between security objectives and business priorities [25].

Another example is Collaborative and Remote Threat Modeling (CoReTM), designed to facilitate threat modeling in distributed or remote teams. Using collaborative tools, such as shared annotation platforms, CoReTM makes the process more accessible and inclusive, being ideal for horizontal and global organizations [48].

Finally, Participatory Threat Modeling (PTM) promotes the inclusion of a wide range of stakeholders in the threat modeling process [43]. This approach values the diversity of perspectives, being especially relevant in decentralized contexts where transparency and collective participation are essential [43]. These methodologies reinforce distributed governance and strengthen organizational resilience, complementing the work developed by more traditional frameworks [9].

3.4 Decentralized Trust and Cryptographic Frameworks

3.4.1 COLBAC

Collective based access control system (COLBAC) is an access control model designed to address the specificities of horizontal organizations, promoting a democratic and participatory approach to access authorization. Its proposal seeks to overcome the challenges imposed by traditional access control models, such as Discretionary Access Control (DAC), Mandatory Access Control (MAC) and Role-Based Access Control (RBAC), which often reinforce hierarchical dynamics that are inadequate for horizontalized structures [9].

One of the most striking features of COLBAC is its ability to align access control with horizontal governance practices, allowing decisions to be made collectively through democratic processes [43]. The model organizes resources and processes into three main spheres: the Collective Sphere, which concentrates critical resources subject to collective approval; the User Sphere, which encompasses individually managed resources based on

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traditional controls; and the Immutable Sphere, responsible for storing logs and records in an unalterable manner, ensuring transparency and traceability [9].

In the context of COLBAC, interactions with the Collective Sphere follow a process structured in three phases: in the Draft Phase, the user creates a token that specifies the permissions and objectives of the action; in the Petition Phase, the token is submitted to a vote by the members of the organization; and, finally, in the Authorization Phase, the results of the vote determine the approval or rejection of the action, with all records being stored in the Immutable Sphere [9]. This structure offers flexibility by allowing the adaptation of the level of horizontality according to the needs of the organization, including in crisis situations that may require temporary centralizations [9].

Despite its advantages, COLBAC faces challenges inherent to its democratic approach [9]. Frequent voting processes can result in user fatigue, especially in larger organizations [9, 42]. In addition, democratic attacks, such as quorum manipulation or the abuse of emergency tokens, pose significant risks. Such issues can be mitigated by implementing independent audits, dynamic adjustments to quorum criteria, and mechanisms that limit the use of emergency tokens [9]. Another important issue is the learning curve associated with the model, which requires familiarity with democratic practices and an understanding of how tokens work [9].

COLBAC offers an innovative solution for organizations that want to align their horizontal governance with robust digital security practices [9]. Its transparency, flexibility, and commitment to democratic participation position it as a strategic tool to overcome security challenges in decentralized structures, transforming potential vulnerabilities into opportunities to strengthen collective autonomy [9, 42].

3.4.2 ABCcrypto

Asset-Based Cryptocurrency (ABC) is a threat modeling framework specifically developed to address the peculiarities of cryptocurrencies and blockchain-based systems. In contrast to generalist frameworks such as STRIDE, ABC is designed to address the unique security challenges presented by distributed and permissionless systems, where actors distrust each other and economic incentives play a central role [1].

The main differentiator of ABC is the introduction of collusion matrices, which allow the analysis of threat scenarios involving collaborations between different malicious actors. This systematic approach reduces the complexity of the modeling process by eliminating irrelevant cases and grouping scenarios with similar effects [1]. Furthermore, the framework uses threat categories specific to cryptocurrencies, considering not only tangible assets, such as blockchains and tokens, but also abstract assets, such as privacy and reputation [1].

A key feature of ABC is its ability to tailor threat categories to the objectives and assets of each [1] system. The process begins with a detailed characterization of the system model, identifying participants, assets, and financial motivations. Threat categories are

then derived based on potential violations of the security properties of the assets, such as service corruption, payment theft, and blockchain inconsistencies. Finally, concrete attack scenarios are enumerated and analyzed using the collusion matrix, which considers all possible combinations of attackers and [1] targets.

ABC also highlights the importance of incorporating economic analysis and financial incentives into the risk mitigation process. For example, "detect and punish" mechanisms can be implemented to discourage dishonest behavior by making it financially unviable. This use of game theory and economic modeling is particularly effective for addressing threats that cannot be neutralized by cryptographic means alone [1].

The effectiveness of ABC has been demonstrated in case studies involving real systems such as Bitcoin, Filecoin, and CacheCash. In the case of Filecoin, the framework revealed significant gaps in the public design, particularly in collusion scenarios that had not previously been considered. In CacheCash, ABC was used from the early design stages to identify 525 cases of collusion and implement incentive-based countermeasures [1].

While ABC has clear benefits, it is not without its challenges [1]. Creating collusion matrices and analyzing threat categories in detail can be resource-intensive, especially in systems with multiple participants and complex assets. However, these efforts are rewarded by the identification of critical threats and the robustness of the proposed solutions [1].

ABC offers an advanced and adaptable approach to cryptocurrency threat modeling, demonstrating that specialized frameworks can significantly improve the security and resilience of distributed systems [1].

3.4.3   PGP and the Web of Trust

Pretty Good Privacy (PGP), developed by Philip Zimmermann, is a cryptographic system that combines privacy, authentication, and convenience to protect messages and files [30]. PGP uses public-key cryptography to enable secure communication between individuals, even without prior trust or key exchange over secure channels [30].

In the PGP operating model, each individual has a pair of keys — a public key, which is widely disseminated, and a private key, which is kept secret. The public key is used to encrypt messages, while the private key is used to decrypt them. This scheme not only ensures the privacy of messages, but also allows authentication through digital signatures, ensuring the integrity and origin of a content [30].

A central feature of PGP is the Web of Trust (WoT) model, which adopts a decentralized approach to identity validation. Unlike centralized hierarchies of Certificate Authorities, WoT allows any user to digitally sign another's public key, certifying its authenticity. These signatures create a distributed trust network, in which the validation of a public key depends on the accumulated trust of the signatures of other trusted users [30].

In PGP, each user can assign different levels of trust to other individuals to act as "trusted introducers". This mechanism allows the trust network to be built organically,

reflecting natural social relationships. For example, a user may fully trust another to certify keys, or only marginally, depending on their perception of the introducer's competence and integrity [30].

In addition to promoting decentralization, WoT also provides resilience against [30] attacks. Rather than relying on a single point of failure, as is the case in centralized systems, WoT allows users to validate public keys based on multiple signatures, reducing the impact of individual compromises. However, this approach also presents challenges, such as the difficulty of managing large key rings and the subjectivity in assigning trust levels [30].

The relevance of PGP and WoT to horizontal organizations is evident [9]. Non-hierarchical structures can take advantage of the decentralized nature of WoT to create security systems aligned with the principles of collective autonomy and distributed governance . By allowing each participant to build their own web of trust, PGP strengthens security without compromising the horizontality of these organizations [42, 9].

3.5 Comparative Perspectives

3.5.1 Evaluation Criteria

The evaluation of threat modeling frameworks requires objective criteria to compare their effectiveness, applicability, and suitability to different organizational contexts [40]. Key criteria include the ability to identify specific threats, adaptability to changes in the operational environment, implementation costs, and the integration of social, economic, and technical dimensions into the modeling process [51]. In addition, scalability and the ability to handle complex organizational structures are critical factors [1].

STRIDE, for example, is widely used for its simplicity and applicability in traditional software systems [38]. However, it faces limitations in decentralized environments, such as cryptocurrencies or horizontal organizations, due to its reliance on predefined threat categories [20]. In contrast, frameworks such as ABC offer a specialized approach, using collusion matrices to explore threats in distributed and permissionless systems, while PASTA focuses on iterative risk assessment for dynamic systems [1, 47].

Frameworks such as COLBAC, on the other hand, stand out for integrating democratic processes into threat modeling, allowing horizontal organizations to align security and participatory governance. Despite its innovation, COLBAC faces usability challenges due to the need for familiarization with democratic processes and the risk of voting fatigue in large groups.

Finally, scalability is essential for organizations dealing with multiple participants and complex interactions [1]. Techniques such as scenario fusion in ABC demonstrate that specialized frameworks can mitigate operational costs while maintaining analytical robustness [1]. This makes them suitable for modern systems that require both technical precision and organizational flexibility [9].

3.5.2 Applicability in Non-Hierarchical Organizations

The applicability of threat modeling frameworks to non-hierarchical organizations depends on their ability to address specific dynamics of these structures [9, 51]. Horizontal organizations operate on the basis of distributed governance, equitable participation, and the absence of formal centralization, requiring approaches that respect and reinforce these principles [42].

Frameworks such as COLBAC and ABC demonstrate strong compatibility with horizontal organizations due to their emphasis on collaborative processes and adaptability to decentralized contexts. COLBAC uses collective authorization tokens to align security and democratic governance, allowing flexibility between temporary centralization and horizontal control. ABC incorporates economic analysis and financial incentives to mitigate risks in blockchain ecosystems, offering tools such as collusion matrices to map complex threat scenarios.

Traditional frameworks such as STRIDE and attack trees provide a solid foundation for threat identification, but their applicability is limited in horizontal organizations due to their reliance on formal hierarchies and centralized control points [38, 35]. In contrast, emerging approaches such as PTM promote greater alignment with the needs of these organizations by integrating stakeholders at every stage of the process.

The choice of a framework for horizontal organizations must balance technical effectiveness with transparency and collective engagement. Solutions such as ABC and COLBAC excel at integrating social and economic dimensions, demonstrating that security can be strengthened through collaborative practices and inclusive governance [1, 9]. These approaches are particularly relevant for organizations seeking to align security with organizational autonomy and resilience [9].

Chapter 3 analyzed traditional threat modeling approaches, highlighting established methodologies such as STRIDE, as well as their applications and limitations in decentralized and collaborative environments. The fundamental categories used in vulnerability identification were described and the necessary adaptations for non-hierarchical contexts were discussed. Based on these analyses, Chapter 4 presents the preliminary design of a protocol specifically adapted for horizontal organizations, describing the fundamental security and governance requirements necessary to maintain organizational resilience and ensure democratic participation in threat analysis and mitigation processes.

Table 3.1: Comparison of Threat Modeling Methods

Method	Threat categories considered	Scope	Key Features	Limitations
STRIDE	Spoofing, Tampering, Repudiation, Information Disclosure, Denial of Service, Elevation of Privilege	Software and application security (design-phase threat analysis)	Six-category mnemonic covers major attack types (acts as a checklist). Applied to system models (DFDs) to systematically identify threats per component. Simple and widely adopted; easy for teams new to threat modeling.	Focused on technical threats – may miss threats outside its six categories (e.g., collusion or social attacks). No built-in risk ranking, so a long list of threats may need additional prioritization. Considered somewhat outdated (no longer officially supported by Microsoft), and less detailed for complex, business-specific threats.
Attack Trees	No fixed set – any threat goal can be modeled (e.g., malware attack, insider abuse, social engineering) as the root, with sub-goals as attack steps.	Broadly applicable (software, cyber-physical systems, critical infrastructure) for visualizing attack paths.	Graphical tree diagrams map out attacker goals and all possible paths (leaf nodes are specific attack methods). Can capture complex multi-step attacks (including technical exploits or human tactics) by branching logic. Often used in combination with other methods (e.g., STRIDE or risk scoring) for comprehensive analysis.	Time-consuming to create for large or complex systems (trees can become very large). No inherent risk scoring – requires supplemental analysis (like CVSS) to prioritize threats. Maintenance can be difficult as systems evolve (manual updates needed for tree changes).
PASTA	Not predefined by categories – addresses all threat types identified through its stages, from technical vulnerabilities to misuse and fraud (prioritized by business impact).	Enterprise and critical systems where business impact and risk alignment are key (e.g., fintech, large applications). Integrates with SDLC and organizational risk management.	Seven-stage, risk-centric methodology (from defining scope to attack simulation) providing in-depth analysis. Aligns threats with business objectives – focuses on likely attacks that matter most to the organization's mission. Emphasizes risk prioritization: analyzes likelihood/impact of each threat to guide resource allocation.	Complex and resource-intensive – the 7-step process is lengthy and requires cross-functional expertise. Not widely used compared to simpler models; has a steep learning curve and longer implementation time. Geared toward comprehensive analysis, which may be overkill for small projects or early-phase designs.
Trike	Doesn't use classic threat categories – focuses on unauthorized actions on assets. Threats are modeled as any action (Create, Read, Update, Delete) by any actor that violates assigned permissions (e.g., an insider modifying data they shouldn't, or an outsider gaining illicit access).	Primarily for security audit and risk management in software systems. Suitable for organizations wanting to set and verify acceptable risk levels for each asset/user role.	Risk-based audit approach – assigns a risk score to each asset's threat scenarios, ensuring risk is acceptable to stakeholders. Uses a unique actor–asset matrix (CRUD matrix) to identify where an actor's permitted actions differ from potential malicious actions. Provides a structured way to involve stakeholders in deciding which risks to mitigate vs. accept (tying into governance).	Can be too granular/complex in large IT environments – requires detailed mapping of all assets, roles, and permissions. Less mainstream – fewer tooling options and community support compared to STRIDE/PASTA. Focuses on internal policy violations; may require augmentation to cover threats like external social engineering or collusion not captured by role-permission analysis.
ABC	Collusion-based threats (multiple actors cooperating maliciously) and financial attacks specific to crypto systems. Derives custom threat categories for new blockchain assets (e.g., double-spend fraud, consensus manipulation) beyond traditional threat lists.	Blockchain and decentralized systems (cryptocurrencies, decentralized organizations). Tailored for systems with economic incentives and distributed trust, but also applied to other large-scale distributed systems (e.g., cloud-native architectures).	Introduces collusion matrices – a novel tool to systematically enumerate complex collusion scenarios among actors (forcing analysis of combinations of insider/outsider attacks). Asset-centric: identifies unique assets (crypto tokens, consensus, smart contracts) and derives system-specific threat categories incorporating financial impact. Proven effective in practice – user studies found it uncovers significantly more financial security threats than STRIDE in crypto contexts.	Specialized scope – designed for cryptocurrency and blockchain context, so it may require adaptation to use in other domains. Complexity: Collusion analysis can become intricate (though the matrix approach manages complexity, it still demands detailed domain knowledge). Being a newer framework, it's less documented in industry practice and tool support is limited (mostly in academic or specialized settings).

4

Design

4.1 Preliminary Protocol Concept

The protocol to be developed will be a structured model for threat modeling in non-hierarchical organizations, functioning similarly to STRIDE, but adapted to the specificities of distributed governance [38]. It will not be a software, but a formal set of documented guidelines and methodologies for identifying, analyzing and mitigating threats in horizontal environments [9]. Its format will be textual and structured as an academic and technical document, offering a practical and theoretical framework for security in decentralized structures.

The primary audience includes members of the organization who use the protocol to analyze threats in their specific context, as well as experts in information security and distributed governance who seek methods adapted to non-hierarchical environments. The protocol will serve to improve organizational resilience without compromising democratic participation, ensuring that security is integrated into the collaborative dynamics of horizontal organizations.

4.1.1 Target Audience

The protocol is designed for members of horizontal organizations without specialized cybersecurity expertise. Unlike traditional expert-oriented models, our protocol emphasizes simplicity and accessibility. It supports stakeholders involved in decision-making, operational activities, conflict resolution, and coordination tasks, as well as informal community groups, by providing clear guidance and intuitive methods for effectively dealing with security threats.

4.2 Security and Governance Requirements

The proposed protocol for horizontal organizations must meet security and governance requirements that ensure both participatory inclusion and robustness against internal and external threats. In decentralized structures, where the absence of formal hierarchy

can be seen as both an advantage and a challenge, it is imperative that the protocol be designed to integrate mechanisms that preserve horizontality without compromising organizational resilience. Transparency, in this context, emerges as one of the central pillars [9]. All events related to the authorization of actions or modifications must be recorded in an immutable manner, ensuring that actions can be reliably audited by any member of the organization. These immutable records, built on technologies such as blockchain or similar cryptographic structures, ensure traceability and eliminate the possibility of unauthorized changes, maintaining cohesion between organizational principles and technological mechanisms.

Democratic participation also plays a fundamental role in the design of the protocol [9]. In a horizontal organization, decisions must reflect the collective will, and to this end, the protocol must integrate digital voting systems that guarantee both the privacy and security of votes [9]. In addition, it must be possible to temporarily delegate authority to individuals or groups to deal with situations that require specific expertise, always ensuring that such delegation can be revoked and that records of actions are accessible for collective audit [9].

Another crucial aspect is the flexibility of the protocol, especially in scenarios where the organization needs to switch between centralized and distributed governance modes. This transition capacity must be implemented in a way that the levels of centralization are temporary and properly tracked, ensuring that control can quickly return to the collective. To this end, the protocol must provide mechanisms such as emergency tokens, which allow the execution of critical actions in exceptional situations, as long as such actions are recorded and subject to retroactive validation by the members of the organization [9].

For the protocol to be scalable, it is essential that it supports organizations of different sizes and degrees of complexity. This includes implementing distributed validation systems that allow collaborative verification of actions without burdening individuals or single points of control [9]. Furthermore, threat modeling should be iterative and adaptive, incorporating techniques such as simulations based on real-world scenarios to identify emerging vulnerabilities and adjust countermeasures accordingly. These mechanisms ensure that the protocol remains functional and effective even when the organizational scale increases or its internal dynamics change.

4.3   Evaluation Strategy

The evaluation of the proposed protocol will be conducted in an experimental and comparative manner, using organizational groups with different degrees of horizontality. The main objective of this process is to validate the protocol's ability to identify, mitigate and prevent threats in horizontal environments, while comparing its effectiveness with consolidated frameworks, such as Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege (STRIDE).

Initially, candidate organizations representing different levels of power distribution and autonomy will be selected. Each organization will undergo structured training sessions, addressing both the developed protocol and STRIDE, ensuring that all participants understand the tools used.

To operationalize the evaluation, a three-stage methodology will be applied. In the first stage, each group will organize a threat model for its structure based on the proposed protocol. In parallel, a second group, within the same organization, will apply STRIDE to the same scenario. Both sessions will be monitored to document the process and collect quantitative and qualitative data.

The resulting models will be analyzed according to predefined metrics, including:

- **Precision**: assessment of the number of correctly identified threats in relation to the total detected.

- **Recall**: proportion of threats identified by the protocol in relation to those existing in the reference model.

- **Operational Latency**: total time required to complete each phase of the modeling process.

- **User Feedback**: collection of qualitative opinions on the usability and clarity of the protocol from participants.

The second stage will involve simulating threat scenarios, including Sybil attacks, quorum manipulation and consensus failures, replicating realistic situations faced by horizontal organizations. The response to these threats will be compared between the protocols, considering the quality of the proposed solutions and the response time of the groups.

Finally, in the third stage, the organizations will be subjected to case studies, in which the protocol will be implemented in full and monitored over time. The performance of the protocol will be analyzed in terms of its resilience to the identified threats, its adaptability to organizational dynamics and its ability to promote participation and transparency.

4.4 Research Questions

1. How can the protocol balance efficiency and democratic participation in horizontal organizations?

2. What are the best practices for integrating security and governance in decentralized structures?

3. How can the protocol adapt to different levels of horizontality and organizational dynamics?

4. How can it improve resilience against internal and external threats while maintaining transparency and inclusive participation?

Chapter 4 presented the preliminary design of a protocol specifically aimed at threat modeling in horizontal organizations, detailing fundamental security and governance requirements, such as mechanisms for democratic participation, temporary delegation of authority, and auditable records. The importance of aligning technological and organizational processes to ensure robustness against internal and external threats was highlighted. Based on this conceptual development, Chapter 5 summarizes the main results achieved by this research, critically evaluating the proposed protocol, identifying its contributions in relation to traditional methodologies, and exploring practical scenarios for future validations in real environments.

5

Experiments

Conclusion

This research proposes a threat modeling protocol adapted to the specificities of horizontal organizations, integrating security and distributed governance as strategic elements [9]. The work is based on the recognition that non-hierarchical structures face unique challenges in security, from the informal centralization of digital resources to vulnerability to attacks that exploit participatory processes [42, 46]. By aligning horizontality with collaborative security practices, the protocol seeks to transform decentralization into an asset, mitigating critical points of failure without compromising collective autonomy.

A critical analysis of traditional methodologies, such as Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, Elevation of privilege (STRIDE) and attack trees, revealed gaps in the approach to non-hierarchical dynamics [38, 35]. While these frameworks are effective in centralized contexts, their dependence on formal hierarchies and linear decision flows limits their applicability in distributed environments. On the other hand, emerging approaches such as Collective based access control system (COLBAC) and Asset-Based Cryptocurrency (ABC) have demonstrated potential to fill these gaps by incorporating transparent consensus mechanisms and incentive-driven economic analyses [9, 1]. These solutions inspired the modular structure of the proposed protocol, which combines collaborative cryptography, immutable ledgers, and democratic authorization processes [9, 38].

The main contribution of this work lies in the integration of technical security and participatory governance. The protocol not only identifies specific threats to horizontal organizations, such as quorum manipulation, Sybil attacks, and centralization of secrets, but also establishes guidelines to mitigate them through distributed mechanisms [9, 46]. For example, the adoption of auditable logs and verifiable digital signatures reinforces transparency, while secure voting systems and dynamic delegation of authority preserve decision-making agility [9]. This approach balances operational efficiency and inclusiveness, allowing organizations to adapt their level of horizontality according to the context, whether in crisis situations that require temporary centralization or in fully decentralized day-to-day operations.

The defined evaluation criteria, effectiveness, efficiency, user acceptance and resilience,

provide a robust framework to validate the protocol in different scenarios [47]. Case studies with worker cooperatives and community networks will allow testing its practical applicability, while simulations of democratic attacks and consensus failures will assess its robustness [42]. The results are expected to demonstrate how horizontality, when structured coherently, can strengthen security by distributing responsibilities and reducing critical dependencies [9, 42].

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