Péter Jámbor

# From pen and paper to pixels.

## Usability and User Acceptance of Digital Signatures: A Customer-Centric Study in Hungarian SMEs

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Expert Career Ph.D.

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Doctoral thesis

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2025

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*"I believe in innovation and that the way you get innovation is you fund research and you learn the basic facts."*

Bill Gates

## Dedication

***In memory of my beloved grandmother, whose unwavering belief in me and her constant support continue to inspire me.***

I dedicate this research to the advancement of digital transformation in Hungarian small and medium-sized enterprises, and to all stakeholders working toward bridging the gap between technological innovation and practical business adoption

## Acknowledgment

I would like to express my sincere gratitude to my supervisor, **Dr. Péter Fehér**. His balanced approach—providing expert direction while respecting my intellectual autonomy—created the ideal environment for independent creative work.

I am deeply grateful to **NETLOCK** for providing not only the practical context and industry insights that shaped this customer-centric research approach, but also for generously supporting this research with time and resources that made the quantitative survey phase possible. Special thanks to **my colleagues** for their encouragement and professional collaboration throughout this journey. I extend my appreciation to the 200 **SME leaders** who participated in the quantitative survey and the 14 experts who shared their experiences in the qualitative interviews.

My heartfelt thanks go to **Attila Loibl** for his collaboration and encouragement during the development of this work.

Finally, I extend my deepest appreciation to my family, especially to my wife, **Andi**, for her unwavering support, patience, and encouragement throughout the challenging yet rewarding process of completing this doctoral dissertation.

# 1 ABSTRACT

Hungary ranks 22nd in the EU Digital Economy and Society Index, with only 53.2% of SMEs demonstrating basic digital intensity, compared to 57.7% across the EU (*Digital Decade Country Report 2024: Hungary*, 2024).

This dissertation investigates the adoption of a foundation tool, digital signature, through a customer-centric lens, employing an exploratory mixed-methods design: a phone-assisted survey of 200 SMEs and 14 semi-structured expert interviews.

Logistic regression reveals that company size and sectoral orientation -not partner proximity- predict adoption (Nagelkerke $R^2 = 0.426$); industrial firms demonstrate 89% lower odds of adoption compared to service-sector firms.

Thematic analysis identifies five barriers (partner resistance, knowledge gaps, cultural inertia, perceived lack of necessity, process misalignment) and four enablers (cost-effectiveness, ease of use, international partner pressure, generational change). Digital maturity emerges as a bridging construct linking organizational readiness to both adoption likelihood and integration depth.

Contributions include the first comprehensive segment-level requirements map for Hungarian SMEs, as well as actionable recommendations for trust service providers on onboarding, education, and product design.

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# 2 RESEARCH GOAL AND SIGNIFICANCE

## 2.1 RESEARCH OBJECTIVE

As Business Development Director at NETLOCK, a Qualified Trust Service Provider (QTSP) under the eIDAS Regulation (EU No 910/2014) delivering trusted digital identity, signature, and time-stamping services across the European Union and global markets, I confront a daily paradox: despite robust legal frameworks (eIDAS; Act XXXV of 2001) and mature cryptographic infrastructure, digital signature adoption among Hungarian SMEs remains stubbornly low.

Hungary ranks 22nd in the EU Digital Economy and Society Index, with 53.2% of SMEs demonstrating at least basic digital intensity versus 57.7% EU wide (*Digital Decade Country Report 2024: Hungary*, 2024). Infrastructure is not the constraint. Very High-Capacity Network coverage reaches 84.1%, above the EU average of 78.8%. Yet adoption of enabling technologies remains uneven. 37.1% of enterprises use cloud services compared to 38.9% in the EU, and only 3.7% report AI use compared to 8% in the EU. Digital skills have improved to 58.9% in 2023 from 49% in 2021, but gaps persist among older and vulnerable groups (Obermayer et al., 2023). Hungarian SMEs demonstrated adaptability during COVID-19 by intensifying online communication yet lagged regional peers in exploring value proposition improvements through digitalization (Marolt et al., 2024).

This infrastructure-readiness gap echoes earlier research on Hungary's digital divide (Kis, 2010), which identified persistent territorial disparities in ICT infrastructure access that continue to shape technology adoption patterns among Hungarian enterprises.

Extensive scholarship addresses technological and legal aspects of digital signatures, but evidence on user acceptance and segment specific usability requirements in Central and Eastern European SMEs remains scarce (Adams & Lloyd, 2003; Gubán & Sándor, 2021; Mandják et al., 2022; Marciniak et al., 2020; Marolt et al., 2024)

This dissertation investigates digital signatures as a foundational digital tool and pursues three objectives:

1. Synthesize international evidence on factors influencing SME adoption of digital signatures.
2. Quantify how Hungarian SME characteristics (size, sectoral orientation, partner geography, revenue) predict adoption using a 200 firm phone survey and logistic regression.
3. Identify segment-specific usability and user acceptance requirements through 14 expert interviews and translate findings into actionable onboarding, education, and product design strategies.

The study adopts a customer-centric lens grounded in practitioner experience to bridge the gap between technological possibilities and real-world use. It focuses on barriers such as partner resistance, knowledge gaps, cultural inertia, and process misalignment, and on enablers including cost-effectiveness, ease of use, and international partner expectations. The practical contribution is a segment-level requirements map and guidance that can accelerate the diffusion of digital transformation among Hungarian SMEs and support national digital transformation goals.

Scope. The analysis centers on SME level characteristics and technology-specific acceptance factors. Broader organizational and macro-level determinants are acknowledged but remain outside the present scope.

## 2.2 EXPLORATORY RESEARCH QUESTIONS

In my professional career, I have found that one of the main challenges in bringing innovative solutions to market is identifying the target audience that would benefit the most from these solutions. Specifically, in the case of digital signature technology, while there has been extensive research conducted on the technological and legal aspects of its implementation, there is limited information available on the potential benefits and user acceptance of the technology.

A significant number of doctoral theses in the field of business informatics at the Institute of Information Systems do not rely on hypotheses. Instead, the authors define and address research questions (Klimkó, 2001; Ternai, 2008; Vas, 2007)

Although numerous studies address the technological and legal aspects of digital signatures (Adams & Lloyd, 2003; *European Comission*, 2024), empirical research on the SME sector -particularly in the Central and Eastern European region- reveals gaps.

The lack of such research is especially striking with regard to Hungarian SMEs, evidenced by the fact that at the time of writing this thesis, none of the Hungarian academy of sciences category "A" economics journals contain any contributions related to the primary examination of digital signatures, despite several articles discussing corporate digitalization efforts see, for example, (Marciniak et al., 2020), on factors affecting digitalization efforts; (Gubán & Sándor, 2021), on the digital maturity lifecycle model for SMEs; or (Marolt et al., 2024), on the accelerating effect of external disruptions. For example., COVID-19 on digitalization.

This work aims to fill this gap by understanding what factors influence the adoption of digital signatures among Hungarian SMEs.

This goal aims to be achieved by answering the following main exploratory research question:

HOW DO THE SPECIFIC CHARACTERISTICS OF HUNGARIAN SMES INFLUENCE THE INTRODUCTION OF DIGITAL SIGNATURES, AND WHAT ARE THE DISTINCT USABILITY AND USER ACCEPTANCE REQUIREMENTS

Internalizing Gábor Klimkó's approach (Klimkó, 2001). The previous main topic is broken down into the following exploratory research questions

| |
|---|
| RQ1<br>WHAT ARE THE KEY FACTORS INFLUENCING DIGITAL SIGNATURE ADOPTION IN SMES ACCORDING TO EXISTING INTERNATIONAL RESEARCH? |
| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES? |

The exploration of these questions provides a rich understanding of the barriers and motivators that influence the acceptance of digital signatures across various industries and organizational sizes by identifying preferences and user acceptance factors across a broader sample of SMEs

None of the research questions formulates a hypothesis to be validated; instead, all questions are exploratory, and they need validation based on the results of exploration.

The first and second questions were further divided into sub-questions to allow for a more structured approach in extracting the core insights of the main research questions.

The structure of my research questions is presented in Figure 1

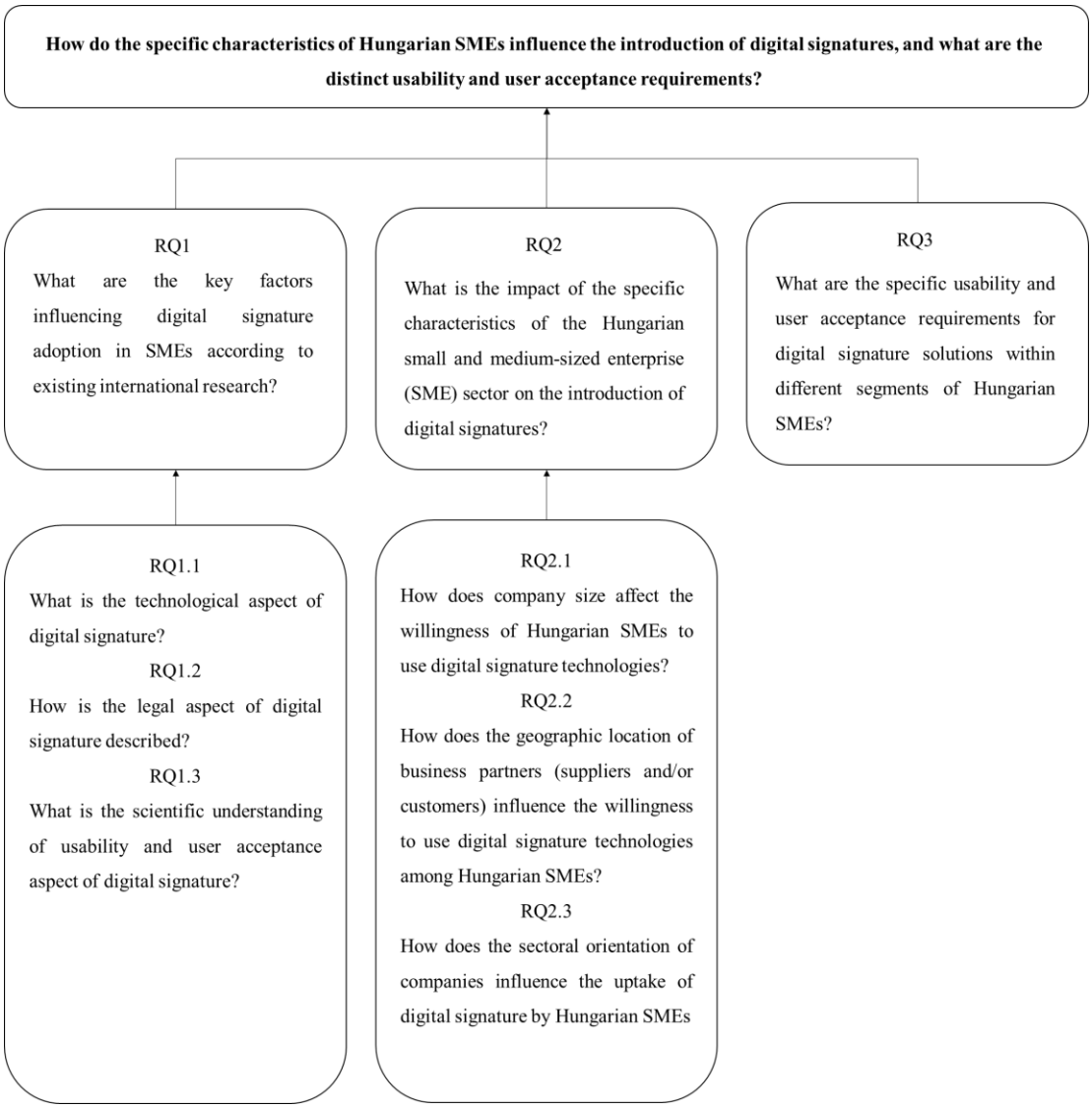



*Figure 1 Structure of research questions*

## 2.3 CUSTOMER-CENTRIC RESEARCH APPROACH

As an expert career Ph.D. candidate, I have a responsibility to ensure that the research I conduct is not only rigorous but also has practical implications for real-life business development.

I use customer/user-centric design method in product development strategy, as it is well known and practical nowadays. Potentially, the best way to achieve my Ph.D. track goal is to adopt a customer-centric approach to my research, as it can provide insights that are more relevant and actionable than other methods. (Cherkaoui et al., 2016)

The customer-centric approach is a research method that focuses on understanding the needs, preferences, and behaviors of customers. It involves engaging with customers through surveys, interviews, and other data collection methods to gather insights that inform product development and improve customer experience. By employing this approach, I can gain a deeper understanding of customer needs and preferences, which informs product design and marketing strategies that meet customer demands.(Bingley et al., 2023)

Research and development at most companies are inwardly focused, but market leaders realize that successful innovation requires deep customer empathy. Consider GE Healthcare IT, which made a point of visiting hospitals to understand how they (and their patients) experienced GE equipment. After noticing that children often cried when they saw MRI machines, GE representatives decided to visualize the rooms as children would, even kneeling to be at a child's height. They ended up helping hospitals transform MRI rooms into adventure experiences, such as a pirate ship and patient satisfaction scores increased by 90 percent.(*Adventure Series for MR*, 2023)

Joint innovation centers, where technical staff from a company collaborate closely with technical staff from top customers or suppliers, are also a powerful practice. Innovation labs, embraced by companies across industries (e.g., Finastra, Amazon, Huawei, FICO), give customers the opportunity to work closely with dedicated cross-functional teams of technology and solution development experts.

Even if, as Apple co-founder Steve Jobs famously remarked, customers themselves do not yet realize they have a need, R&D teams should be trained in customer-centric thinking,  they should embrace collaboration and co-innovation with customers and partners as a key component of solution development and demonstrate how new products and features will meet real and pressing customer needs.(Hughes et al., 2021)

One of the key benefits of using a customer-centric approach is that it can help to identify areas where products or services are falling short of customer expectations. By collecting feedback from customers, pain points and areas for improvement can be identified, which can inform product development and lead to more successful products in the marketplace. In contrast, non-customer-centric approaches such as

market research may provide insights into broader trends or competitor activity but may not provide the same level of insight into customer needs and preferences.

As I am not only a researcher, I also have the advantage of practical usage of my research therefore another advantage of using a customer-centric research approach is that it can help me build stronger relationships with customers. By engaging with customers in a meaningful way and taking their feedback seriously, it is possible to build trust and loyalty, which can lead to increased customer retention and advocacy. This can be particularly valuable in today's digital age, where customer expectations are high, and competition is fierce.

A customer-centric approach can also help me stay ahead of the curve regarding product innovation. I can identify emerging trends and market opportunities that inform future product development by listening to customers and understanding their needs and preferences. This can be particularly important in industries where innovation is key to staying competitive.

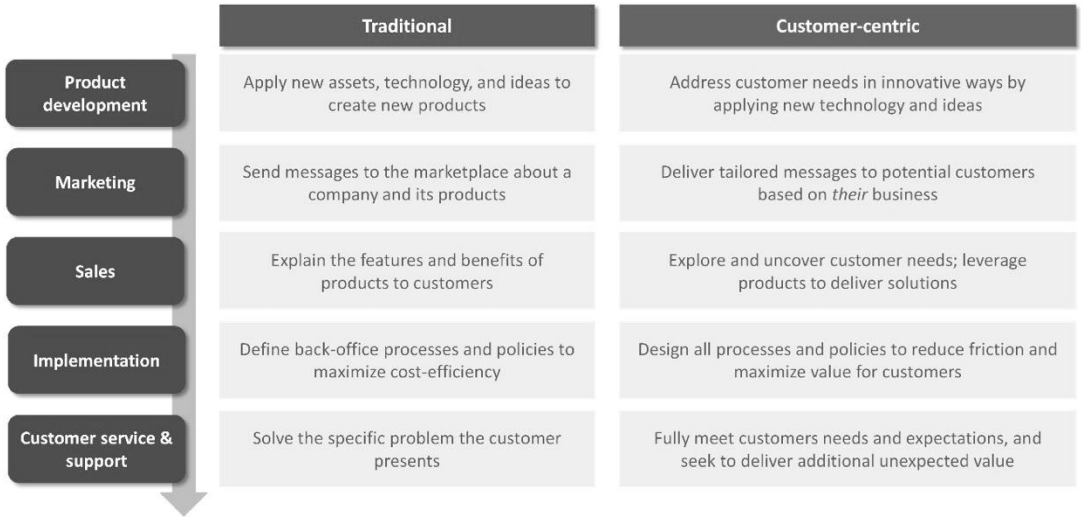



*Figure 2 Company's value chain for customer-centricity (Hughes et al., 2021)*

By engaging with customers, a deeper understanding of their needs and preferences can be gained, pain points and areas for improvement can be identified, stronger relationships, and stay ahead of the curve in terms of product innovation can be built.

Therefore, for my expert track thesis, a customer-centric approach is ideal, as it ensures that my research generates findings relevant to both academic understanding and business practice..

## 2.4 THESIS STRUCTURE

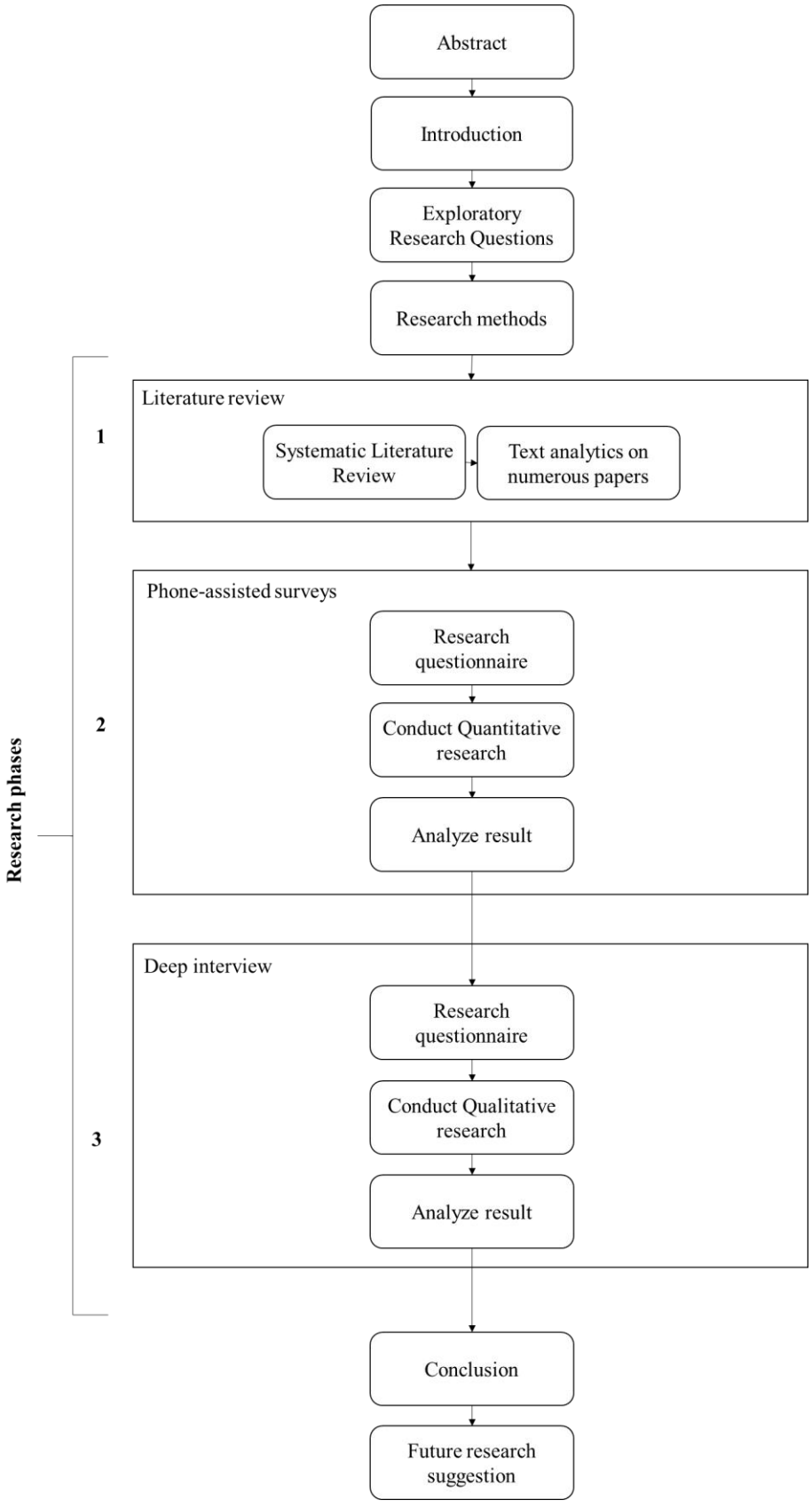



*Figure 3 Thesis structure*

# 3 RESEARCH METHODS USED IN RESEARCH PHASES

Digital signatures represent a foundational digital transformation tool, yet adoption among Hungarian SMEs remains uneven despite mature technology and legal frameworks. Understanding the factors influencing adoption requires examining technological, legal, and usability dimensions from a customer-centric perspective.

This thesis employed an exploratory mixed-methods design across three phases.

**Phase 1** comprised a systematic literature review and text mining analysis (1,469 documents) examining three aspects: technological foundations (cryptography, PKI), regulatory frameworks (eIDAS, Hungarian legislation), and usability/user acceptance factors (TAM extensions, adoption barriers).

**Phase 2** involved exploratory quantitative research to investigate how the characteristics of Hungarian SMEs—size (in terms of revenue and staff), sectoral orientation, and proximity to partners—impact digital signature adoption. Telephone surveys were conducted with 200 SME representatives using a 41-question instrument. The telephone format mitigated response rate concerns given questionnaire length.

**Phase 3** comprised semi-structured expert interviews with 14 Hungarian SME stakeholders (business owners and IT managers), each lasting 45-60 minutes, to identify segment-specific usability and user acceptance requirements.

This mixed-methods approach enabled triangulation of findings across quantitative adoption patterns and qualitative implementation barriers, providing actionable insights for trust service providers and SME stakeholders.

## 3.1 RESEARCH PHASES

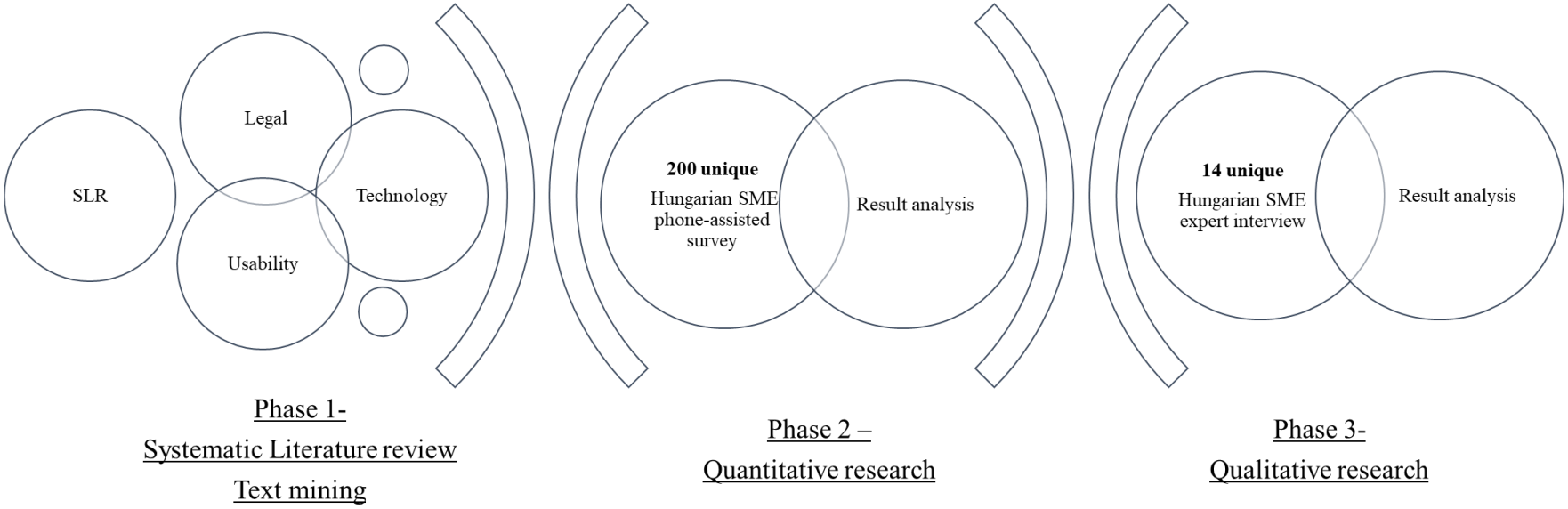



*Figure 4 Research Phases*

## 3.2 DETAILED RESEARCH METHODS IN EACH PHASE

From a research method perspective, I divide my thesis into three main phases. My thesis employs various methods in distinct phases. I am determining the potential applicability of digital signatures from various perspectives. is conducted using a mixed-methodology approach that combines qualitative and quantitative methods.

**Justification for Exploratory Mixed-Methods Design**

This study employs an exploratory mixed-methods approach for three key reasons specific to digital signature adoption in Hungarian SMEs. First, digital signature adoption represents an emerging socio-technical phenomenon where existing theoretical frameworks may not capture the unique constraints of resource-limited SMEs, as "information systems (IS) phenomena are inherently emerging, i.e., they dynamically evolve and mutate during our engagements with them" (Monteiro et al., 2022). Second, SME heterogeneity across size, sector, and digital maturity requires adaptive methodologies, since "the majority of the research is exploratory, and a limited number of studies are in development and testing" indicating "the depth of the study is still shallow and needs more advanced research" (Zamani, 2022). Third, the complex interplay between technological, regulatory, and organizational factors necessitates mixed methods because "no single research approach is sufficient by itself to capture the breadth and depth of complex IS research" (Jokonya, 2016; Venkatesh et al., 2013).

In the current study, the mixed-research method is applied. The concept of mixing methods was first introduced by (Jick, 1979), as a means for seeking convergence across qualitative and quantitative methods within social science research (Tashakkori & Creswell, 2007)

Mix-method research elements of qualitative and quantitative research are combined to understand the phenomenon deeply and affirm the findings (Onwuegbuzie & Collins, 2015). This type of research is more and more recognized as valuable because it can exploit the strengths of qualitative and quantitative approaches (Östlund et al., 2011)

The focus here is not merely on collecting data through two different methods but also on analyzing that data. Jick defined mixed methods as "research designs that

extensively integrate both fieldwork and survey research" (emphasis added). The significance of the term "extensively" indicates that both qualitative and quantitative data must be collected and analyzed within the study. Mixed methods research is therefore defined as empirical research that satisfies the following conditions.:

- at least two different methods are used for collecting data
- at least one of the data collection methods is qualitative (e.g., interviews)
- at least one of the data collection methods is quantitative (e.g., surveys)
- both qualitative and quantitative data are presented
- both qualitative and quantitative data are analyzed
- The research addresses a theoretical question rather than providing a description only

**Researcher Reflexivity and Positionality**

I acknowledge my dual role as both researcher and industry practitioner, serving as Business Development Director at NETLOCK, rather than constituting a limitation, this insider position provided unique methodological advantages: (1) deep contextual understanding of the digital signature ecosystem, enabling more nuanced interpretation of SME barriers and enablers; (2) established industry networks that facilitated access to diverse SME respondents who might otherwise be reluctant to participate; and (3) practical knowledge of implementation challenges that informed the development of targeted survey questions and interview protocols.

NETLOCK's organizational support extended beyond access to industry networks. The company provided dedicated time and resources, enabling the execution of the comprehensive quantitative survey phase. This institutional commitment to academic research demonstrates the organization's recognition of the importance of evidence-based business development strategies.

To ensure scientific rigor and mitigate potential bias due to my professional career position, I implemented several safeguards: the mixed-methods design incorporated both quantitative (n=200) and qualitative (n=14) data to triangulate findings; the sample included both users and non-users of digital signatures to capture balanced perspectives; statistical analyses employed objective regression models with multicollinearity checks (VIF analysis); and interview transcripts were systematically coded using predetermined themes rather than emergent categories that might reflect practitioner assumptions. Furthermore, the research explicitly adopted a customer-centric rather than provider-centric lens, prioritizing SME needs and experiences over technological or commercial considerations.

This reflexive awareness of my positionality, combined with rigorous methodological controls, leverages insider knowledge while maintaining the analytical distance necessary for scholarly inquiry.

### 3.2.1 PHASE 1 - LITERATURE REVIEW

To find answers to one of my main exploratory research questions

> RQ1.
> WHAT ARE THE KEY FACTORS INFLUENCING DIGITAL SIGNATURE ADOPTION IN SMES ACCORDING TO EXISTING INTERNATIONAL RESEARCH?

I needed to understand the current state of scientific research on the applicability of digital signatures.

For this, I conducted a literature review with two different approaches.

1. Systematic Literature Review (SLR)
2. Text mining on a large volume of relevant scientific papers.

The reason I chose to use text mining after a systematic literature review is that it gives me significant complementary benefits since the two approaches serve different but synergistic purposes, scalability, and pattern discovery

SLR provides a deep, qualitative understanding of the research field through carefully selected and manually reviewed studies. It identifies key themes, research gaps, and well-established findings but is limited in scope due to the labor-intensive nature of the process.

On the other hand, Text Mining allows me to analyze a much larger corpus of scientific papers beyond what is feasible in an SLR. It uncovers trends, hidden patterns, and relationships across an extensive dataset that might not emerge through manual review.

#### 3.2.1.1 SYSTEMATIC LITERATURE REVIEW

I selected well-filtered papers to conduct a comprehensive and systematic literature review.

For this approach, I choose the method developed by Webster and Watson, which meets the following requirements:

- Comprehensive and systematic: The Webster and Watson method follows a rigorous and systematic approach to identify, evaluate, and synthesize relevant literature. This ensures that the review is comprehensive and unbiased.
- Reproducibility: The method provides a clear and transparent framework that can be replicated by other researchers. This increases the credibility of the review and makes it easier for others to build upon it.
- Flexibility: The Webster and Watson method can be adapted to different research questions and contexts. This makes it suitable for a wide range of research topics and disciplines.
- Quality assessment: The method includes a comprehensive quality assessment of the included studies. This helps to ensure that only high-quality studies are included in the review.
- Clear reporting: The Webster and Watson method provides a clear and structured approach for reporting the review findings. This makes it easier for readers to understand the review process and the key findings.

Overall, the Webster and Watson method is a robust and reliable approach for conducting Systematic Literature Reviews, and its use can enhance the quality and credibility of research outputs.

I adopted key steps in order to have a clear understanding of the current state of digital signature through the content of scientific research in three main areas.

| |
|---|
| RQ1.1<br>WHAT IS THE TECHNOLOGICAL ASPECT OF DIGITAL SIGNATURE? |
| RQ1.2<br>HOW IS THE LEGAL ASPECT OF DIGITAL SIGNATURE DESCRIBED? |
| RQ 1.3<br>WHAT IS THE SCIENTIFIC UNDERSTANDING OF USABILITY AND USER ACCEPTANCE ASPECT OF DIGITAL SIGNATURE? |

#### 3.2.1.2 TEXT MINING

The phrase “text mining” is generally used to denote any system that analyzes large quantities of natural language text and detects lexical or linguistic usage patterns in an attempt to extract probably useful information (Sebastiani, 2001)

While data mining can be broadly described as the process of identifying patterns in data, text mining focuses on uncovering patterns within text. Despite this apparent similarity, the two methods differ significantly. Data mining is more precisely defined as the extraction of implicit, previously unknown, and potentially valuable information from data (I. Witten et al., 2006) The information is implicit in the input data: it is hidden, unknown, and could hardly be extracted without recourse to automatic techniques of data mining. With text mining, however, the information to be extracted is clearly and explicitly stated in the text. It’s not hidden at all—most authors go to great pains to make sure that they express themselves clearly and unambiguously—and, from a human point of view, the only sense in which it is “previously unknown” is that human resource restrictions make it infeasible for people to read the text themselves (I. H. Witten, 2003)

This study presents an exploratory text mining analysis conducted on 1,469 article abstracts related to electronic signatures sourced from Scopus. The research methodology included a systematic search for relevant publications in electronic databases, followed by an in-depth analysis of their metadata. Utilizing tools such as

Excel, VOS viewer, and Voyant, a variety of statistical analyses and data visualizations were performed to identify patterns and trends within the dataset, namely:

1. Documents by subject area
2. Data network visualization
3. Distribution of produced papers
4. Density of text
5. Bibliographic data visualization
6. Voyant terms analytics

### 3.2.2 PHASE 2 - QUANTITATIVE RESEARCH -PHONE-ASSISTED SURVEY

After conducting a comprehensive literature review to identify global findings on the maturity of digital signatures, my research focused on understanding the specific characteristics and challenges of the Hungarian small and medium-sized enterprise (SME) market in this context. This shift was motivated by the recognition that while global trends provide a valuable macro-level perspective, the applicability and adoption of digital signature technologies often hinge on local market conditions, regulatory frameworks, and organizational practices. As an expert career PhD student, I have this recognition in practice as well.

The Hungarian SME sector is a cornerstone of the national economy, comprising a significant proportion of enterprises and making substantial contributions to employment and GDP. However, SMEs often face unique constraints, such as limited financial resources, reduced access to cutting-edge technologies, and lower levels of digital literacy compared to larger enterprises. These factors make it particularly important to examine how digital signature technologies are perceived, adopted, and utilized within this segment.

In the course of my qualitative research, I was looking for answers to two of my main exploratory research questions:

| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| --- |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES? |

The telephone survey methodology may introduce bias toward less digitally mature companies, as enterprises with limited digital infrastructure might be more accessible via traditional phone contact. To address this potential bias and ensure adequate representation of more digitally mature segments, disproportionate stratification was employed.

According to KSH (2022), 251,047 enterprises employ 2–249 people. This study focuseson firms with 5–249 employees. Because the KSH size bin 2–9 includes 2–4 employee micro firms that were outside our sampling frame, we operationalize the micro segment as 5–9 employees to align the population definition with the survey frame and avoid denominator bias (*9.1.1.7. Vállalkozásdemográfia (Működő Vállalkozások Száma) Létszám-Kategóriák Szerint – BD-SBS Harmonizált Módszertan*, 2024).

Disproportionate sampling approach:

- Small enterprises (5–9 employees): under-sampled relative to their population share to avoid overrepresentation of the smallest firms in regression.
- Medium and larger enterprises (10–249 employees): over-sampled to ensure adequate statistical power for model estimation and confidence interval precision.

This approach specifically counteracts the potential bias toward less digitally mature companies, as larger enterprises typically demonstrate higher digital maturity and technology adoption rates (as confirmed by the quantitative findings).

The design effect (deff) accounts for the reduced statistical efficiency due to disproportionate sampling:

$$deff = n \times (\Sigma\, w\_i^2) \,/\, (\Sigma\, w\_i)^2$$

Where n=200 and w_i represents the sampling weight for each stratum. All statistical analyses incorporate the effective sample size (n_eff = n/deff) to ensure robust conclusions despite the intentional departure from proportionate representation.

This sampling strategy strengthens the study's ability to detect technology adoption patterns across different enterprise segments while maintaining statistical validity.

### 3.2.3 PHASE 3 - QUALITATIVE RESEARCH – EXPERT INTERVIEW

To further enhance the customer-centric research approach, I analyzed the usability and acceptance criteria for a digital signature solution by examining the specific requirements of customers

To achieve this, I utilized semi-structured expert interviews to effectively identify and understand the needs of our customers (Belk, 2013).

Expert interview: This form of interview is defined by the specific target group—people in certain professional positions, who can inform about professional processes or a specific group.(Flick & Flick, 2011)

Semi-structured interviews represent one of the research methods used to collect data from this group of subject matter experts. They combine structure with flexibility, as they include a predefined set of survey questions posed to all respondents while also allowing for in-depth exploration of topics that emerge during the discussions between the researcher and respondents. These survey questions are often open-ended, meaning no predefined response categories are provided, and data are collected directly from the respondents' answers(Ahlin, 2019;).

By conducting the interviews, I was looking for answers to two of my main exploratory research questions:

| |
|---|
| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES? |

14 Semi-structured expert interviews were conducted with selected SME stakeholders, mainly business owners and IT managers, to gain nuanced insights into the contextual factors influencing digital signature adoption.

The 14 expert interviews represent an appropriate sample size for this qualitative research phase, consistent with established guidelines for expert interview studies in business research contexts (Mason, 2010; Saunders et al., 2018). Mason's (2010) analysis of 560 PhD studies using qualitative interviews found a mean sample size of 31, with significant variation based on research design and participant expertise. Expert interviews, due to participants' specialized knowledge and the focused nature of inquiry, typically achieve theoretical saturation with smaller samples than general population studies. The current sample size aligns with recommendations for expert interview studies in business and management research, where 10-20 participants are often sufficient for achieving meaningful saturation (Bekele & Ago, 2022)

The interview is structured to begin with two initial questions aimed at determining whether the company represented by the expert utilizes digital signature solutions and to gain insight into the organization's current processes and systems. Following these general questions, the interview addresses ten specific topics for detailed discussion. Each interview took about 45-60 minutes.

The complete semi-structured interview protocol is provided in Appendix (16.2), ensuring research transparency and replicability

The interviews were recorded and transcribed later on after the interviews; the transcript of the expert interviews was coded based on the research questions.

## 3.3 OPERATIONAL MEASURES AND VARIABLE MAPPING

### 3.3.1 OVERVIEW OF MEASUREMENT FRAMEWORK

To ensure methodological rigor and address the hierarchy of research questions, the following operational definitions and variable mappings were established:

### 3.3.2 RESEARCH QUESTION 1: SME CHARACTERISTICS IMPACT

- **Company Size:** Operationalized through (a) Annual revenue categories (ordinal scale based on company classifications), (b) Employee count (3 categories: 5-9, 10-49, 50-249 employees)
- **Geographic Proximity:** Distance to majority of business partners (Local/Domestic/International)
- **Sectoral Focus:** Primary business activity (Industry/Commerce/Services)
- **Dependent Variable:** Digital signature usage (Binary: 1=Yes, 0=No

### 3.3.3 RESEARCH QUESTION 2: USABILITY AND USER ACCEPTANCE

- **Benefits Assessment:** Cost savings, efficiency benefits, environmental impact (Mixed Likert scales: 4-point and 5-point)
- **Usage Patterns:** Document types, service costs, automation level
- **Qualitative Validation:** 17 coding categories applied to 261 interview responses for triangulation

### 3.3.4 STATISTICAL ANALYSIS FRAMEWORK

Three progressive logistic regression models were specified:

- Model 1: $Usage = \alpha + \beta_1 Revenue + \beta_2 Staff$
- Model 2: $Usage = \alpha + \beta_1 Revenue + \beta_2 Staff + \beta_3 Proximity$
- Model 3: $Usage = \alpha + \beta_1 Revenue + \beta_2 Staff + \beta_3 Proximity + \beta_4 Sector\_Commerce + \beta_5 Sector\_Services$

### 3.3.5 VALIDITY AND RELIABILITY MEASURES

- VIF analysis for multicollinearity assessment (threshold: VIF < 5)
- Chi-square tests for independence between categorical variables
- Correlation analysis for construct relationships
- Qualitative coding reliability assessment (inter-rater agreement to be established)

This framework operationalizes abstract constructs through measurable variables while maintaining alignment with Technology Acceptance Model (TAM) theoretical foundations (detailed in section 4.2) and addressing both quantitative (N=200) and qualitative (N=14) data sources.

# 4 LITERATURE REVIEW

## 4.1 INTRODUCTION

The use of digital signatures has increased significantly in recent years, especially in the wake of the COVID-19 epidemic, which has accelerated the adoption of digital solutions (Goździaszek, 2021). Among Hungarian small and medium-sized enterprises (SMEs), the adoption of the technology can be hindered by a number of factors, including cost, legal uncertainties, and lack of technical knowledge. However, Hungary's technology adoption trajectory has been historically shaped by infrastructure development patterns and regulatory frameworks (Kis, 2010), where the effectiveness of state intervention significantly influences SME digitalization capacity. This research aims to explore these factors systematically, building on the existing literature.

The concepts of electronic and digital signatures are often confused. However, it is worth clarifying the difference between the two terms, as a simple rule of thumb, all digital signatures are electronic, but not all electronic signatures are digital (Connective, 2021). Digital signatures can be used by individuals, businesses, and government entities to authenticate official documents, making transactions faster and more secure (*European Comission*, 2024). The European Union's regulation on electronic identification, authentication, and trust services (Electronic Identification, Authentication and Trust Services, eIDAS) establishes a unified framework for the levels of electronic signatures, stating that qualified electronic signatures - typically based on digital signatures - have the same legal effect as handwritten signatures and must be mutually recognized throughout the EU, provided certain requirements are met (Prasetya & Bawono, 2022).

Alongside this international framework, Hungarian law also regulates the use of electronic signatures. Act CIII of 2023 (DÁP Act), recognizing the significance of digital authentication, phased out the previously used AVDH (Document Authentication Based on Identification) service effective December 31, 2024, and introduced the eSignature service operating as part of the Digital Citizenship Program effective January 1, 2025. (*adozona.hu*, 2025) P Act limits the possibility of digital

signatures to individuals (*Digitális Állampolgárság Program (DÁP)*, 2025). For the above reasons, non-natural persons will be able to use trusted solutions available from market providers on the EU/EEA Trusted List Browser (*EU/EEA Trusted List Browser*, 2025).

An electronic signature can be simply an image or an e-mail confirmation. Digital signatures are a more secure solution, utilizing Public Key Infrastructure (PKI) technology to protect data (Adams & Lloyd, 2003; Connective, 2021; Pierre, 2019). Digital signatures use asymmetric cryptography to ensure the security, authenticity, and integrity of documents as well as the undeniable identity of the signer. The technology is legally equivalent to a handwritten signature in the EU (*European Comission*, 2024; Mitchell, 2000). Cryptography is used to encrypt and protect data, preventing unauthorized access. However, despite their advantages, electronic documents pose a security risk as they can be hacked and stolen and therefore need protection, for example by preventing data modification or destruction (Vijay et al., 2020). Signatures are important for legal, commercial and artistic reasons, providing authenticity. In the electronic space, a secure infrastructure is particularly critical, as without it electronic signatures cannot be trusted. Legislation plays a key role in the use and security of these technologies (Bakhtiarifar & Savrai, 2018).

This research addresses gaps by examining the feasibility of digital signature adoption, building on the conclusions of existing research on digital maturity. The analysis is based on a telephone survey conducted with 200 Hungarian SME leaders. No comprehensive research has been found on this topic concerning the Hungarian SME sector, making the study's findings not only a contribution to academic knowledge but also a practical aid in developing business strategies.

## 4.2 DIGITAL MATURITY AND TECHNOLOGY ACCEPTANCE MODEL (TAM)

Digital maturity refers to the extent to which an organization or individual can integrate and effectively utilize digital technologies to achieve strategic objectives. Digital maturity encompasses multiple dimensions, including technological infrastructure, digital skills, organizational culture, and innovation capabilities. In recent years, there has been increasing attention on measuring and developing digital maturity as companies and institutions increasingly adopt digital solutions to enhance

efficiency, improve customer experience, and gain a competitive advantage (Park & Kim, 2014).

In examining this area, it is worth recalling Rosenberg's (Rosenberg, 1972) perspective, which suggests that the diffusion of innovations is characterized by two defining and ambivalent features: on the one hand, the overall slowness, and on the other, the significant variability in the acceptance of individual innovations, and thus in the speed of their diffusion. The issue of innovation diffusion and the investigation of what factors, how, and to what extent determine the spread of innovations and the speed of their diffusion continue to be subjects of ongoing research.

Rosenberg also draws attention to a less explored but highly important explanation for the slow diffusion of innovations. The further development of old technology often continues even after the introduction of new technology, thus prolonging the point at which the new solution clearly surpasses the old one. This phenomenon is observable in many industries and significantly impacts the spread of new technologies, such as digital signatures. One of the most widely applied theoretical frameworks for studying the acceptance and use of digital technologies is the Technology Acceptance Model (TAM) , developed by Davis (Davis & Davis, 1989). According to the model, technology acceptance is fundamentally influenced by two factors: Perceived Usefulness (U) and Perceived Ease of Use (E). Perceived Usefulness refers to the extent to which a user believes that technology will enhance their performance, while Perceived Ease of Use refers to the degree of effort required to use the technology.

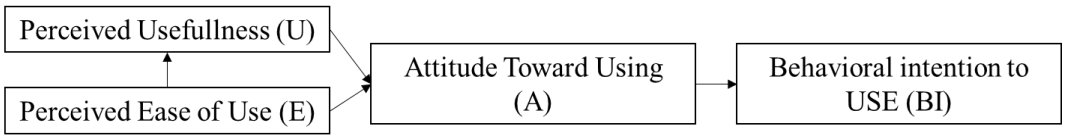



*Figure 5 Technology Acceptance Model*

According to Nyírő (Nyírő, 2011), an individual's own belief about their ability to use a new technology significantly impacts the perceived ease of use of that technology. This means that users who feel more confident in using digital tools are more likely to perceive technology as easier to use, which ultimately increases the likelihood of its acceptance and active use.

Business enterprises typically exhibit a higher level of information security awareness maturity than nonprofit organizations (Tarján, 2020). This means that businesses often

allocate greater resources and attention to information security, as appropriate security measures are necessary to maintain a competitive edge, ensure legal compliance, and preserve customer trust. In contrast, nonprofit organizations, which generally operate with more limited budgets and resources, often lack the same level of information security awareness. Such differences can also impact the adoption of digital signatures and other digital solutions, as information security and trust are critical factors in the successful implementation of these technologies.

Over the years, the TAM model has been further developed and expanded to include additional variables, such as social influence, facilitating conditions, and perceived risk, resulting in the creation of TAM2 (Venkatesh & Davis, 2000) and the Unified Theory of Acceptance and Use of Technology (UTAUT). These models have been applied across various fields, including the digital transformation of SMEs, where factors such as organizational support, the regulatory environment, and customer expectations significantly influence the adoption of technology.

The integration of digital maturity and the TAM model provides a deeper understanding of the challenges businesses—particularly SMEs—face during digital transformation. The most common barriers include low awareness, resource shortages, and resistance to change. Additionally, generational differences, industry-specific needs, and trust in digital systems also play significant roles in shaping digital maturity. Targeted strategies based on these factors can help organizations achieve successful digital adaptation. In the Hungarian context, digital maturity development is intrinsically linked to infrastructure availability and regulatory support mechanisms. (Kis, 2010) demonstrated that ICT adoption among Hungarian enterprises correlates strongly with both technical infrastructure access and governmental policy interventions, suggesting that digital signature adoption operates within broader ecosystem constraints beyond individual organizational factors..

Theories related to the diffusion of innovations – including Rosenberg's observations – are highly applicable to the study of digital signature adoption, as the adaptation of this technology also shows significant variation across different organizations and industries. The introduction of digital signatures is fundamentally influenced by technological maturity, as well as the perceptions of individual and organizational decision-makers: the greater the perceived usefulness and the smaller the perceived

difficulty, the faster the solution is likely to spread in practice. According to some studies, the size of the company has a significant positive impact on the adoption of digital signatures (Santosa & Alamsjah, 2022).

The results of this research align with the TAM model and digital maturity models, reinforcing the assumption that the acceptance of digital signatures is closely related to the technological development of the company. According to the TAM model, the acceptance of technology is influenced by perceived usefulness and perceived ease of use, factors clearly defined by variables identified in the research, such as company size, revenue, and industry. Larger and digitally more advanced companies are more likely to adopt digital signatures, as they possess the necessary financial and technological resources, and the administrative and efficiency benefits are more apparent to them.

## 4.3 SYSTEMATIC LITERATURE REVIEW

One of my main goal by conducting the Systematic Literature Review is to have a better understanding related to one of my main exploratory research questions:

> RQ1. WHAT ARE THE KEY FACTORS INFLUENCING DIGITAL SIGNATURE ADOPTION IN SMES ACCORDING TO EXISTING INTERNATIONAL RESEARCH?

Webster and Watson (2002) introduced a methodology for conducting a Systematic Literature Review (SLR) with the aim of providing a rigorous approach to synthesizing research studies in a particular field. The methodology is widely accepted and has been opted by many researchers in various fields.

In order to provide a relatively comprehensive overview of the contributions to the literature in this area, a search was conducted for as wide a range of digital signature-related articles as possible.

The following databases were used to identify such papers and to identify records relevant to the topic of the study.

- Scopus
- Web of Science
- ResearchGate
- Mendeley
- Google Scholar
- PubMed databases
- Google search.

The keywords used for the search were derived for the research (understanding and systematizing the factors influencing the use of digital signatures in Hungarian SMEs). In this context, the contributions of digital signature research were considered important to be better understood from a technological, legal, and usage domain perspective, which could be systematically used to design the questionnaire for the empirical research of my thesis.

The list of keywords and the related research perspectives are included in Table 1

| Research perspective | Used Keywords |
|---|---|
| General keywords for digital signature | Digital signature, electronic signature |
| Technology aspect of digital signature | Signature key certificate, certification authority, PKI, signature container, applied cryptography, blockchain, hashing, encryption, RSA, elliptic curve cryptography, ECDLP, IFP, public-key cryptography, timestamp, security |
| Legal aspect of digital signature | Regulation, international commercial contract in electronic form, writing, digital transactions |
| Usability and use-cases | Internet of things, embedded device security, lightweight cryptography, digital signature in health industry, education system, usability, use cases, TAM, cloud-based service |

*Table 1 Keywords for research perspectives*

The keywords in the list were combined using logical operators to ensure that a list of contributions relevant to the research problem was obtained. Based on the search results, around 1,500 articles were identified, including numerous literature reviews dealing with digital signature adoption. These studies provided valuable insights into various aspects of technology, such as legal implications, organizational applications, pandemic-related uses, and technological details.

I used Zotero as a reference manager tool to keep all my findings organized.

Based on the literature review, the main research question was segmented into the following three research questions:

| RQ1.1<br>WHAT IS THE TECHNOLOGICAL ASPECT OF DIGITAL SIGNATURE? |
|---|

This question explores the technical foundation of digital signatures, including encryption methods, security mechanisms, implementation challenges, and technological advancements. Understanding these aspects provides insight into digital signature solutions' reliability, efficiency, and adaptability across various domains.

| RQ1.2<br>HOW IS THE LEGAL ASPECT OF DIGITAL SIGNATURE DESCRIBED? |
|---|

This question examines the legal frameworks and regulatory guidelines governing digital signatures. It includes discussions on compliance requirements, jurisdictional differences, legal recognition, and the role of digital signatures in contractual agreements and authentication processes.

| RQ 1.3<br>WHAT IS THE SCIENTIFIC UNDERSTANDING OF USABILITY AND USER ACCEPTANCE ASPECT OF DIGITAL SIGNATURE? |
|---|

This question investigates how users perceive and adopt digital signatures. It encompasses usability factors, user experience studies, barriers to adoption, and theoretical models such as the Technology Acceptance Model (TAM) to analyze acceptance trends and behavioral factors influencing digital signature usage.

PRISMA flow of screening the literature

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a widely used framework for conducting systematic reviews and meta-analyses of research studies.

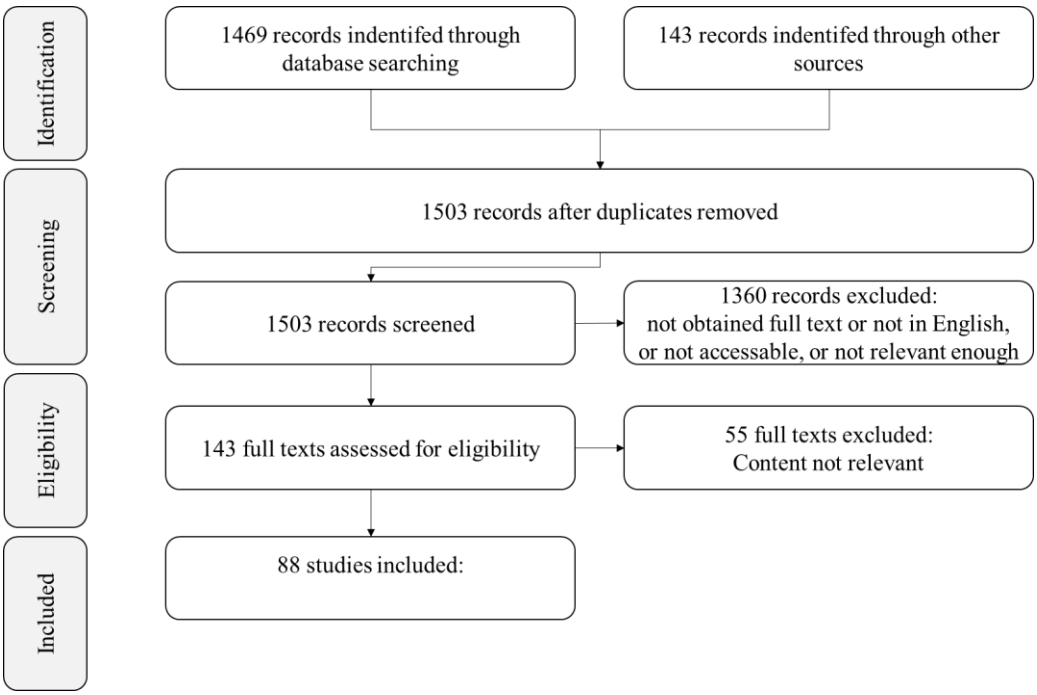



*Figure 6 PRISMA flow of screening the literature*

### 4.3.1 CODING OF MY SYSTEMATIC LITERATURE REVIEW QUESTIONS

What is the technological aspect of digital signature? (Concept code: TA)

- TA1- Public key infrastructure (PKI): the infrastructure used to support digital signatures, including certificates and certificate authorities.
- TA2- Cryptography and digital signatures: key concepts and principles.
- TA3- Timestamping: how digital signatures can be timestamped to provide additional security and authenticity?
- TA4- Hashing: how digital signatures use hashing to create a unique fingerprint of the document?
- TA5- Types of digital signature algorithms and their strengths/weaknesses.
- TA6- Digital signature verification and authentication mechanisms.
- TA7- Emerging trends and advancements in digital signature technology.

How is the regulatory aspect of digital signature described? (Concept code: RA)

- RA1- Electronic signature vs. digital signature: legal distinctions and implications.
- RA2- Trust: how trust is established in digital signatures, including trust models and trusted third parties?
- RA3- Requirements for legal validity of digital signature (e.g. authentication, integrity, non-repudiation).
- RA4- Key legal considerations for implementing digital signature solutions.

What is the academic understanding of usability and user acceptance aspect of digital signature? (Concept code: UA)

- UA1- Human factors in digital signature implementation and design.
- UA2- User acceptance of digital signature solutions: barriers and facilitators.
- UA3- User experience: how users perceive and interact with digital signatures, including ease of use and satisfaction.
- UA4- Best practices and guidelines for designing user-friendly digital signature systems.

- UA5- User training: how training and education can improve usability and user acceptance of digital signatures.
- UA6- Case studies on user acceptance and adoption of digital signature in different contexts (e.g. healthcare, finance, government).
- UA7- Human factors: how human factors such as age, gender, and education affect the use of digital signatures.
- UA8- Adoption: factors that influence the adoption of digital signatures, including perceived usefulness and ease of use.
- UA9- Trust and confidence: how trust and confidence in digital signatures affect user acceptance.

### 4.3.2 CONCEPT CODE: TA

| RQ1.1<br>WHAT IS THE TECHNOLOGICAL ASPECT OF DIGITAL SIGNATURE? |
|---|

Understanding the technological foundations of digital signatures is essential for analyzing user acceptance and adoption patterns within SMEs. While this dissertation maintains a customer-centric focus, the technical infrastructure, - including public key infrastructure (PKI), cryptographic algorithms, trust service providers, and security mechanisms - directly influences both perceived ease of use and perceived usefulness, the core constructs of the Technology Acceptance Model. The following sections examine these technical foundations to establish the baseline understanding necessary for interpreting how SMEs perceive, evaluate, and adopt digital signature solutions. This technical context provides the foundation for understanding the usability challenges and acceptance barriers identified in subsequent empirical research phases.

#### 4.3.2.1 PUBLIC-KEY DIGITAL SIGNATURES

A Public Key Infrastructure (PKI) is an essential system for securing electronic communication and transactions that involve sensitive or confidential data. It consists of a comprehensive set of components, including policies, procedures, hardware, and software, to manage the creation, distribution, storage, use, and revocation of digital certificates for public-key encryption. PKI is crucial for network activities such as e-commerce, internet banking, and confidential email, where simple passwords are insufficient for authentication and more rigorous proof is required to verify the identity of the communicating parties and validate the information being transferred (Höglund et al., 2020).

In plain terms, PKI provides trust services to ensure that human or machine entities can be trusted in their actions or outputs. (Boldyreva et al., 2007) These trust services aim to uphold one or more of the following capabilities: Confidentiality, Integrity, and Authenticity (CIA), and are further explained as follows:

- Confidentiality: PKI ensures that the payload remains secure from malicious or inadvertent access. Data is encrypted to render it unintelligible to

unauthorized entities. The most common application of PKI for confidentiality purposes is in the context of Transport Layer Security (TLS), which underpins data security in transit, particularly during transmission. For instance, when logging on to a web-based service by entering a password, TLS is a classic example of confidentiality in action.

- Integrity: PKI guarantees that any alteration or tampering of transmitted data is detectable and tamper evident. While tamper-proofing is not always possible, it is crucial to have clear evidence of any tampering. PKI ensures that if an entity changes or tampers with transmitted data, it would be evident that the integrity of the data would have been compromised.
- Authenticity: PKI provides assurance to entities that they are connected to a legitimate service or source. Server-side authentication is typically used when authenticating to a web server using a password. At the same time, client-side authentication is sometimes employed when authenticating using a smart card that stores a digital certificate and private key. PKI enables every entity to know what it is connected to or to provide evidence of its legitimacy when connecting to a protected service.

Signature protocols have three primary objectives, which include maintaining message integrity (i.e., ensuring the message remains unaltered during transit), message authentication (i.e., verifying the authenticity of the sender), and non-repudiation (i.e., preventing the sender from denying message creation) (Paar & Pelzl, 2010) The transferability of non-repudiation is dependent on the method of dispute resolution, allowing a message recipient to verify if the message is likely to be accepted by another recipient if forwarded.

An informal definition of a secure signature scheme comprises three essential properties (Amiri & Andersson, 2015):

- Unforgeability: A dishonest entity should not be able to send a message successfully while pretending to be someone else.
- Non-repudiation: The signer should not be able to deny successfully sending a signed message with their signature.
- Transferability: If a verifier accepts a signature, they should be confident that any other verifier, such as a judge, would also accept the signature.

In cryptography, PKI serves as an arrangement that binds public keys to the corresponding identities of entities such as individuals and organizations. (Chien, 2021) The binding process involves registration and issuance of certificates by a Certificate Authority (CA), which can be automated or done under human supervision. For secure enrollment or certificate management, a network requires using a secure certificate protocol such as CMP.(Pierre, 2019)

A Registration Authority (RA) is a PKI role that a CA may delegate to ensure accurate and valid registration. RA is responsible for accepting digital certificate requests and authenticating the entity making the request. According to the Internet Engineering Task Force's RFC 3647, RAs perform tasks like identifying and authenticating certificate applicants, approving or rejecting certificate applications, initiating certificate revocations or suspensions under specific circumstances, processing subscriber requests to revoke or suspend their certificates, and approving or rejecting requests by subscribers to renew or re-key their certificates. However, RAs do not have the authority to sign or issue certificates and are delegated specific tasks by the CA. Though Microsoft may have referred to a subordinate CA as an RA, this is not in line with the X.509 PKI standards. RAs only manage the vetting and provisioning of certificates and do not have the signing authority of a CA. In Microsoft PKI cases, RA functionality is provided through Microsoft Certificate Services website or Active Directory Certificate Services, which enforces Microsoft Enterprise CA and certificate policy through certificate templates and manages certificate enrollment. (Boldyreva et al., 2007)

In a CA domain, an entity must be uniquely identifiable based on information about that entity. A Third-Party Validation Authority (VA) can provide this entity information on behalf of the CA. The X.509 standard is the most commonly used format for public key certificates.(Mitchell, 2000)

A public key infrastructure (PKI) is a system that generates, stores, and distributes digital certificates to validate that a particular public key is associated with a specific entity. The PKI creates digital certificates that map public keys to entities, stores them in a central repository securely, and revokes them if necessary.(Trcek, 2006)

The components of a PKI include (Ariwa & El-Qawasmeh, 2011):

- A certificate authority (CA) that manages the storage, issuance, and signing of digital certificates.
- A registration authority (RA) is responsible for verifying entities' identity requesting their digital certificates to be stored at the CA.
- A central directory serves as a secure location where keys are stored and indexed.
- A certificate management system that manages tasks such as access to stored certificates or delivery of certificates to be issued.
- A certificate policy that outlines PKI's requirements regarding its procedures. It aims to enable external parties to assess the PKI's reliability.

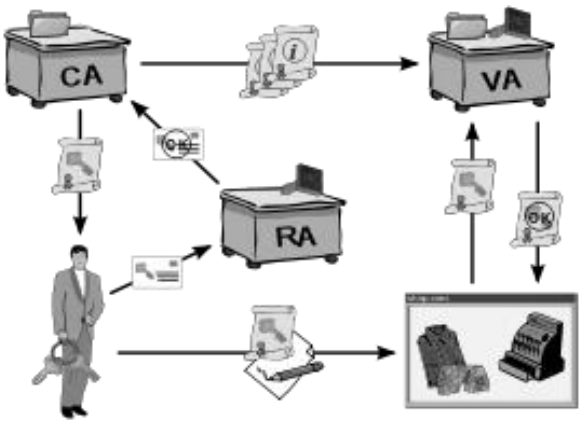



*Figure 7 Diagram of a public key infrastructure*

#### 4.3.2.2 PUBLIC KEY CRYPTOGRAPHY

RSA-based cryptosystems currently dominate the digital world and public-key cryptography segment, but there is a growing interest in cryptosystems based on elliptic curves as an alternative. The security of RSA (named after Rives-Adleman-Shamir) is dependent on the integer factorization problem (IFP). In contrast, elliptic curve cryptography (ECC) security is based on the elliptic curve discrete logarithm problem (ECDLP). ECC has gained attention since the best-known algorithm for solving the ECDLP takes full exponential time while solving the IFP of RSA takes sub-exponential time. This suggests that ECC requires less memory than RSA and is particularly suitable for memory-constrained devices. Overall, ECC is considered a

more favorable option than RSA.(Amiri & Andersson, 2015; Imam et al., 2021; Mahto & Yadav, 2017)

When it comes to the security of RSA and ECC, the fastest algorithm currently known for solving the ECDLP is Pollard's rho algorithm, which has an expected running time of $\sqrt{\pi n}/2$ and is considered a full-exponential time algorithm. The largest ECDLP instance solved using this algorithm as of 2003 was an elliptic curve over a 109-bit prime field. On the other hand, Pollard's general number field sieve (NFS) is the best-known generic factoring method for RSA, with a heuristic expected runtime of L[n] = [1/3, 1.923] needed to find a factor of a composite number n. The largest integer factored using the NFS takes sub-exponential time, which was RSA200, a 200-digit number (665 bits) that was factored in May 2005. This suggests that ECC can use significantly smaller parameters than RSA to achieve the same level of security. For example, to achieve a security level of 112 bits, RSA requires a key size of 2048 bits, while ECC only needs a key size of 224 bits. A comparative analysis of RSA and ECC is also presented based on encryption and decryption times for data of 8 bits, 64 bits, and 256 bits.(Mahto & Yadav, 2017)

| Security Bit Level | RSA | ECC |
|---|---|---|
| 80 | 1024 | 160 |
| 112 | 2048 | 224 |
| 128 | 3072 | 256 |
| 192 | 7680 | 384 |
| 256 | 15360 | 512 |

*Table 2 NIST Recommended Security Bit Level*

#### 4.3.2.3 TRUST SERVICE PROVIDER

TSPs, or Trusted Service Providers, are highly skilled market operators with a European Union (EU) trust mark, selected by European governmental agencies through a strict conformity assessment process in accordance with Regulation EU No. 910/2014 - eIDAS. These providers typically offer a range of services such as creating, verifying, and validating electronic signatures, seals, time stamps, and digital certificates, as well as managing electronic storage and archiving documents.

The eIDAS Regulation establishes a legal framework for digital services provided to the public with effects on third parties, requiring TSPs to meet specific requirements for high-level security standards, use of trustworthy systems, performance audit, legal certainty, customer protection, and ensuring trustworthiness of services and long-term preservation of information. Notably, the Regulation also holds TSPs liable for noncompliance with due diligence. (Atzori, 2018; *The European Banking Union*, 2015)

#### 4.3.2.4 DIGITAL SIGNATURE SCHEME

The Diffie-Hellman key exchange is a mathematical technique that enables the secure exchange of cryptographic keys over a public channel. It was among the first public-key protocols, proposed by Ralph Merkle and named after Whitfield Diffie and Martin Hellman. In 1976, Diffie and Hellman published the earliest known work proposing the concept of a private key and corresponding public key. Before this, secure communication between parties required exchanging keys through secure physical means. With Diffie-Hellman, two parties with no prior knowledge of each other can establish a shared secret key over an insecure channel, which can be used to encrypt subsequent communication with a symmetric-key cipher. Diffie-Hellman is commonly used to secure internet services, but research suggests that some DH internet applications may be vulnerable to compromise by well-funded attackers. The scheme was first published by Diffie and Hellman in 1976, but it was later revealed that British signals intelligence agency GCHQ had previously shown how public-key cryptography could be achieved. While the Diffie-Hellman key exchange is a non-authenticated protocol, it serves as the basis for a variety of authenticated protocols and is used to provide forward secrecy in Transport Layer Security's ephemeral modes. RSA, an implementation of public-key cryptography using asymmetric algorithms, was developed shortly after the Diffie-Hellman method.(Diffie & Hellman, 1976)

In the Diffie-Hellman key exchange protocol, both parties create a public/private key pair and share the public key with each other. Once they have obtained authentic copies of each other's public keys, they can compute a shared secret offline. This shared secret can be utilized as a key for a symmetric cipher, among other things.

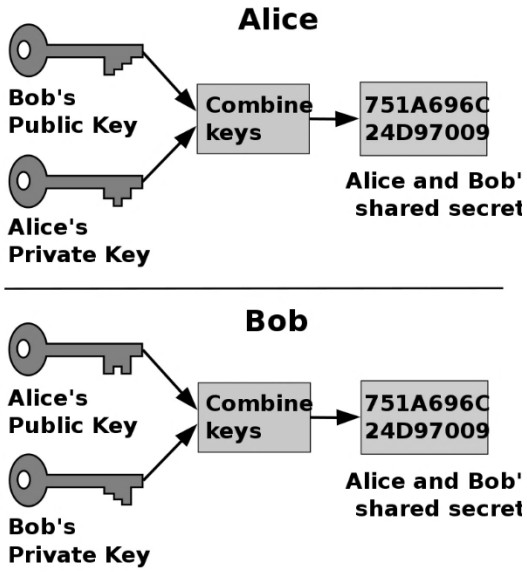



*Figure 8 Diffie–Hellman key exchange scheme*

The Diffie-Hellman key exchange method creates a shared secret between two parties to enable secure communication over a public network. To explain this concept, an analogy is used, replacing large numbers with colors. Alice and Bob initially agree on a common starting color: yellow. Next, they each select a secret color, red and cyan, respectively. They then mix their secret color with the common color to create two new colors, which are publicly exchanged. Finally, each party mixes the color they received from their partner with their own secret color to arrive at a final color mixture that is identical for both parties.

If a third party were to eavesdrop on this exchange, they would only know the common and initial mixed colors. However, determining the final secret color is computationally expensive and practically impossible, even for modern supercomputers. By using this analogy, we can better understand the secure key exchange process.

Public-key cryptography is a cryptographic method that allows secure communication over an insecure public network and facilitates verifying the identity of an entity through digital signatures (Adams & Lloyd, 2003).

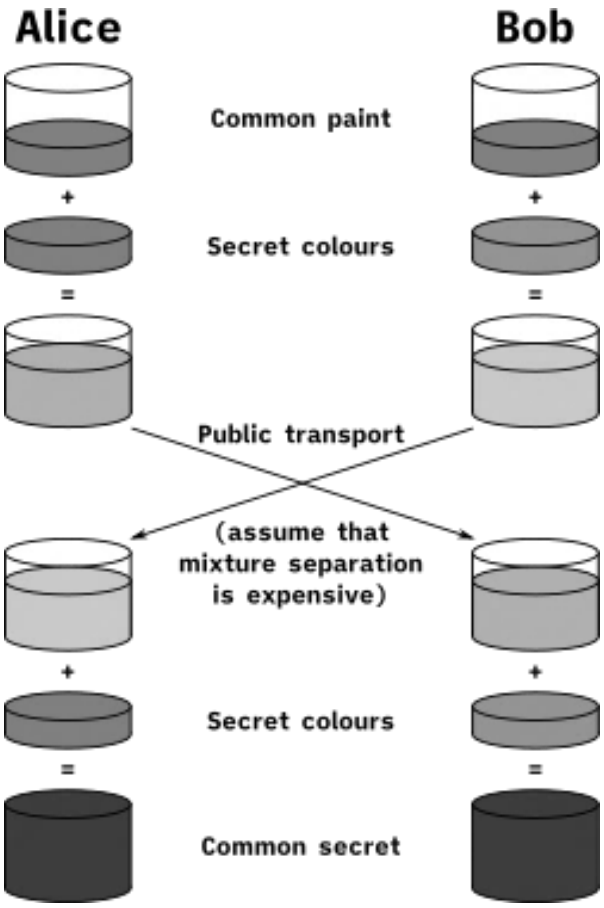



*Figure 9 Illustration of the concept behind Diffie–Hellman key exchange*

In 2002, Hellman proposed that the algorithm, which is commonly referred to as Diffie-Hellman key exchange, should also acknowledge Ralph Merkle's contribution to creating public-key cryptography. Hellman argued that although the system was initially introduced in a paper authored by Diffie and himself, it is a public key distribution system that Merkle developed. Therefore, it should be called "Diffie-Hellman-Merkle key exchange" to properly recognize Merkle's significant contribution. Hellman expressed his hope that his suggestion would raise awareness of Merkle's role in inventing public key cryptography.(Hellman, 2002)

A digital signature scheme contains the following components (Goldwasser et al., 1988):

- A security parameter that is chosen by the user when he creates his public and secret keys. The parameter determines the number of quantities (length of signatures, length of signable messages, running time of the signing algorithm, overall security, etc.).

- A message space, which is the set of messages to which the signature algorithm may be applied.
- A signature bound which is an integer bounding the total number of signatures that can be produced with an instance of the signature scheme.
- A key generation algorithm that any user can use to generate in polynomial time a pair of matching public and secret keys. The secret key is sometimes called the trap-door information.
- A signature algorithm, which produces a signature for a message using the secret key.
- A verification algorithm, which tests whether a valid signature is used for message using the public key

#### 4.3.2.5 RSA-ECC

Several authors have conducted comparative analyses on the security and performance of RSA and ECC using various measurement parameters. (Gura et al., 2004) investigated the efficiency of point multiplication operations of elliptic curves compared to RSA on two 8-bit processor computer systems. Their findings indicate that on both systems, ECC-160-point multiplication is more efficient than RSA-1024 private key operation.

(Bos et al., 2015) evaluated the risks associated with RSA and ECC key lengths and concluded that until 2014, using 1024-bit RSA carries a small risk, while 160-bit ECC over a prime field is safe to use for a more extended period. (Mahto & Yadav, 2017)observed that RSA is faster than ECC, but in terms of security, ECC outperforms RSA.

(Zahan et al., 2020) compared the usage of digital signatures in RSA and ECC and suggested that RSA may be suitable for applications where message verification is more important than signature generation. (Alese et al., 2012)suggested that currently, RSA is stronger than ECC, although ECC may outperform RSA in the future.(Mahto & Yadav, 2017)demonstrated that ECC is more operationally efficient and secure than RSA.

Given the widespread usage of RSA, DSA, and ECDSA, it was perhaps unsettling (and exciting) that quantum computers could efficiently factorize prime numbers and

find discrete logarithms. This means that any scheme relying on these problems will become completely insecure in a post-quantum world.(Shor, 1997)

| ***Key point*** | ***ECC*** | ***RSA*** |
|---|---|---|
| *Key sizes* | Shorter pair of keys | Larger pair of keys |
| *Bandwidth* | Significant | Considerably less than ECC |
| *Key Generation* | Quicker | Slower |
| *Encryption* | Quicker | Slower |
| *Decryption* | Slower | Faster |
| *Efficiency* | More competent for insignificant devices | Less competent |

*Table 3 Comparison of ECC and RSA with reference toward different key issues*

#### 4.3.2.6 POST-QUANTUM CRYPTOGRAPHY

Post-quantum cryptography seeks to develop encryption and signature schemes capable of resisting attacks by quantum computers. With advances in quantum computing, traditional algorithms like RSA and ECC may become vulnerable, spurring interest in quantum-resistant alternatives (Amiri & Andersson, 2015; *Microsoft's Majorana 1 Chip Carves New Path for Quantum Computing*, 2025) Ongoing standardization efforts aim to ensure widespread adoption of post-quantum schemes across platforms (Bos et al., 2015).While these developments represent an important consideration for long-term digital signature security, they remain largely theoretical concerns for current SME adoption decisions, which focus on immediate usability and partner acceptance rather than future cryptographic threats.

#### 4.3.2.7 HASHING

When signing a document, it is common practice not to encrypt the entire file using one's private key. Instead, only an imprint is encrypted due to the slowness of public key cryptography and the limited size of private keys. However, splitting the document into blocks and signing them separately is not a recommended solution as it could lead to undetectable block swaps or deletions by an attacker. Therefore, it is necessary to merge the blocks in a secure way. One way to achieve this is by hashing the document using a collision-resistant and image-resistant algorithm and then signing the resulting imprint. In many cases, digital signatures are legally recognized as equivalent to

handwritten signatures. Hashing is a fundamental technology that enables the creation of legally compliant digital signatures. This makes hashing essential for businesses and individuals who need to sign electronic documents in a legally binding manner.When using one of the approved digital signature algorithms to generate a digital signature for a message, the message should first be processed using one of the approved hash algorithms. A well-regulated technique specified is used to randomize the original message prior to hashing. (Dang, 2009; Goldwasser et al., 1988; Muhammad et al., 2021)

#### 4.3.2.8 TIMESTAMP

A timestamp, which is also referred to as a timestamp, is a statement signed by a trusted organization, i.e., a trusted token provider, within the public key infrastructure (PKI). This statement confirms the existence of a particular document at a specific moment in time.(Zhou & Deng, 2000)

Timestamps are the most prominent means to guarantee proof-of-existence for data objects in a PKI. That is, timestamps allow us to infer a date on which a data object existed. This facility is necessary to sort data objects in chronological order.

The use of timestamps requires the so-called Timestamp Authority (TSA), which is a trusted entity that provides signed timestamps with a trustworthy date value. That is, given a data object, the TSA provides a timestamp that binds the data object to the current value of the TSA's clock, which is protected and synchronized with a legal source of time.(Vigil & Custódio, 2012)

A CA is liable for the revocation of the certificates that the CA issues, but until these certificates expire.

The presence of a timestamp on an electronically signed document serves two purposes: first, it confirms the identity of the signer whose certificate is used to verify the signature; second, it guarantees that neither the document nor the signature has been altered since the time of signing. Timestamps play a crucial role in electronic signature applications, especially when a certificate authority (CA) revokes a signer's certificate (e.g., due to the loss of the private key associated with the signature). If a timestamp was applied to the electronic signature, it can be verified that the signature

was created before the certificate was revoked and is therefore considered valid.(Đức Phong et al., 2008)

While the technological infrastructure described above establishes the feasibility of digital signatures, technology alone does not determine adoption. The regulatory environment - examined in the following section - provides the legal foundation that transforms technical possibility into business reality for SMEs.

### 4.3.3 CONCEPT CODE: RA

| RQ1.2<br>HOW IS THE LEGAL ASPECT OF DIGITAL SIGNATURE DESCRIBED? |
|---|

A digital signature is a method of electronically signing a document or file using encryption techniques to ensure its authenticity, integrity, and non-repudiation. From a legal perspective, digital signatures are generally recognized as equivalent to traditional handwritten signatures, provided that they meet certain requirements and are used in accordance with applicable laws and regulations.(Prasetya & Bawono, 2022)

Signatures hold great significance in legal, commercial, and even artistic contexts as they represent an individual's personality and credibility. They play a crucial role in validating not only important international documents, but even something as simple as a greeting card. Signatures on documents serve as significant evidence to attribute its contents to the signatory and indicate their acknowledgement and acceptance of the document's contents. Ensuring the security of this process is critical, especially in the digital space where it is doubly important. Without the necessary security infrastructure, electronic services cannot be provided as electronic signatures cannot be trusted without the technologies required to validate and regulate electronic documents. The legislation, along with these technologies, is a crucial factor in realizing the security of electronic signatures since proper application and implementation of these technologies are dependent on the enactment of relevant statutes. (Bakhtiarifar & Savrai, 2018)

#### 4.3.3.1 GLOBAL LEGAL FRAMEWORK

Digital signature regulation in the European Union rests on the eIDAS Regulation (EU No 910/2014), which establishes a tiered system of signature types—simple, advanced, and qualified (De Sutter et al., 2022). Qualified electronic signatures (QES) are treated as legally equivalent to handwritten signatures when they satisfy specific technical conditions: a unique link to the signatory, verifiable identification, creation under the signatory's sole control, and a secure link to the signed data that detects any changes  Under Article 25(2) of eIDAS, QES carry a legal presumption of authenticity, integrity, and validity, effectively reversing the burden of proof in disputes—challengers must prove invalidity rather than relying parties proving authenticity (*E-Signature: Who Bears the Burden of Proof? - VDB Law*, 2020; *What Is the eIDAS Regulation?*, 2024). The regulation mandates Qualified Trust Service Providers (QTSPs), which undergo independent conformity assessment and regular audits by accredited institutions, ensuring institutional reliability and cross-border recognition within the EU ((*Remote Identity Proofing - Attacks & Countermeasures*, 2022; *What Is a Qualified Trust Service Provider?*, 2019).

In the United States, regulation under UETA and the Electronic Signatures in Global and National Commerce (ESIGN) Act adopts a fundamentally different approach. Both acts establish four core requirements: intent to sign, consent to do business electronically, association of signature with the record, and record retention (*Electronic Signature Laws & Regulations - United States*, 2025). However, US law is explicitly technology-neutral and prescribes no specific cryptographic standards, device security requirements, or mandatory certification frameworks (Determann, 2019). When electronic signature authenticity is challenged, the party relying on the signature bears the burden of proving its validity through digital evidence and audit trails, as no legal presumption of validity exists ((*Electronic Signature Laws & Regulations - The European Union*, 2025)

This technology-neutral versus technically prescriptive dichotomy extends beyond the EU-US comparison to reveal a global hierarchy of digital signature legal recognition. Analysis of frameworks across jurisdictions demonstrates three distinct regulatory tiers (Table 4).

| Tier | Characteristics | Example Jurisdictions | Technical Requirements |
|---|---|---|---|
| **Level 1: Technology-Neutral** | Any technology identifying signer and demonstrating intent | United States (ESIGN/UETA), Australia (ETA), Canada (PIPEDA) | Minimal; no mandatory cryptographic or device standards |
| **Level 2: Certificate-Based** | Digital certificates from accredited or recognized authorities | Brazil (ICP-Brasil), Singapore (ETA), Japan (E-Signature Act), South Africa (ECTA) | PKI certificates from national certification authorities; varying oversight rigor |
| **Level 3: Qualified Signature** | Qualified certificates, secure devices, strict identity verification | EU (eIDAS QES), Switzerland (ZertES), UAE (Approved Electronic Signatures) | Qualified certificates, qualified signature creation devices, qualified trust service providers |

*Table 4 Global Hierarchy of Digital Signature Legal Frameworks*

Technology-neutral frameworks at Level 1, including Australia's Electronic Transactions Act 1999 and Canada's PIPEDA, ensure legal recognition without mandating technical implementations, requiring only that signatures identify the person, indicate intent, and be "as reliable as appropriate" (Canada, 2008; Secretariat, 2021)

Certificate-based frameworks at Level 2 demonstrate significant variation: Brazil's ICP-Brasil infrastructure grants legal presumption functionally equivalent to eIDAS QES, while Singapore's Electronic Transactions Act, Japan's Act on Electronic Signatures and Certification Business (2000), and South Africa's Electronic Communications and Transactions Act establish certificate-based systems with varying oversight rigor though QTSP conformity assessment under eIDAS, requiring independent audits, ongoing supervision, and inclusion on EU Trust Lists, generally exceeds national certification authority oversight mechanisms (*Conformity Assessment of Qualified Trust Service Providers | ENISA*, 2024; *Electronic Signature Laws & Regulations - Brazil*, 2025; *Electronic Signature Laws & Regulations - Japan*, 2023; *Electronic Signature Laws & Regulations - Singapore*, 2024; *Electronic*

*Signature Laws & Regulations - South Africa*, 2023; 'Electronic Signatures in South Africa - SigniFlow eSignatures', 2020).

Level 3 frameworks include Switzerland's ZertES, which maintains a parallel qualified signature framework to eIDAS, and the UAE's Federal Decree Law No. 46 of 2021, which references eIDAS technical specifications. Latin American frameworks show varying alignment: Colombia's Law 527 of 1999, modeled on UNCITRAL principles, distinguishes electronic from digital signatures, while Mexico's NOM-151-SCFI-2016 recognizes advanced electronic signatures comparable to eIDAS standards (*Electronic Signature Law in Commercial Contracts in Colombia*, 2020; *Electronic Signature Laws & Regulations - Colombia*, 2025; *eSignature Legality in Mexico | OneSpan*, 2020; *The Importance of NOM 151 for Electronic Signatures | OneSpan*, 2022)

This regulatory diversity creates implications for cross-border interoperability and international business transactions, as the EU's structured technical and procedural requirements provide legal certainty and automatic cross-border recognition within the Single Market, while technology-neutral frameworks offer implementation flexibility at the potential cost of evidentiary complexity in disputes (De Sutter et al., 2022; Gregušová et al., 2022). For Hungarian SMEs engaging in international transactions, particularly those with service-sector orientations and international partner networks identified as adoption drivers in this research, understanding these jurisdictional variations becomes essential for digital signature implementation strategies.

#### 4.3.3.2 ELECTRONIC SIGNATURES VS. DIGITAL SIGNATURES VS. ENHANCED DIGITAL SIGNATURES

Digital signature regulation by countries refers to the legal framework and technical requirements that govern the use of digital signatures within a specific jurisdiction. Digital signatures are electronic equivalents of handwritten signatures and are used to authenticate the identity of the signatory and the integrity of the signed document. Different countries have different laws and regulations regarding the use of digital signatures, and these laws may vary in terms of their scope, requirements, and enforcement mechanisms. In general, digital signature regulation aims to provide legal recognition for electronic signatures, establish technical standards for their use and verification, ensure their reliability and security, and promote their use in electronic transactions. The regulation of digital signatures is important for facilitating electronic

commerce, promoting cross-border trade, and ensuring legal certainty and security in the digital economy.

While the terms electronic signature and digital signature are sometimes used interchangeably, it is important to note that digital signature is actually a specific type of electronic signature. According to Oxford Dictionaries, an electronic signature involves attaching symbols or other data in digital form to an electronically transmitted document to verify the sender's intent to sign. This can be in the form of a typed name, an image of the person's handwritten signature, or any other form of electronic representation. On the other hand, digital signatures are a type of electronic signature that use encryption codes to sign and authenticate the authenticity of a document.

Unlike electronic signatures, digital signatures involve a stringent verification process and come under specific standards. They ensure the integrity of a message by encrypting a random key with the receiver's public key and validating the received fingerprint with a temporary digital fingerprint hashed from the key. PKI is the most common technology used to create digital signatures, providing a cryptographic key pair that encrypts messages and guarantees that their content has not been altered.(Daza Jaller et al., 2020)

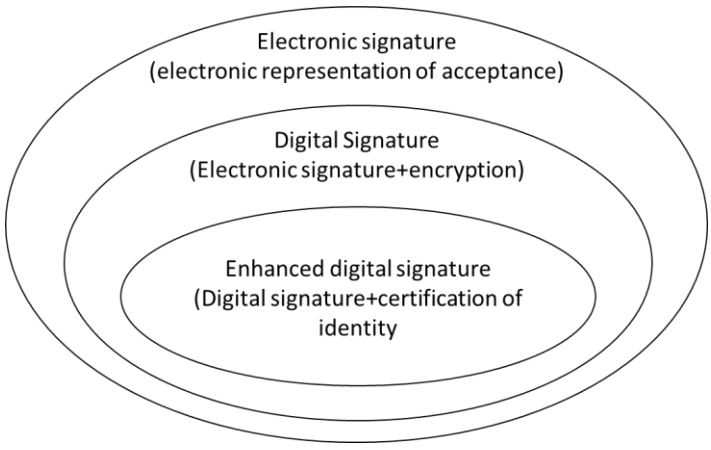



*Figure 10 Levels of signature*

#### 4.3.3.3 ADVANCED AND QUALIFIED SIGNATURE IN HUNGARY

For this chapter the book of Dr. Berta István Zsolt, “Nagy e-szignó könyv”, was one of my primary sources (Berta, 2011).

Legislation on electronic signatures is closely tied to specific technologies and mathematical models, which enable a series of bits to be linked to a handwritten signature. Electronic signatures use cryptographic encryption and can trigger legal effects, making them an equivalent to handwritten signatures. This creates an intriguing intersection between the fields of law and cryptography. The legal definition of electronic signatures is provided by Act XXXV of 2001 (Eat.).

“Eat. § 2 "6. Electronic signature: electronically signed electronically logically associated with or linked to an electronic document for identification purposes or inextricably linked to it. [1]"

The law in effect before 2004 referred to as a "simple electronic signature" did not qualify as an enhanced security measure and was not necessarily reliant on cryptographic solutions. Examples of such simple electronic signatures include inserting one's name at the end of a document or replicating a scanned handwritten signature.

The Eat. is based on cryptographic solutions for secure electronic signatures (and qualified signatures) based on advanced security solutions, and with an electronic signature that is not secure, it only says that it should not reject an electronic document merely because it exists electronically.[2]

The Hungarian regulatory framework has evolved significantly with Government Decree 321/2024, which came into effect January 1, 2025, introducing additional nuances to the electronic signature hierarchy and their legal validity in various administrative and business contexts. Table 5 presents a detailed comparison of

[1] 2001. évi XXXV. törvény az elektronikus aláírásról (a 2004. évi módosításokkal), 2001.” *Eat. 2. § „6. Elektronikus aláírás: elektronikusan aláírt elektronikus dokumentumhoz azonosítás céljából logikailag hozzárendelt vagy azzal elválaszthatatlanul összekapcsolt elektronikus adat. ”*

[2] *Eat. 3 § (1) „Elektronikus aláírás, illetve dokumentum elfogadását – beleértve a bizonyítási eszközként történő alkalmazást – megtagadni, jognyilatkozat tételére, illetve joghatás kiváltására való alkalmasságát kétségbe vonni – a (2) bekezdés szerinti korlátozással – nem lehet kizárólag amiatt, hogy az aláírás, illetve dokumentum elektronikus formában létezik. ”*

signature types under current Hungarian law, distinguishing between simple electronic signatures (SeS), advanced electronic signatures (AeS), advanced electronic signatures based on qualified certificates, qualified electronic signatures (QeS), and AVDH (Azonosításra Visszavezetett Dokumentum Hitelesítés) framework.

| **Type** | **Simple electronic signature (SeS)** | **Advanced electronic signature (AeS)** | **Advanced e.s. based on qualified certificate** | **Qualified electronic signature (QeS)** | **AVDH (from January 01, 2025)** |
|---|---|---|---|---|---|
| **Written? (Ptk. 6:7. §)** | ? | with timestamp | with timestamp | with timestamp | - |
| **Full probative force? (PP 325. §)** | * | - | ✓ | ✓ | - |
| **Authentic? (Vhr. 31. §)** | - | - | ✓ | ✓ | - |
| **Suitable for company procedures?** | - | - | ✓ | ✓ | - |
| **Suitable for real estate registry procedures?** | - | - | ✓ | ✓ | - |
| **Suitable for creating electronic private documents? (DÁPtv. 109. §)** | exclusively in the closed, audited system of an MNB-supervised service provider!* | with timestamp | with timestamp | with timestamp | - |
| **Same legal effect in all EU member states?** | - | - | - | ✓ | - |

*Table 5 Types of Electronic Signatures and Their Legal Effects in Hungary*[3]

For SME decision-makers, these regulatory distinctions translate into practical adoption considerations. Qualified electronic signatures (minősített elektronikus aláírás) require personal identification with official documents (ID card or passport), creating an equivalence to in-person authentication. The service provider issues a personalized electronic certificate, and a private key is stored on a certified hardware

[3] Source: Dr. Ferenc Kósa, president of Digitális Aláírás Szövetség

device, ensuring the highest level of security. This signature type is mandatory to accept throughout the European Union and is legally equivalent to handwritten signatures.

Critically, qualified electronic signatures create documents with full probative force (teljes bizonyító erejű magánokirat), meaning courts must accept them as authentic, and the burden of proof falls on those disputing the signature's validity rather than on those presenting the document. They are also authentic (hiteles), requiring all authorities to accept that the signature originates from the person named on the certificate.

In contrast, advanced electronic signatures without qualified certificates do not create documents with full probative force. While they may constitute written documents with timestamps, they lack authenticity and cannot be used in company registry procedures (cégeljárás), real estate registry procedures (ingatlan-nyilvántartási eljárás), or any context where regulations require documents with full probative force or authenticated documents. Government Decree 321/2024 § 44 generally requires authenticated copies for paper-based documents, effectively limiting the utility of non-qualified signatures in formal business contexts.

Furthermore, only qualified certificate-based signatures can be used for creating authenticated electronic copies (hiteles másolat), as specified in §§ 70-74 of Decree 321/2024. Recipients may choose whether to accept advanced electronic signatures without qualified certificates, whereas qualified electronic signatures with qualified certificates have the same legal effect as qualified electronic signatures only within Hungary—even these are not mandatory to accept within the EU, where only qualified electronic signatures carry universal acceptance obligations.

These regulatory requirements create a tiered adoption challenge particularly relevant for the SME segment studied in this research. While advanced signatures may suffice for internal processes and informal business communications, qualified signatures become necessary for formal procedures that constitute a significant portion of SME administrative burden. This regulatory context directly influences the cost-benefit calculations, usability requirements, and adoption barriers explored in the quantitative (Section 5) and qualitative (Section 6) research phases.

#### 4.3.3.4 ADVANCED ELECTRONIC SIGNATURE

Eat. 2 § 15. Advanced electronic signature as the following

"Advanced electronic signature: an electronic signature that

- is capable of identifying the signatory,
- uniquely bindable to the signatory,
- created by means which are under the sole control of the signatory,
- and is linked to the content of the document in such a way that all the information contained in the signature and
- the document after the signature has been affixed is perceptible."

In Hungary under the law, the enhanced security (or qualified) electronic signature is deemed to be a written document.

#### 4.3.3.5 QUALIFIED ELECTRONIC SIGNATURE

Enhanced security electronic signatures that meet particularly stringent requirements are referred to as enhanced electronic signatures in the Eat.[4]

An enhanced security electronic signature can only be considered a qualified electronic signature if:

- The signature is created using a secure signature-creation device. The private key is protected by a secure signature-creation device so that the private key cannot be duplicated, and the device authenticates the signers when using a private key with the help of, for example, a PIN code.(Andrianova, 2018)
- A validated certificate confirms that the public key associated with the private key

  is held by whom. A publicly available qualified certification service provider can issue a qualified certificate. Media and Communications Authority shall be subject to particularly strict controls. If the private key is compromised, the certificate must be revoked immediately. The qualified CA shall be financially

[4] *Eat. 2 § 17. „Minősített elektronikus aláírás: olyan – fokozott biztonságú – elektronikus aláírás, amelyet az aláíró biztonságos aláírás-létrehozó eszközzel hozott létre, és amelynek hitelesítése céljából minősített tanúsítványt bocsátottak ki. ”*

liable for any damage caused by the certificate and is covered by liability insurance.

Qualified electronic signatures are subject to strict rules, so if you have a valid qualified signature document with a valid electronic signature, it is safe to assume that the signature-creation data was in the sole possession of the person who signed the certificate at the time the signature was created. (Eka Putra & Riswadi, 2022)

Thus, we can assume that the person in the certificate signed the document. Accordingly, the Eat. assigns probative value to the qualified electronic signature.[5]

According to the Act, a document with a qualified electronic signature is a private document with full evidential value, just like a document signed in front of a notary or two witnesses or a document written entirely in someone's own hand.

Thus, if a document contains a valid qualified electronic signature, the court must presume that the person who signed the signature certificate created the signature and signed that very document. If someone claims otherwise, they must prove their claim (as is the case, for example, with private documents that have full probative value and are signed in front of a notary or two witnesses).

Enhanced electronic signatures do not carry the legal effect mentioned above. If a document is signed with only an enhanced (now qualified) signature, it is in written form, but there is limited information on the reliability of the signature's authenticity. It is unclear if the Certificate Service Provider (CSP) has met the certificate's subject in person, as the certificate may have been obtained through mail or online.

According to the EU e-Signature Directive, qualified electronic signatures are considered equivalent to handwritten signatures in all Member States. This means that what constitutes a qualified signature in one Member State will also be recognized as qualified in other Member States.

[5] *Eat. 4. § „(2) Ha az elektronikusan aláírt elektronikus dokumentumon minősített elektronikus aláírás szerepel és az aláírás ellenőrzésének eredményéből más nem következik, vélelmezni kell, hogy a dokumentum tartalma az aláírás óta nem változott.[ ... ] (5) Amennyiben az aláírás-létrehozó adatot olyan szolgáltató helyezte el az aláíráslétrehozó eszközön, amely az adat elhelyezésekor e szolgáltatás tekintetében a szolgáltatók nyilvántartásában minősítettként szerepelt, az ellenkező bizonyításig vélelmezni kell, hogy az aláírás-létrehozó adat kizárólag a szolgáltatást igénybe vevő birtokában van. ”*

However, the specific requirements for qualified signatures can differ significantly between Member States, making the process more complex. For example, some Member States may have additional requirements for qualified electronic signatures, such as the use of a qualified signature-creation application, in addition to the use of qualified certification authorities and secure signing devices.

#### 4.3.3.6 SIGNATURE CONTAINER

The signature container, which adheres to a specified structure, serves to encapsulate one or more signature blocks and may also contain the signed document(s) themselves. Through knowledge of the signature container format, a signature-verification application can locate the signature blocks and potentially discern the precise scope of the signatures. This may be achieved by examining the signature block itself, for instance, an XAdES signature may reference the location of the signed content using a URI. In some cases, the format may not support this, and as a result, the container must be interpreted such that the signature applies to everything except the signature block. Notably, some PDF signatures require such an interpretation.

If the signature container itself is a document format, such as PDF or Microsoft Word, then the container dictates how the signed content should be presented. If different documents can be inserted into the container, as in the case of an e-file, the MIME type of the signed content often dictates the manner of presentation through the signature blocks.

Multiple documents can be stored in the container, and multiple signatures can be placed on each document. Signatures can be related to each other in various ways. Parallel signatures, for instance, are independent of one another, allowing for the removal of any signature without adversely affecting the remaining signatures.

Examples of specific signature containers

- Hungary

  The term "e-akta," an electronic case file, denotes a specific file format designed by Microsec Kft. for the Ministry of Justice and Public Administration to be used in electronic corporate procedures. This format includes documents, electronic signatures, and timestamps. The signatures

present on the documents conform to the ETSI specification for XAdES signatures, thus providing a standardized approach

The e-akta (*Az e-akta formátum specifikációja*, 2015)format has gained the status of a de facto standard in Hungary, with numerous user communities and applications being able to manage electronically signed documents in this format.

Indonesia

- KOMINFO (the Ministry of Communication and Information Technology) of the Republic of Indonesia has implemented a digital signature scheme to provide a secure and efficient way to sign electronic documents and transactions.(Afrianto et al., 2020)

Having established both the technical capabilities and the legal frameworks governing digital signatures, the critical question becomes: how do end-users, particularly SMEs, perceive, accept, and integrate these solutions into their workflows? The following section examines the usability and user acceptance literature that addresses this customer-centric perspective.

### 4.3.4 CONCEPT CODE: UA

| RQ 1.3<br>WHAT IS THE SCIENTIFIC UNDERSTANDING OF USABILITY AND USER ACCEPTANCE ASPECT OF DIGITAL SIGNATURE? |
|---|

The User-Centered Design (UCD) philosophy prioritizes the user's needs and preferences in the development process of a system. This approach is facilitated by a range of techniques, methods, tools, procedures, and processes that support creating interactive systems focused on the user.(Cavus & Sancar, 2023)

The impact of digital transformation is being felt globally across all industries. Research has shown that modern technologies have made human life more efficient, fast, and secure compared to traditional tools and methods. In today's information-driven society, organizations strive to increase competitiveness and move quickly.

(Paol, 2017) As a result, there is a need for urgent approvals from authorized personnel to facilitate transactions. To this end, approval processes such as the signature process need to be digitized. The use of digital signatures offers benefits to users such as increased transaction speed, improved security, (Ricky, 2020)and reduced costs. Various free and commercial digital signature software options like DocuSign, PandaDoc, and SignEasy have been developed to enable users to create, manage, and sign documents online from anywhere and on any device. However, users must understand the importance and benefits of using digital signature software before adopting and utilizing them. As such, it is crucial to determine users' awareness of e-signatures.(Sancar & Cavus, 2021)

There are some papers investigate selected factors affecting the intention to adopt the next generation of cloud computing, (including digital signature) mainly focusing on the Technology Acceptance Model (TAM)

In their research on the acceptance of cloud computing, (Lynn et al., 2018) utilized the TOE framework and identified the positive impact of technical, organizational, and environmental characteristics. (Mohammed et al., 2016) also employed the TOE framework, along with the work skill fit theory and skill readiness variables, and found that uncertainty was a crucial variable, suggesting the integration of multiple theories in future research. (Park & Kim, 2014) utilized the TAM model to examine the factors affecting the acceptance of mobile cloud services and determined that perceived mobility, usability, connectivity, security, and service and system quality were significant variables. Similarly, (Pańkowska et al., 2020) used the TAM model to investigate the adoption of sustainable cloud computing solutions and discovered that perceived availability and security influenced perceived usability and system service quality, which in turn impacted attitudes and usage. In their study, (Oliveira et al., 2014)confirmed that technology readiness and top management support positively affected acceptance, while complexity had a negative effect, using the theory of diffusion of innovation and the TOE model. Finally, (Gangwar et al., 2015) integrated the TAM and TOE models and determined that relative advantage, fitness, organizational competence, education and training, and top management support were significant predictors of perceived ease and usefulness, while competitor pressure and partner support influenced acceptance intention positively.

Cloud-based digital signature technology and services utilize cloud storage for authentication keys to prevent theft, leakage, and the need for renewal or portability. This technology utilizes biometric authentication to verify and authenticate transaction activities. While cloud-based digital signature services have gained popularity worldwide since their introduction in the United States in 2017, there is still a lack of research on their adoption in business administration. To address this gap,(Quinting et al., 2017) developed a theoretical model for the adoption of sustainable cloud digital signature services based on the TOE model and the theory of diffusion of innovation. Additionally, (Chong et al., 2021)conducted an empirical study on factors influencing the intention to accept cloud digital signature services using the TAM.

In the next chapter, I will explore the purposes of digital signature implementation through concrete examples. This section will highlight the practical applications of digital signatures across various industries, demonstrating how they enhance security, streamline workflows, and ensure legal compliance. By analyzing real-world use cases, I will illustrate the key motivations behind adopting digital signatures, such as efficiency gains, fraud prevention, and regulatory adherence. These examples will provide a clearer understanding of how businesses and organizations integrate digital signatures into their processes and the benefits they derive from this technology.

#### 4.3.4.1 PROCUREMENT

The adoption and utilization of e-procurement pose significant challenges. These challenges stem from various factors, including technical issues, as well as broader concerns such as dissatisfaction with e-procurement systems that fail to meet the needs of users, resulting in the adoption of multiple workarounds (Roman & Mccue, 2012**)**; Inadequate user-friendliness of e-procurement (Krogstie, 2008); Complex systems (Engstrom et al., 2009); Difficulty in recruiting a sufficient number of suppliers in a timely manner to encourage the use of information systems; The use of technology that conflicts with established cultural norms regarding IT use, bureaucratic processes, and business practices (Williams & Hardy, 2005).

According to Costa, Arantes, and Tavarez (Aguiar Costa et al., 2013), the use of digital signatures for e-procurement is both complicated and expensive, despite being mandatory. Conversely, Ojha and Pandey (Ojha & Pandey, 2014) discovered that digital signatures can be overly secure, resulting in the exclusion of some suppliers.

However, it should be noted that the adoption of digital or electronic signatures may conflict with the values, beliefs, and customs of stakeholders who associate manuscript signatures (Srivastava, 2011) with authenticity.

**Tax purpose**

There are two distinct trends concerning the use of electronic communication for tax purposes that should be distinguished. Firstly, electronic communication is increasingly being used and is often the only acceptable form of communication. The COVID-19 pandemic has accelerated the transition to digital tools, except when the use of electronic communication was already mandatory as required by the law. Secondly, the prevalence of cyber threats is on the rise, which is contrary to the trend.

The prioritization of communication security hinders rapid technological development, particularly when it comes to simple identity verification solutions. The existing system of electronic signatures in tax matters is inconsistent with regulations concerning electronic signatures outside of tax administration.

The year 2021 was significant for the computerization of the tax administration in Poland as its end will mark the disabling of the "e-Deklaracje Deskop" (e-Tax Declarations Deskop) application, i.e., software installed on personal computers that allows individuals to submit electronic forms without the need to have a qualified electronic signature. The Polish system allows for various solutions such as qualified electronic signature, trusted signature, personal signature, and possibly a simple identity verification mechanism that uses an account in an ICT system secured solely by a password. Although the variety of options may be cause for concern, it is justified by the goal of achieving the widest and fastest possible communication.(Goździaszek, 2021)

#### 4.3.4.2 VOTING

The selection of representatives for a country or organization is accomplished through the process of voting. However, there may be voters who do not participate in elections due to personal or public reasons. One potential solution to this issue is Internet voting (I-voting), which allows individuals to vote from any location and at any time. While I-voting offers several advantages, there are also some drawbacks to consider. Many I-voting systems have been proposed, with Helios being a popular open-source option.

paper from (Abid & Faraj Al-Janabi, 2021) introduces Helios++, an enhanced I-voting system that builds upon Helios and utilizes public-key certificates. The system incorporates improvements such as the addition of a certification authority (CA) that generates voter certificates containing public and private keys for encryption and digital signature generation. The voting process allows for the use of either RSA or DSA algorithms for signing votes. Each voter is provided with one authentic account and additional fake accounts to use in case of coercion.

#### 4.3.4.3 CONSENTS

The paper of (Siqueira et al., 2022) discusses the exploration of innovative approaches to enhance medical education amidst the COVID-19 pandemic, taking into account the evidence on competency-based curricula and the advantages of volunteerism. The research delves into the perspectives and driving factors behind the development of leadership and management proficiencies among medical students participating in the COVID-19 Volunteering Program at a medical school in Brazil.

Upon completion of the program, students who participated in management-related tasks were given the opportunity to partake in focus group discussions aimed at gathering their insights on volunteering in this domain. The data obtained underwent both descriptive and content analyses. All 286 individuals involved in the study provided electronic signatures indicating their informed consent.

#### 4.3.4.4 HEALTH INDUSTRY

The medical industry faces significant challenges with respect to safeguarding medical data security and privacy, which pose significant hurdles to its growth and proliferation. To ensure the authenticity and availability of medical data, digital signatures are essential tools (He et al., 2018; Xu et al., 2020). However, not all applications require access to the complete electronic medical record. For instance, during medical reimbursements, patients only need to furnish the insurance company with authentic treatment and insurance number details, and divulging other non-essential personal information must be avoided.

To protect patients' privacy, a potential solution is to limit the scope of signed information solely to medical claims (Jin et al., 2019). Nevertheless, every time a new subset of the electronic medical record is shared, signers must repeat the signing

process, incurring high computational costs and potential difficulties in the event of a signer's departure. Sanitizable signatures (Ateniese et al., 2005), which enable controlled modification of signed messages, provide an optimal solution by ensuring the integrity and authenticity of medical data while efficiently concealing sensitive patient information (based on specific sharing targets). This not only adheres to the HIPAA privacy rules' "minimum necessary" disclosure norm (Lucido et al., 2003) but also promotes the use of value-added medical information, leading to enhanced scheme efficiency. Hence, in smart medical scenarios, sanitizable signatures are well-suited to address data security and privacy protection concerns.

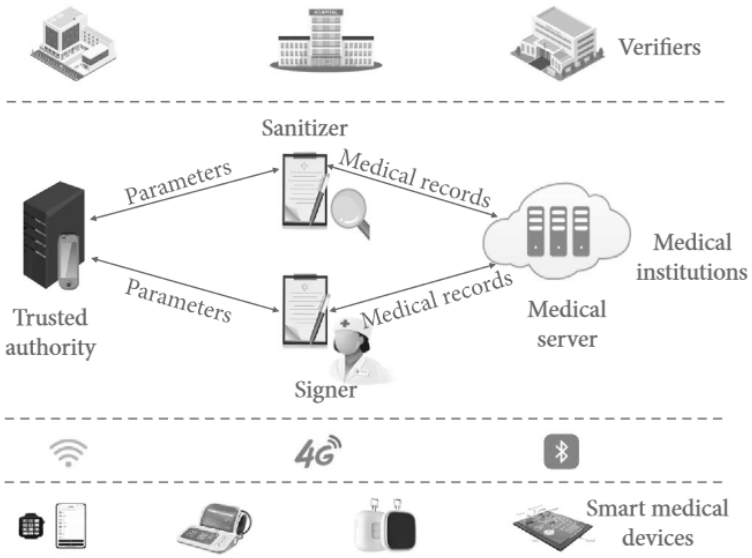



*Figure 11 The architecture of smart mobile medical scenarios (Xu et al., 2020)*

#### 4.3.4.5 INTERNET OF THINGS (IOT)

A complex network chain connects different physical objects through the Internet of Things (IoT), which is commonly used in various fields such as smart home appliances, elder care, medical healthcare, transportation, vehicle-to-everything communication, home automation, and industrial applications. Nevertheless, due to the extensive connection of multiple devices with different communication protocols, IoT is also susceptible to significant security threats. The primary security challenges that IoT faces include issues with privacy, hardware, data encryption, web interfaces, limited network awareness, insecure software, side-channel attacks, and rogue IoT devices. (Dawood, 2020; Gama et al., 2012; Yousefnezhad et al., 2020)

The research of (Fathima et al., 2022) employs a method of exchanging information between communicating nodes in the environment through a challenge and response approach. Additionally, the model integrates both backward and forward secrecy in the development of a lightweight encryption process.

Figure 12 showcases a top-down architecture of the proposed authentication mechanism, where digital signatures and key management are crucial components.

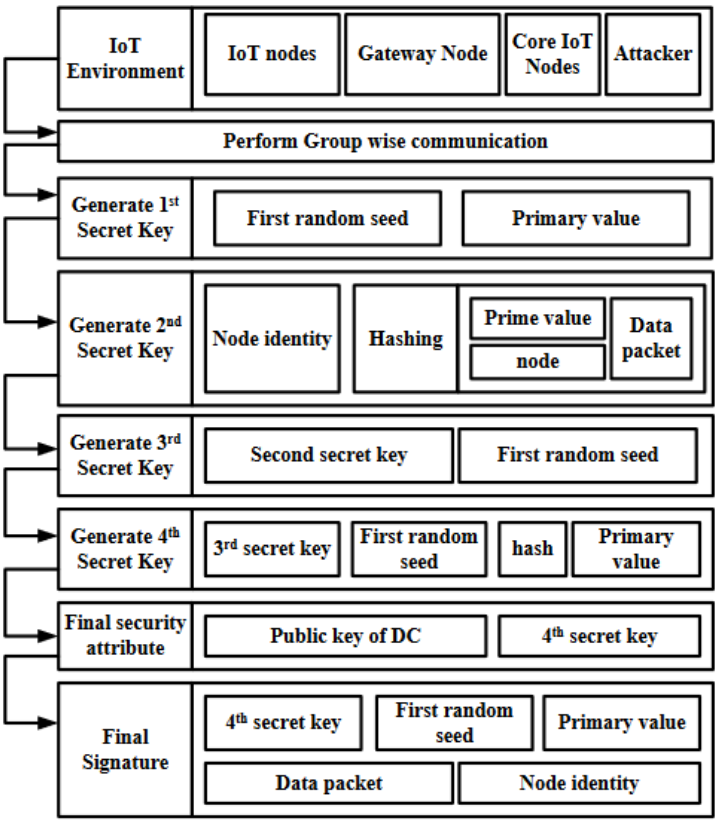



*Figure 12 Proposed architecture of data security and authentication*

#### 4.3.4.6 POSSIBLE OBSTACLES TO USER ACCEPTANCE OF ELECTRONIC SIGNATURES CAN BE IDENTIFIED AS RESISTANCE FACTORS.

'Fear always springs from ignorance' [13]. (Srivastava, 2011) made research with 27 companies (Legal = 13; IT = 7; SM = 7). The research shows that the adoption of new technology can be met with apprehension and concern over potential problems and risks. Such is the case with electronic signatures, as there exists a level of resistance to their implementation.

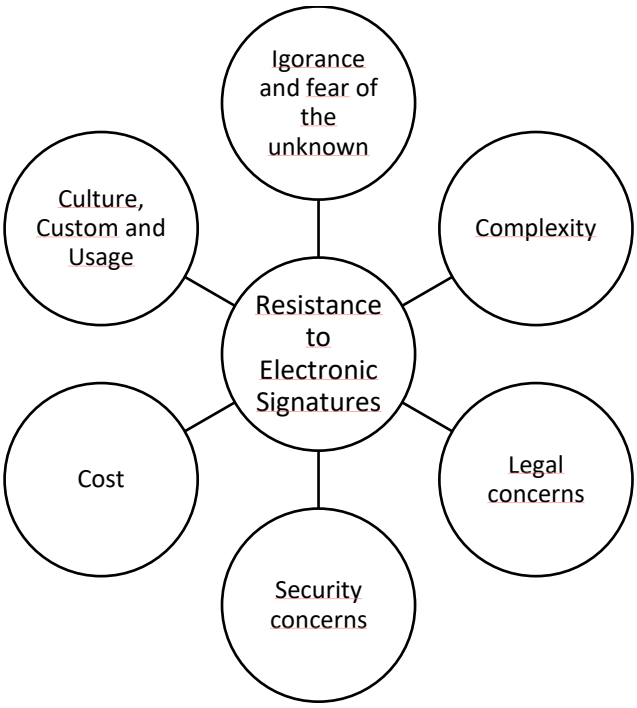



*Figure 13 Resistance to electronic signatures (Srivastava, 2011)*

A significant contributor to this resistance is the lack of awareness and knowledge within the business community about electronic signatures. This lack of understanding is evident in the views expressed by participants, indicating that the rejection of this technology is, to a large extent, a result of a lack of familiarity with its potential benefits and functionality. To overcome this resistance, education and awareness programs may be necessary to increase the knowledge and understanding of electronic signatures, their applications, and their benefits within the business community.

#### 4.3.4.7 DIGITAL TRANSFORMATION CONTEXT IN HUNGARIAN SMES

While international research provides valuable theoretical frameworks for understanding technology acceptance, the Hungarian SME context presents distinct

characteristics that shape digital signature adoption patterns. Research on Hungarian SMEs' digital transformation reveals several contextual factors relevant to this study.

**Digital Maturity and Organizational Readiness:** Hungarian research on digitalization has traditionally focused on macro or company levels, with relationship-focused approaches representing a novel area in Hungarian Industry 4.0 research (Gubán & Sándor, 2021; Mandják et al., 2022) developed a digital maturity lifecycle model specifically for SMEs, highlighting that smaller enterprises often lack the organizational structures and resources that facilitate technology adoption in larger firms.

**External Disruption and Adaptation:** Research on Hungarian SMEs during the COVID-1 9 pandemic revealed that while these enterprises demonstrated adaptability by intensifying online communication channels, Hungarian SMEs lagged behind regional counterparts in exploring opportunities to improve value propositions through digitalization (Marolt et al., 2024). This pattern suggests reactive rather than proactive technology adoption—a dynamic particularly relevant to digital signature implementation.

**Human Factors and Self-Efficacy**: According to Nyírő (Nyírő, 2011), an individual's belief about their ability to use new technology significantly impacts perceived ease of use. Users confident in digital tools are more likely to find technology accessible, increasing acceptance likelihood. This self-efficacy dimension is particularly salient in Hungarian SMEs, where digital competency gaps persist: only 4 9% of the population possesses at least basic digital skills (Obermayer et al., 2023).

**Sectoral Differences**: Business enterprises typically exhibit higher information security awareness maturity than nonprofit organizations (Tarján, 2020), allocating greater resources to security measures. This sectoral variation extends to SMEs, where service-oriented companies may prioritize digital solutions differently than industrial or commercial enterprises due to varying workflow characteristics and customer interaction patterns.

**Cognitive Automation and Process Integration:** Research on digital transformation in Hungarian business service centers (Marciniak et al., 2020) demonstrates that successful technology adoption requires not only technical implementation but also cognitive shifts in how processes are conceptualized and executed. For SMEs

considering digital signatures, this implies that usability extends beyond interface design to encompass workflow integration and process redesign.

These Hungarian-specific findings underscore that technology acceptance models developed in Western contexts must be interpreted through the lens of local digital maturity levels, organizational cultures, and workforce competencies. The present research addresses this gap by examining digital signature adoption specifically within the Hungarian SME ecosystem, integrating international theoretical frameworks with domestic contextual realities.

## 4.4 TEXT MINING

Widening the understanding of the current maturity of digital signatures as an expert career, PhD candidate, and Director of Business Development, my objective is to conduct a customer-centric exploratory research study on the research gap identified by the literature review. I intend to identify the factors that facilitate the widespread global adoption of digital signature technology considered to be part of maturity defined in my research question:

| RQ1. |
| --- |
| WHAT ARE THE KEY FACTORS INFLUENCING DIGITAL SIGNATURE ADOPTION IN SMES ACCORDING TO EXISTING INTERNATIONAL RESEARCH? |

In a customer-centric PhD thesis research, data analytics on a wide range of publications can provide valuable insights into the customer's understanding of the current state of digital signature.

Electronic signatures have become an increasingly popular topic of research, with numerous scholarly articles examining the impact and adoption of this technology. In the following chapters I describe an exploratory text mining research conducted on 1,469 abstract of articles related to electronic signatures from Scopus.

My research methodology involved a comprehensive search for relevant publications in electronic databases, followed by a thorough analysis of their metadata. Using tools

such as Excel, VOSviewer, and Voyant, I performed a range of statistical analyses and data visualizations to identify patterns and trends within the sample.

### 4.4.1 SEARCH CRITERIA

TITLE-ABS-KEY ( "electronic signature" ) OR TITLE-ABS-KEY ( "digital signature" ) AND ( LIMIT-TO ( OA , "all" ) ) AND ( LIMIT-TO ( SUBJAREA , "COMP" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) OR LIMIT-TO ( SUBJAREA , "MATH" ) OR LIMIT-TO ( SUBJAREA , "MATE" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "DECI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR EXCLUDE ( SUBJAREA , "CHEM" ) OR EXCLUDE ( SUBJAREA , "CENG" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) )

1,469 document results

I filtered only on open access publications so I can use any relevant one during my systematic literature review phase as well, not just for text mining.

The decision to limit the search to open access publications represents a methodological constraint that may introduce selection bias. This filter was applied to ensure full accessibility of sources for both the systematic literature review and text mining phases. However, this approach potentially excludes high-quality research published in subscription-based journals, which could limit the comprehensiveness of the literature coverage.

**Sample Size Considerations:** The corpus of 1,469 documents provides adequate statistical power for identifying major research trends and thematic patterns. For proportional analyses (e.g., distribution by subject area), this sample size yields margins of error ranging from ±1.6% to ±2.6% at the 9 5% confidence level, depending on the proportion being estimated. This precision level is appropriate for exploratory text-mining research aimed at pattern discovery rather than precise parameter estimation.

The open access limitation may particularly affect:

- Temporal bias: Older seminal works may be underrepresented, as open access publishing has gained prominence primarily in recent years

- Geographic bias: Research from regions with different open access policies may be disproportionately represented
- Quality considerations: While open access does not inherently indicate lower quality, some prestigious journals with rigorous peer review processes remain subscription-based

Despite this limitation, the open access approach yielded 1,469 relevant documents, providing substantial coverage across multiple subject areas. The large sample size and diverse disciplinary representation suggest that the core findings regarding digital signature research trends remain robust; however, this result should be interpreted with awareness of this methodological boundary.

### 4.4.2 DOCUMENTS BY SUBJECT AREA

This research contributes to a deeper understanding of the subject area and its implications for the role of digital signatures. It facilitates the development of new ideas, theories, and concepts within the field.

The findings of this study reveal a notable increase in the number of publications on electronic signatures, particularly since 2018. This trend reflects the widespread adoption of the technology across various disciplines, including Computer Science, Mathematics, Physics, Business, Management, and Medicine.

Further analysis identified Computer Science (44.8%) and Mathematics (21.8%) as the primary areas of focus for research on electronic signatures. Given the corpus size of 1,469 documents, these proportions demonstrate substantial representation (n=658 and n=320 respectively), providing robust evidence of disciplinary focus. With this sample size, the margin of error for the Computer Science proportion is approximately ±2.5% at the 9 5% confidence level, indicating high precision in domain classification. This prominence is attributed to the integration of cryptographic elements and the emergence of innovative technologies driving research in these fields. Nevertheless, the application of digital signatures has also expanded into other domains, such as Physics, Business, Management, and Medicine, underscoring their versatile utility.

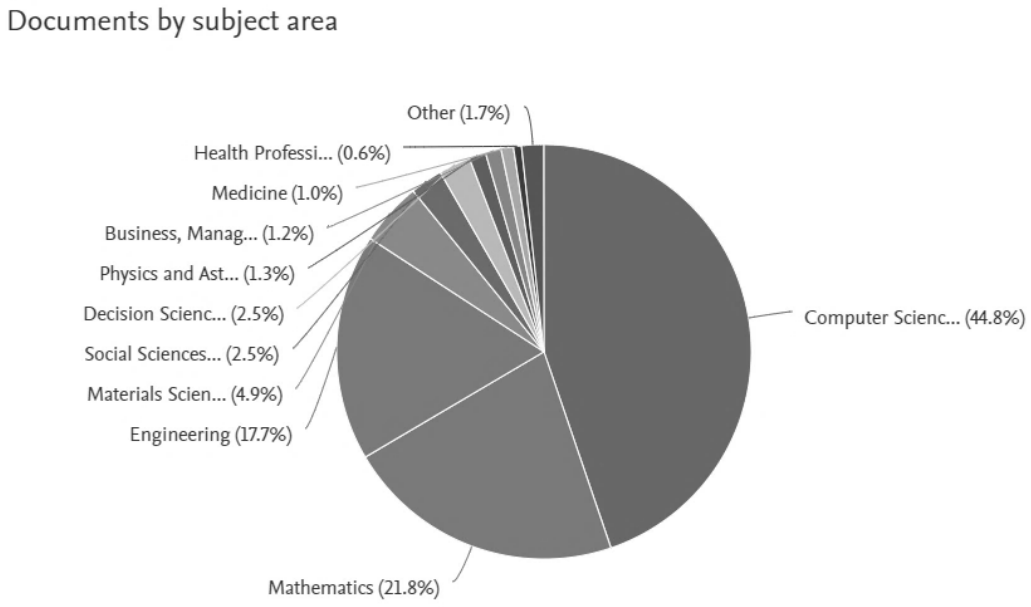



*Figure 14 Documents by subject area*

### 4.4.3 DATA NETWORK VISUALIZATION

This research offers valuable insights into the network structure of data within documents, enabling the identification of patterns and relationships. These insights can be leveraged to optimize data analytics processes and enhance the accuracy of results during the identification of relevant papers for a Systematic Literature Review.

The application of this visualization technique exhibits significant potential across diverse domains, including authentication, medical record-keeping, patient management, and contract management.

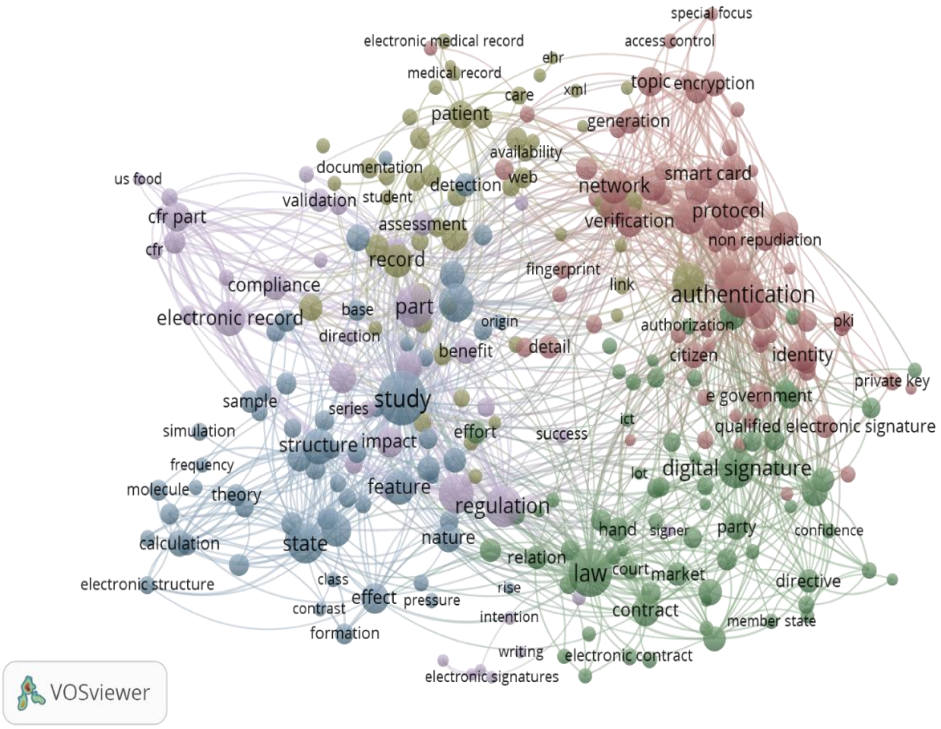



*Figure 15 Network visualization of data*

### 4.4.4 DISTRIBUTION OF PRODUCED PAPERS

An analysis of the countries and territories reveals that the majority of documents are produced in the United States. However, China, Europe, Australia, and the United Kingdom are also well-represented, highlighting the growing significance of this topic across a wide range of countries.

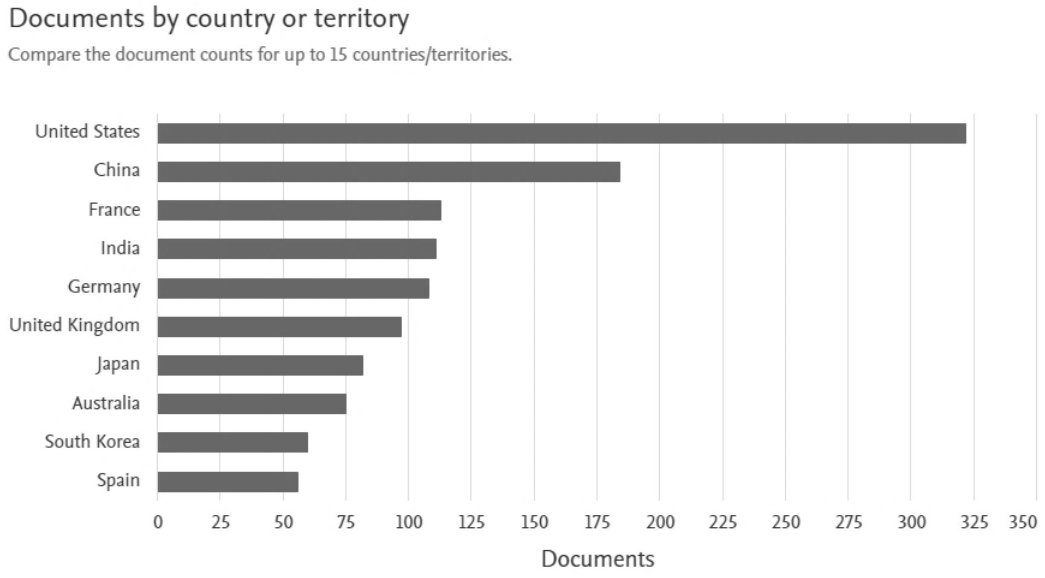



*Figure 16 Documents by country or territory*

### 4.4.5 DENSITY OF TEXT

This research can analyze the density of text in documents related to digital signature. As a customer-centric research approach this also can help in understanding the level of complexity of the content and identifying areas where improvements can be made to make the content more accessible to users.

Examining the text density organized into 6 distinct clusters, it is observed that certain topics such as "Signature scheme," "Technology," "Blockchain," "Service," "Contract," and "Public key" are effectively emphasized, providing a strong foundation of understanding for the technology.

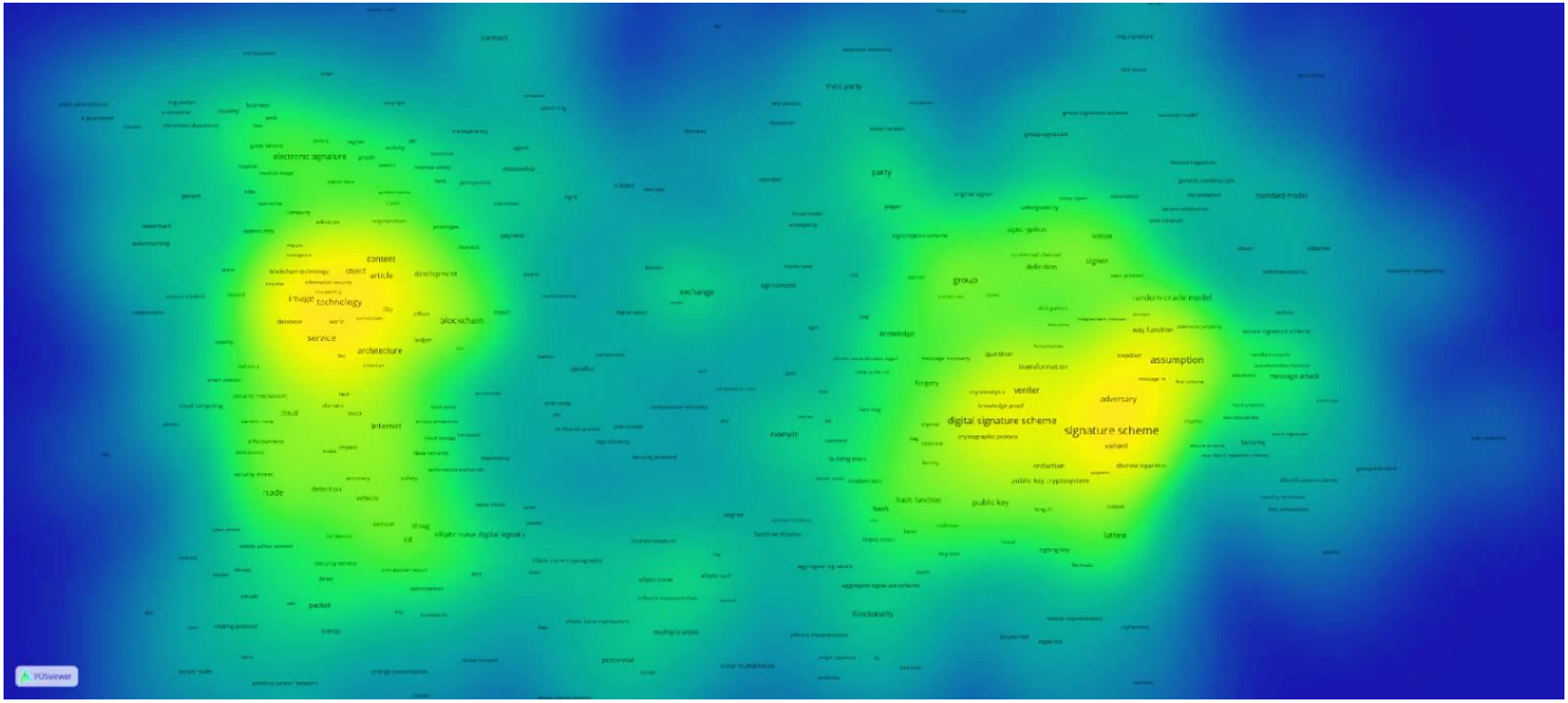



*Figure 17 Density of paper text*

### 4.4.6 BIBLIOGRAPHIC DATA VISUALIZATION

Visualization of bibliographic data provides valuable insights into the sources and references utilized in documents related to digital signatures within data analytics. This process aids in identifying the most influential sources in the field and facilitates a deeper understanding of the current state of research.

Research on bibliographic data visualization highlights that the concept of electronic signatures is not a recent innovation but has been well-documented for decades. Anyone can verify an electronic signature using its corresponding publicly revealed encryption key. Such signatures cannot be forged, and the signer cannot deny the validity of their signature, making them highly applicable in systems such as electronic mail and electronic funds transfer (Rivest et al., 1978).

The enduring significance of Rivest, Shamir, and Adleman's 1978 publication lies in its focus on RSA, one of the foundational components of Public Key Infrastructure (PKI). RSA, a public-key cryptosystem, is widely used for secure data transmission and was invented in 1977, taking its name from the surnames of its inventors.

The RSA cryptosystem remains widely utilized even today, as emphasized in the literature review. However, the transition to more modern algorithms, such as Elliptic Curve cryptography (ECC) or post-quantum cryptographic solutions, represents the current focus of Public Key Infrastructure (PKI) solution providers.

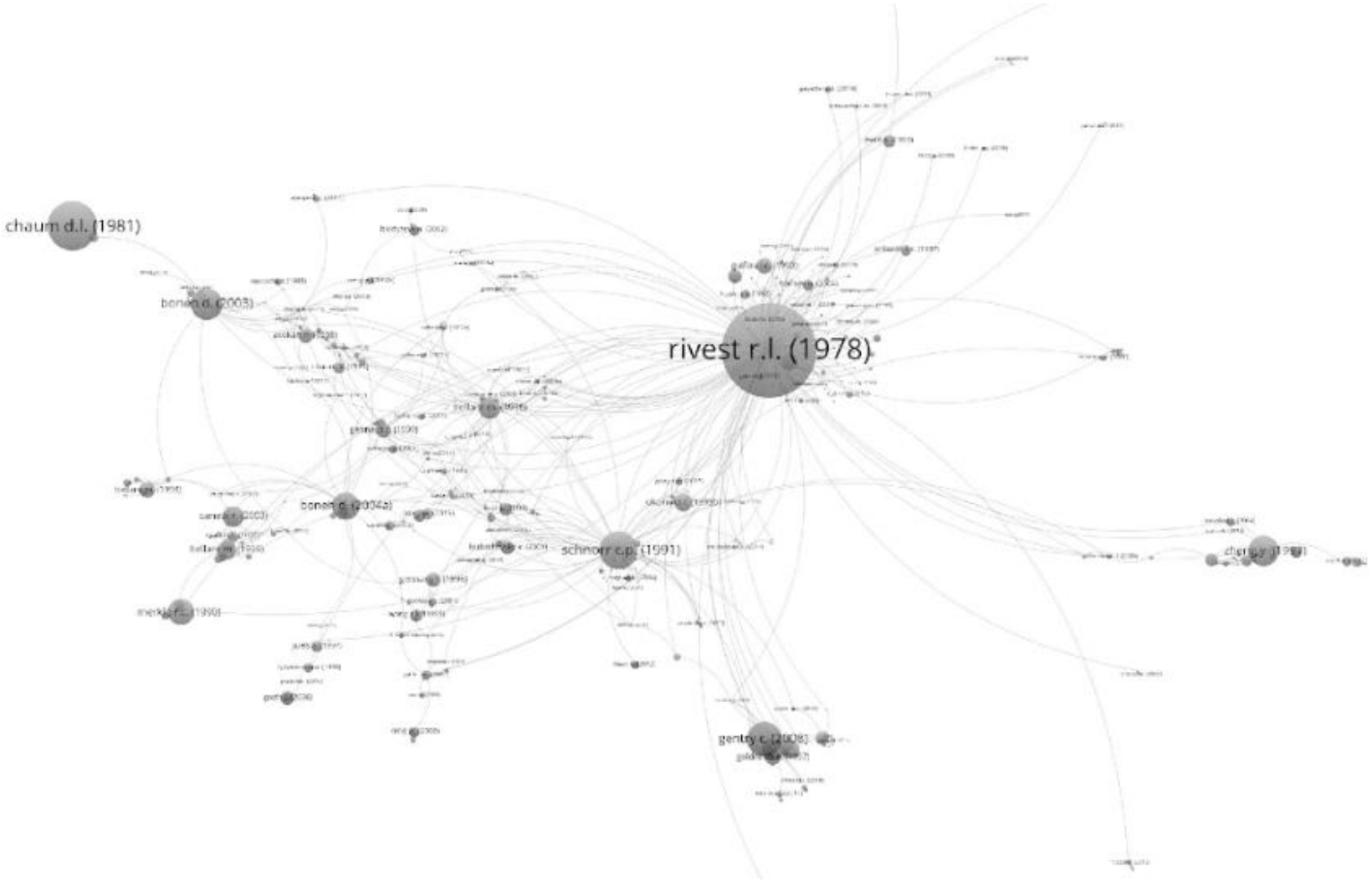



*Figure 18 Data visualization of citation*

### 4.4.7 VOYANT TERMS ANALYTICS

Terms analytics research leverages text analytics to identify the most frequently used terms in documents related to digital signatures in data analytics. This approach aids in pinpointing key concepts and themes in the field while enhancing the understanding of the language and terminology commonly employed. Adopting a customer-centric research perspective, I explored the common understanding of digital signatures, aiming to distill the essence of this technology into the simplest possible summary. Using Voyant, I analyzed the content of approximately 1,500 publications, adjusting the terms, context, and scaling settings to their minimum to uncover the most common match. The result distilled this understanding into three words.

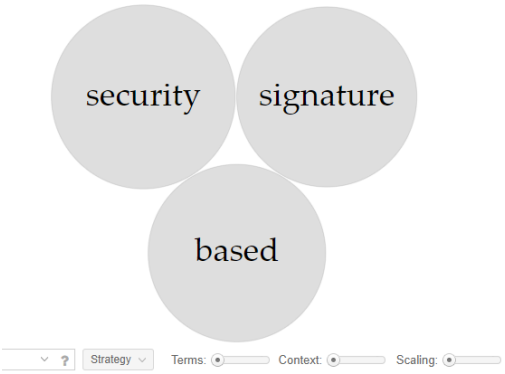



*Figure 19 Prevailing comprehension of digital signature*

The terms "security," "signature," and "based" feature prominently in numerous publications pertaining to digital signatures. Analyzing 1,469 document abstracts, these three terms appeared with high frequency across the corpus, suggesting strong thematic consistency in how the research community conceptualizes digital signatures.

While precise term frequency statistics would require access to the complete Voyant output data, the consistent co-occurrence of these terms across such a large and diverse corpus (spanning 44.8% Computer Science, 21.8% Mathematics, and multiple other disciplines) provides qualitative confidence in the pattern's validity. The exploratory nature of this text-mining analysis prioritizes pattern discovery over statistical hypothesis testing.

As I am making customer-centric exploratory research from a perspective of usability and user acceptance I have formed two phrases that can be used as the common understanding of electronic signature, supported by the corpus-wide term analysis:

These are following:

- **“Security-based signature” or**
- **“Signature-based security”**

**Methodological Note:** This text-mining analysis serves an exploratory, hypothesis-generating function rather than confirmatory statistical testing. The large corpus size (N=1,469) and disciplinary diversity strengthen confidence in observed patterns, though this result should be interpreted as indicative trends rather than statistically validated frequencies.

## 4.5 SUMMARY OF LITERATURE REVIEW

This chapter addressed the following research question through systematic literature review and exploratory text mining:

| RQ1<br>WHAT ARE THE KEY FACTORS INFLUENCING DIGITAL SIGNATURE ADOPTION IN SMES ACCORDING TO EXISTING INTERNATIONAL RESEARCH? |
|---|

The systematic literature review demonstrates that as organizations shift from paper-based to electronic documentation, digital signature technology provides the authentication mechanism necessary to ensure document legitimacy, integrity, and non-repudiation. The review is organized into three interconnected aspects: technology, regulation, and usability.

**Technological Aspect**: The review examined fundamental concepts including public-key infrastructure (PKI), trust service providers, cryptographic algorithms (RSA, ECC, post-quantum cryptography), hashing mechanisms, and timestamping protocols. These technical components collectively ensure secure and efficient electronic transactions. Digital signature technology has achieved maturity and is widely implemented globally with standardized protocols.

**Regulatory Aspect**: The legal frameworks governing digital signatures vary significantly by jurisdiction. The review analyzed regulations across multiple regions, with particular attention to the EU eIDAS Regulation (establishing tiered signature levels: simple, advanced, and qualified), U.S. frameworks (UETA and ESIGN), and Hungarian legislation (Act XXXV of 2001, which recognizes advanced and qualified signatures). Understanding these regulatory differences is crucial for promoting trust in digital transactions, ensuring compliance, and facilitating cross-border operations.

**Usability and User Acceptance Aspect**: Given the customer-centric focus of this PhD thesis, the review extensively explored usability factors and adoption barriers across diverse implementation contexts including procurement, e-voting, education, healthcare, and Internet of Things (IoT) applications. The literature identified multiple

resistance factors: perceived complexity, partner network effects, organizational inertia, and knowledge gaps—despite the technology's technical maturity. The review also examined signature container standards and technical specifications.

**Research Gap Identified**: While digital signature technology is mature and regulatory frameworks are well-established, a significant research gap exists regarding customer-centric usability and user acceptance factors, particularly in small and medium-sized enterprise (SME) contexts. Existing studies predominantly focus on technical implementation or legal compliance, leaving adoption enablers and segment-specific requirements under-researched. The literature shows wide-ranging potential applications across industries globally, yet adoption remains heterogeneous due to perceived complexity and contextual factors.

**Text Mining Contribution**: The exploratory text mining analysis of 1,469 Scopus-indexed publications (detailed in section in 4.4.7) revealed consistent thematic patterns in how the research community conceptualizes digital signatures. The corpus-wide term analysis identified "security," "signature," and "based" as the most prevalent terms across abstracts spanning multiple disciplines (44.8% Computer Science, 21.8% Mathematics, and others). This analysis yielded two complementary customer-centric definitions:

- **"Security-based signature"**: Emphasizes digital signatures as mechanisms ensuring document integrity and authentication.
- **"Signature-based security"**: Positions digital signatures as fundamental components within broader cybersecurity frameworks.

These dual perspectives reflect the bidirectional relationship between signatures and security in scholarly discourse, informing a customer-centric understanding of the technology that emerged from data-driven analysis rather than predetermined theoretical constructs.

# 5 QUANTITATIVE RESEARCH

Based on the above, it can be stated that the adoption of digital signature technologies may be influenced by multiple factors. The aim of this study is to further investigate this topic and identify which of these potential influencing factors play a role in the case of Hungarian SMEs.[6] This understanding will be achieved by answering the following exploratory research questions:

| |
|---|
| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES? |

To gather empirical data, a phone-assisted survey methodology has been implemented. This method facilitates direct interaction with respondents, allowing for a structured yet flexible means of collecting detailed information. It also ensures higher engagement and response rates compared to other survey formats, which is particularly valuable when addressing diverse SME segments.

The central research questions guiding this phase of the study are twofold.

This inquiry will help delineate the preferences, challenges, and expectations of users, ensuring that digital signature solutions are aligned with the practical needs of these enterprises.

[6] *Portions of this chapter have been written with Attila Loibl and accepted for publication in Vezetéstudomány*

Through this customer-centric and methodologically rigorous approach, my research aims to provide actionable insights into the adoption and optimization of digital signature technologies within the Hungarian SME landscape

## 5.1 TARGET GROUP OF THE QUESTIONNAIRE

I have designed the questionnaire based on the suggestions of Ellen Taylor-Powell (Ellen, 1998).

- Use simple wording-
- Avoid the use of abbreviations, jargon, or foreign phrases.
- Be specific.
- Use clear wording.
- Include all necessary information.
- Avoid questions that may be too precise.
- Phrase personal or potentially incriminating questions in less objectionable ways.
- Avoid questions that are too demanding and time-consuming.
- Use mutually exclusive categories.
- Avoid making assumptions.
- Avoid bias in questions.

The research target group presented in this study consisted of small and medium-sized enterprises (SMEs) in Hungary, specifically businesses employing 5 to 249 people. The research was conducted in the second half of 2023, during which 200 Hungarian SME leaders completed the designated questionnaire through an assisted telephone questionnaire.

The questionnaire used in the research ultimately comprised 41 questions, and data collection was conducted via telephone interviews. The choice of telephone-based data collection was primarily motivated by the length of the questionnaire, which could have significantly reduced participants' willingness to respond. Telephone interviews allowed direct interaction with respondents, enabling quick and accurate answers to questions while also contributing to a higher response rate. Additionally, this method enhanced the reliability and representativeness of the research, as it allowed for immediate clarification and explanation of questions for respondents. This

approach was particularly important for questions related to digital signatures, where familiarity with the technology and its application varied across enterprises(Check & Schutt, 2011; Kmetty, 2012).

The analysis of the results was conducted using data visualization, Pearson's chi-square test, and logistic regression methods.

## 5.2 STRUCTURE OF THE QUESTIONNAIRE

The questionnaire was divided into four main sections to facilitate the response process.

The purpose of the first section was to map the basic characteristics of the enterprises. The questions in this section aimed to determine the size of the enterprises, the number of employees, revenue, industry classification, and general characteristics of their production processes. This section supported the collection of essential data regarding the structure and activities of the enterprises. Additionally, it included a question about the use of digital signatures, providing insights into whether the enterprise utilized electronic signatures in its daily operations. The first section comprised a total of 10 closed-ended questions focusing on demographic and operational data about the enterprises. Moreover, it featured a 1–5 Likert-scale question designed to measure the perceived importance of digital signature usage. At the end of this section, an open-ended question allowed respondents to provide more detailed information about the current circumstances of digital signature usage or any other factors influencing its adoption.

The second section was explicitly designed for respondents who use digital signatures, aiming to gather detailed information about the circumstances, benefits, and specific methods of implementing this technology. This section included 14 closed-ended questions focusing on the frequency and types of use, the digital signature services employed, and the technical solutions adopted. Additionally, 1 1–5 Likert-scale questions were included to assess the efficiency of digital signatures and the benefits they provide to enterprises. Respondents were also allowed to elaborate on any other aspects of their experiences with digital signature usage through 3 open-ended questions. This allowed for insights into financial and operational impacts, among other factors. The primary goal of this section was to understand how digital signatures

integrate into the daily operations of enterprises and how they support document management processes. Given that the application of digital signatures often overlaps with other digital tools and solutions used by enterprises, this section provided critical insights into the broader context of their technological adoption.

The third section targeted enterprises that do not use digital signatures, focusing on identifying the factors influencing their lack of adoption. This section consisted of 5 closed-ended questions and an open-ended question examining technological barriers, financial costs, lack of knowledge and information, and resistance among management or employees. Additionally, two 1–5 Likert-scale questions were included to gauge respondents' opinions on the perceived benefits of digital signatures and the potential drawbacks that might hinder their implementation. The purpose of this section was to uncover the obstacles and rejection factors associated with adopting digital signatures. These insights offer crucial information about the challenges that small and medium-sized enterprises (SMEs) encounter in integrating and utilizing this technology, illuminating the broader issues that hinder its adoption within the sector.

The last part of the questionnaire referred to every participant regardless of usage. This part of the questionnaire consists of two interconnected sections designed to assess the perceived benefits and importance of using electronic signatures among respondents. In the first part, participants are asked to evaluate various potential advantages of electronic signatures, such as cost reduction in printing and mailing, enhanced document security, and environmental benefits, using a four-point Likert scale ranging from "strongly disagree" to "strongly agree." Responses indicating agreement (scores of 3 or 4) are then carried forward to the second part, where participants rate the importance of these agreed-upon benefits on another four-point Likert scale, from "not important at all" to "very important." This structured approach identifies and prioritizes the perceived value and significance of electronic signature adoption among enterprises.

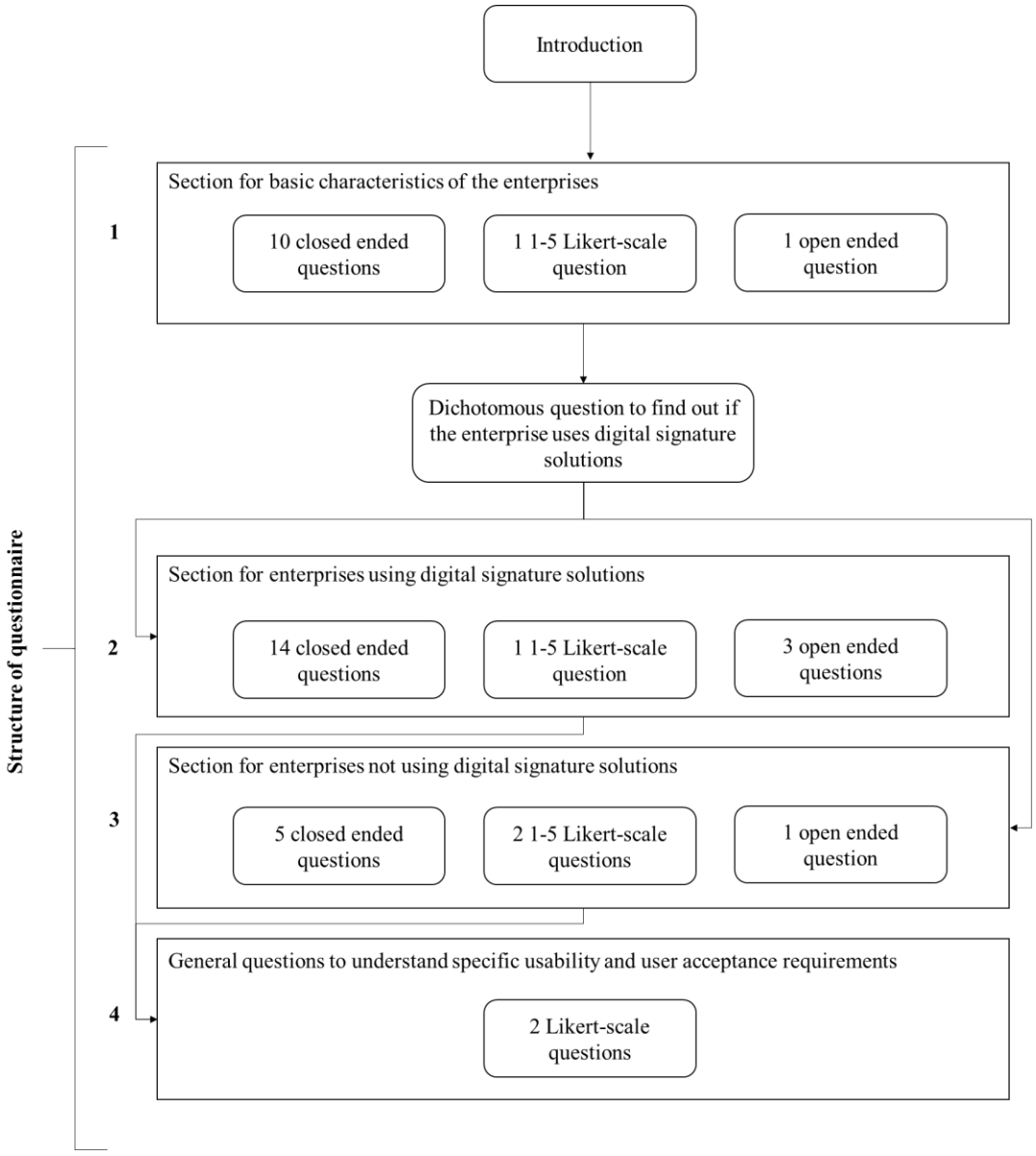



*Figure 20 Structure of questionnaire*

The final dataset for the research was processed using the IBM SPSS Statistics Data Editor (v.29.0.1.0) software, which enabled statistical analysis and the identification of correlations. The SPSS software served as a fundamental tool for research, facilitating the analysis of relationships and correlations between various variables during data processing. A range of statistical methods was employed during the analysis, enabling the exploration of connections between various social, economic, and organizational factors related to the use of digital signatures. The full quantitative questionnaire (41 questions) is provided in Appendix 1 (16.1), and the qualitative interview protocol is provided in Appendix 2 (16.2), both in their original Hungarian versions, ensuring research transparency and replicability.

## 5.3 GENERAL CHARACTERISTICS OF A DATA SOURCE.

In the questionnaire, the question "Does your enterprise currently use an electronic signature service capable of providing legally binding document authentication?" served as the basis for categorizing the surveyed companies into two groups: those using digital signatures and those not using them. The results of this classification are presented in Table 6.

The further characterization of the companies is conducted along these subcategories. As the results indicate, nearly half (44%) of the small and medium-sized enterprises (SMEs) in the sample use digital signatures in their daily operations.

For the first research question, company size was approximated using two proxies: revenue and number of employees. The distribution of digital signature users and non-users within the sample based on company size is presented in Figure 21 and Figure 22. The visualization of the distribution of these two groups according to the geographical location of their business partners and their sectoral orientation is shown in Figure 23 and Figure 24.

| Full population | Using digital signature solutions | Not using digital signature solutions |
|---|---|---|
| 200<br>(100%) | 87<br>(44%) | 113<br>(56%) |

*Table 6 Number of companies by digital signature users and non-users*

The following figures illustrate the distribution of companies in the sample, categorized by digital signature users and non-users, based on employee count and revenue categories.

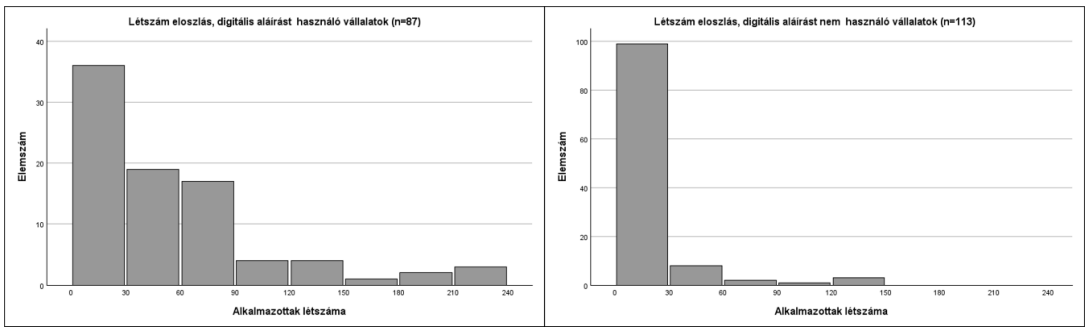



*Figure 21 Distribution of companies in the sample by staff count*

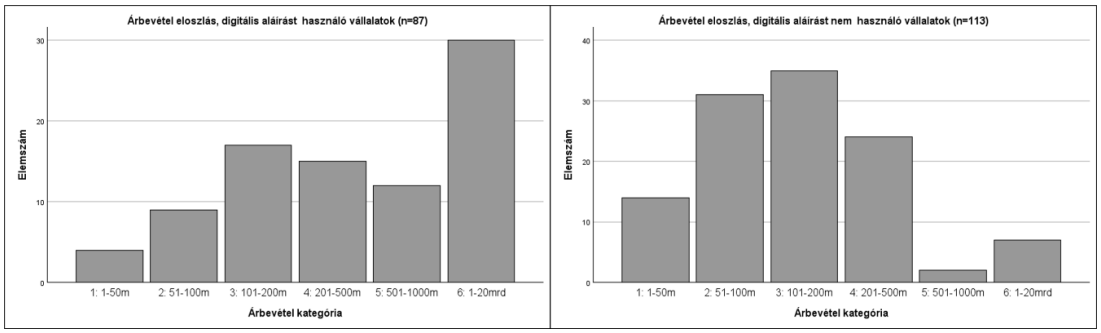



*Figure 22 Distribution of companies in the sample by revenue*

In line with the formulated hypotheses, the analysis focused on metrics describing company size, as well as the distribution of companies by the location of their business partners and their sectoral orientation

The detailed distribution according to these aspects is depicted in following figures. These figures provide insights into how the adoption of digital signatures correlates with company size and business environment, and the extent to which various company characteristics influence the acceptance of this technology within the corporate setting.

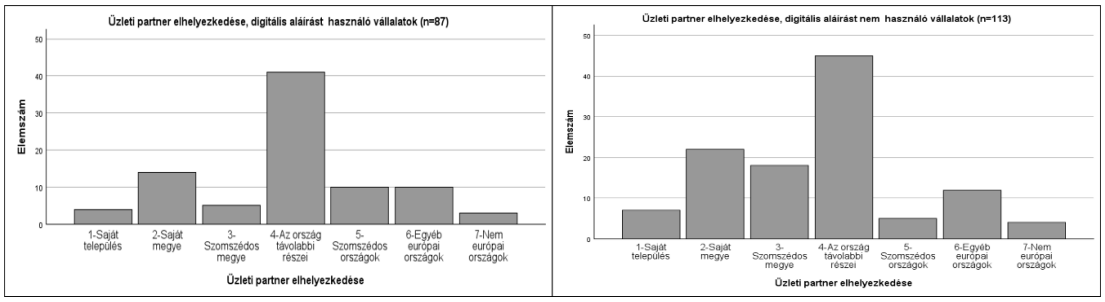



*Figure 23 Distribution of companies in the sample by business partner location*

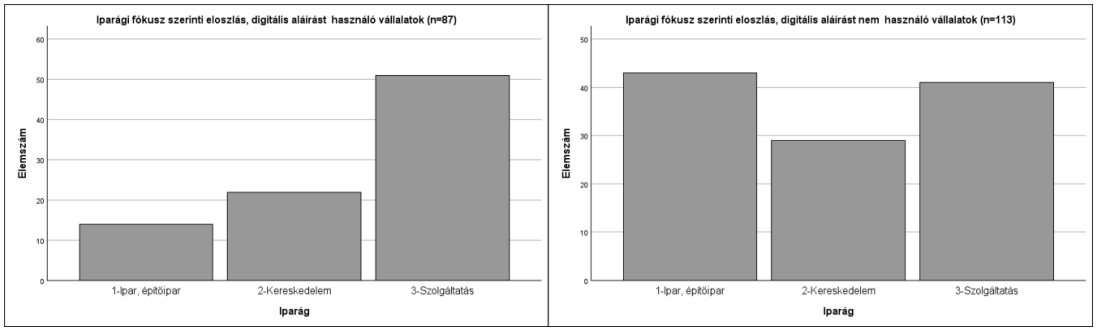



*Figure 24 Distribution of companies in the sample by sectoral orientation*

The figures allow several conclusions to be drawn regarding the characteristics of companies within the different subsets. The diagrams show that companies using

digital signatures are represented in significantly higher proportions among larger businesses (those with 60 or more employees), while companies that do not use the technology are almost entirely composed of smaller businesses with 30 or fewer employees. Furthermore, it can be stated that companies using digital signatures achieve significantly higher revenues compared to their competitors who do not use the technology. This is particularly evident in the case of companies with annual revenues between 500 million and 1 billion forints, as well as those between 1 billion and 20 billion forints, with the former category being especially noteworthy.

Regarding the location of business partners, it can be concluded that SMEs not using digital signatures predominantly have domestic customers and/or suppliers, while the data indicates a broader geographical exposure for companies that use the technology. Finally, significant differences are also observed in sectoral distribution. Companies using digital signatures are overwhelmingly service providers compared to industrial and commercial enterprises, whereas companies not using the technology are predominantly active in the industrial sector.

## 5.4 STATISTICAL ANALYSIS

For the first part of my quantitative research, I was exploring the dataset of the result of the questionnaire to find answers to one of my main research questions[7]:

RQ2

WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES?

[7] *Portions of this chapter have been accepted for publication in Vezetéstudomány*

To establish a more focused research direction, first I have deconstructed my primary research question into three distinct quantitative exploratory research questions.

| |
|---|
| RQ 2.1<br>HOW DOES COMPANY SIZE AFFECT THE WILLINGNESS OF HUNGARIAN SMES TO USE DIGITAL SIGNATURE TECHNOLOGIES? |
| RQ 2.2<br>HOW DOES THE GEOGRAPHIC LOCATION OF BUSINESS PARTNERS (SUPPLIERS AND/OR CUSTOMERS) INFLUENCE THE WILLINGNESS TO USE DIGITAL SIGNATURE TECHNOLOGIES AMONG HUNGARIAN SME'S? |
| RQ 2.3<br>HOW DOES THE SECTORAL ORIENTATION OF COMPANIES INFLUENCE THE UPTAKE OF DIGITAL SIGNATURE BY HUNGARIAN SMES |

### 5.4.1 GENERAL CHARACTERISTICS OF THE RESEARCH SAMPLE

Based on the response to the questionnaire question "Does your enterprise currently use an electronic signature service suitable for authenticating legally binding documents?", companies in the sample were divided into digital signature users and non-users. Figure 25 shows the division results. Further company characterization occurs along these subcategories.

For the first research question, company size was approximated using two proxies: revenue and employee number. Figure 23Figure 26 and Figure 24 illustrate the distribution of the two groups by companies' business partner location and industry orientation, in relation to the RQ2 and RQ3 research questions.

| Full population | Using Digital Signature Full population | Not Using Digital Signature |
|---|---|---|
| 200 (100%) | 87 (44%) | 113 (56%) |

*Figure 25 Number of companies by digital signature users and non-users*

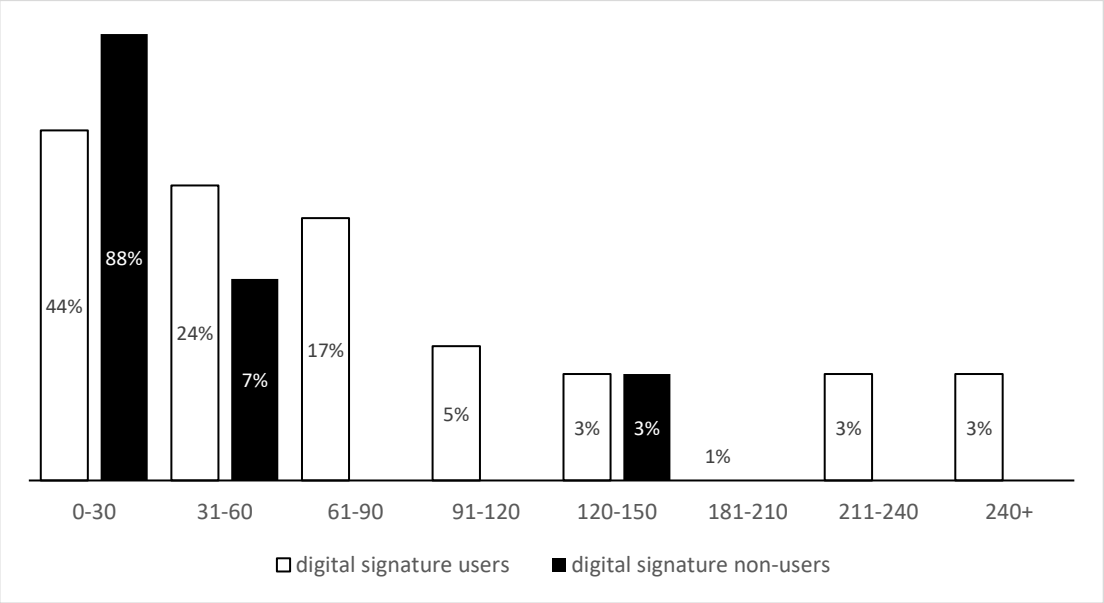



*Figure 26 Distribution of companies in sample by employee number*

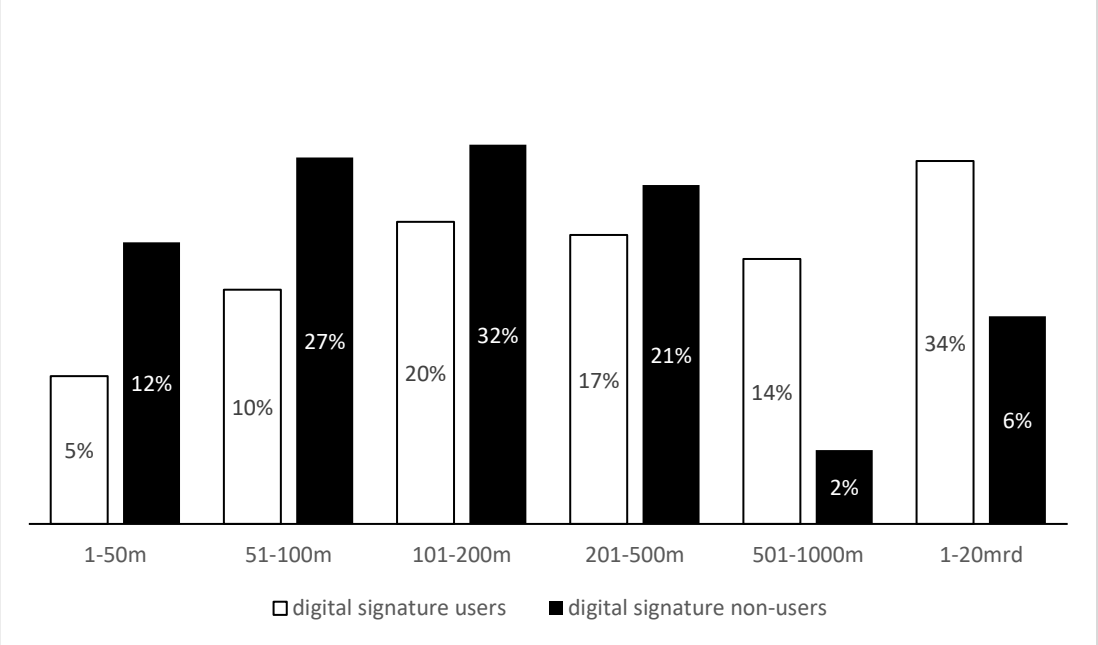



*Figure 27 Distribution of companies in sample by revenue*

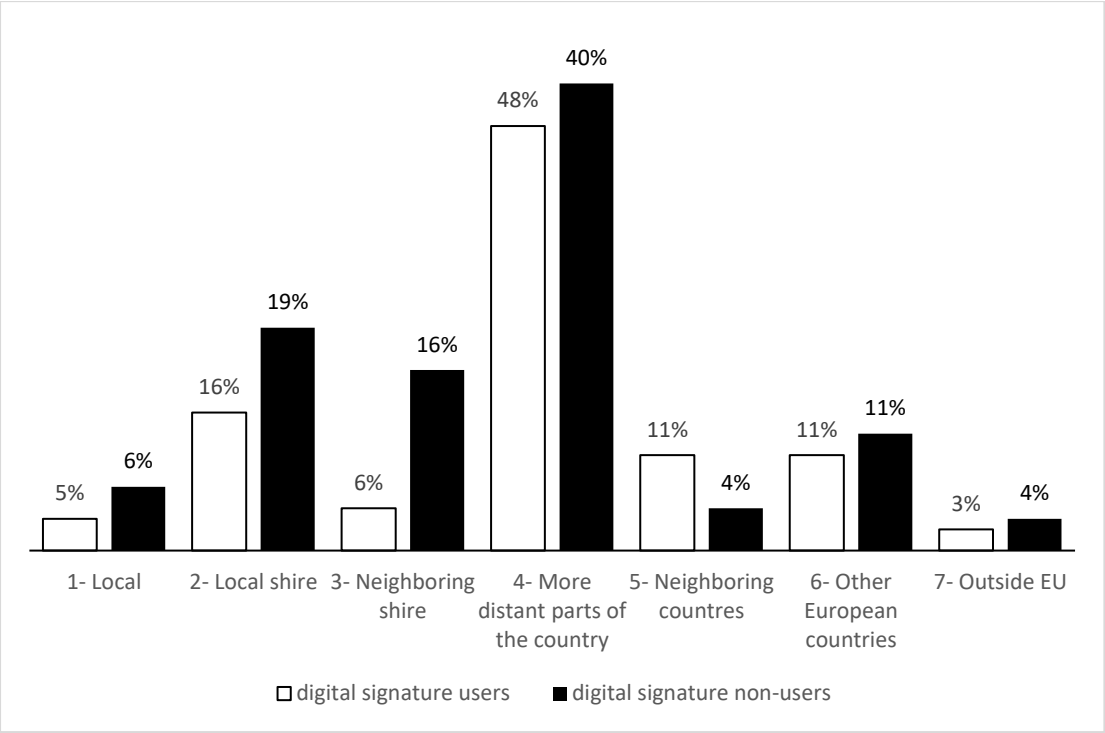



*Figure 28 Distribution of companies in sample by business partner location*

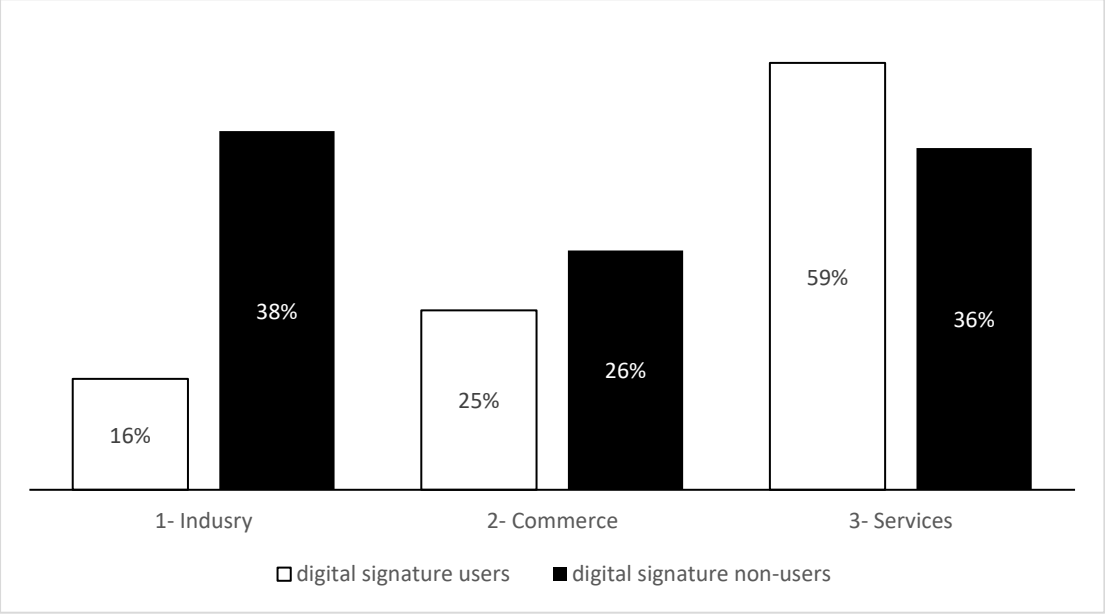



*Figure 29 Distribution of companies in sample by industry orientation*

Several primary conclusions can be drawn from the figures regarding company characteristics found in individual subsets. The diagrams show that digital signature users are represented in much greater proportion by larger companies (with 60 or more employees), while companies not using the technology almost entirely employ 30 or fewer people. It can also be said that digital signature using companies realize

significantly higher revenue compared to their non-technology-using competitors, particularly in cases of companies with annual revenue between 500 million and 1 billion forints, and between 1 billion and 20 billion forints.

Regarding business partner location, it can be established that non-digital signature using SMEs are predominantly companies with domestic customers and/or suppliers, while technology users show data suggesting broader geographical exposure. Finally, regarding industry distribution, marked differences also appear, as service organizations are significantly overrepresented among digital signature using companies, compared to industrial and commercial enterprises, while industrial companies are predominant among non-technology using companies.

### 5.4.2 CHI-SQUARE TEST

To better understand the relationship between the above explanatory variables and the dependent variable related to willingness to use digital signatures, additional statistical examinations are necessary. First, chi-square test application occurs, which is a statistical method that serves to examine the significance of relationships between two discrete variables, comparing observed and expected frequencies (in case of variable independence). It's essential to note that the chi-square test can be categorized into three primary types: goodness-of-fit, independence, and homogeneity testing (Franke et al., 2012). In this research, independence testing was applied to determine whether there is a relationship between the company characteristics and digital signature usage decisions.

Using SPSS software, a crosstab calculation was first performed to examine whether measured differences in individual variables can explain differences in digital signature usage among Hungarian SMEs. Expected frequencies were calculated for all variables (revenue, employee number, business partner location, and industry orientation), separately for digital signature-using and non-using companies. Regarding expected frequency, the lowest value was above the 5.0 threshold (recommended by SPSS) in almost all cases, allowing reliance on chi-square test results, as the sample size was sufficiently high for reliable results in individual combinations. Subsequently, Pearson's chi-square and likelihood ratio indicators and associated p-values were calculated in similar breakdowns to measure relationship strength, direction, and significance between variables.

Table 7 Summary of Chi-Square and Likelihood Ratio Results shows aggregated results. Based on calculations, it can be established that strong, positive, and statistically significant (at a 99% significance level) relationships exist between revenue, employee number, and industry orientation, and digital signature usage decisions. For business partner location, coefficient values are positive, which can be explained by a greater willingness to use generated by more distantly located business partners, consistent with the distribution shown in Figure 28. However, the relationship is not statistically significant at traditional significance levels.

| **Variable** | **Pearson Chi-Square** | **Significance Level** | **Likelihood Ratio** | **Significance Level** |
|---|---|---|---|---|
| Revenue | 44.780 | <.001 | 47.075 | <.001 |
| Staff | 52.440 | <.001 | 55.012 | <.001 |
| Proximity of Business Partners | 8.891 | .180 | 9.242 | .160 |
| Sectoral Orientation | 13.653 | .001 | 14.131 | <.001 |

*Table 7 Summary of Chi-Square and Likelihood Ratio Results*

### 5.4.3 REGRESSION EQUATION

Based on the above statistics and calculations, it can be inferred that a significant relationship exists between company size, sectoral orientation, and decisions related to the use of digital signature solutions. To identify the impact of other variables, the effect of each independent variable on the use of electronic signatures was further examined using a logistic regression method, with data from the sample.

| Variable | Revenue | Staff | Proximity to Business Partners | Sector – Industry | Sector – Commerce | Sector – Services |
|---|---|---|---|---|---|---|
| **Revenue** | 1 | | | | | |
| **Staff** | .662** | 1 | | | | |
| **Proximity to Business Partners** | .354** | .341** | 1 | | | |
| **Sector – Industry** | 0.063 | 0.052 | .166* | 1 | | |
| **Sector – Commerce** | 0.022 | 0.053 | -0.046 | -.369** | 1 | |
| **Sector – Services** | -0.077 | -0.093 | -0.110 | -.583** | -.540** | 1 |

*Table 8 Correlation Matrix Calculated for Independent Variables*

*N = 200; **p<0.01; *p<0.05*

Logistic regression is an effective method for analyzing and understanding the extent to which independent variables impact the value of a binary dependent variable, quantifying the effect of each explanatory variable on the final outcome. Logistic regression is an iterative method that identifies the strongest linear combinations through a series of steps, which are most likely to lead to the desired outcome.

The basic assumptions of logistic regression are as follows:

1. Independence of observations,
2. Linearity of continuous variables,
3. Absence of multicollinearity, and
4. Absence of highly influential outliers.

Among these, the methodology of questionnaire-based surveys ensures that the first assumption of independence of observations is met.

Among the above, based on the survey methodology, the first assumption regarding the independence of observations is met. After analyzing the data, it can also be concluded that the second and fourth assumptions are satisfied, regarding the linearity

of continuous variable and the absence of extreme values. To analyze multicollinearity, a correlation matrix was used in SPSS for the different independent variables (Table 8).

Based on the values, although the correlation is statistically significant in several cases, the values are not excessively high, as none exceed the 0.7 threshold. However, relying solely on the results from the correlation matrix is not sufficient for the analysis; additional methods are needed to fully rule out the presence of multicollinearity between the variables. To this end, Variance Inflation Factor (VIF) indicators were also calculated separately for each explanatory variable to isolate and examine the presence of multicollinearity in the factors included in the potential regression model.

### 5.4.4 VARIANCE INFLATION FACTOR (VIF) AND TOLERANCE ANALYSIS

To this, the Variance Inflation Factor (VIF) indicators were also calculated individually for each explanatory variable. This allows for an isolated assessment of multicollinearity within the factors included in the potential regression model.

The VIF indicators were calculated using SPSS, as in the previous analyses. The results are presented in Table 9. The Tolerance value examines the relationships between independent variables, quantifying the extent to which they are independent of each other. This value is computed through a series of regressions, where each independent variable serves as the dependent variable in the regression models.

A potential regression equation in this context is as follows:

Revenue $= \alpha + \beta_1 Staff + \beta_2 Proximity\ to\ Business\ Partners + \beta_3 Sector - Industry + \beta_4 Sector - Commerce + \beta_5 Sector - Services$

This equation assesses how the revenue of companies in the sample depends on their staff size, the location of their business partners, and their sectoral orientation.

When interpreting the results, it is essential to note that, due to the binary nature of sectoral orientation, SPSS uses one of these binary variables as a reference category. In this case, no coefficient was calculated for the Sector–Industry variable. Thus, the

values for the Sector – Commerce and Sector – Services variables should be evaluated relative to this reference category.

The tolerance value ranges between 0 and 1, where 0 indicates that an explanatory variable is completely correlated with other predictors, while a value of 1 implies that it is entirely independent of the other external variables in the model. The VIF value is the reciprocal of the tolerance value.

As a general rule (see, e.g., (A. H. Studenmund, 2014)), a VIF value exceeding 5 suggests the presence of severe multicollinearity among the explanatory variables. Since all calculated VIF values are below 2, it can be concluded that multicollinearity is not present in the regression models under consideration.

| Variable | Tolerance | VIF |
|---|---|---|
| **Revenue** | 0.543 | 1.843 |
| **Staff** | 0.546 | 1.830 |
| **Proximity to Business Partners** | 0.834 | 1.199 |
| **Sector – Commerce** | 0.696 | 1.438 |
| **Sector – Services** | 0.690 | 1.450 |

*Table 9 Tolerance and VIF Values*

### 5.4.5 MODELS TESTED IN THE RESEARCH

The hypotheses defined among the research objectives were tested using various regression models These are presented in Figure 30. Each model examines the effect of previously outlined independent variables on decisions related to the use of digital signatures, progressively expanding the set of explanatory variables.

The only transformation applied to the independent variables was made for sectoral focus. To improve the interpretability of the logistic regression equation, this variable was divided into three binary variables: Sector – Industry, Sector – Commerce, and Sector – Services. These variables take the value of 1 if the respondent SME indicated industry, commerce, or service, respectively, as their sectoral focus. In all other cases, the value of these variables is zero.

**Model 1**

Usage of digital signature = $\alpha + \beta_1 Revenue + \beta_2 Staff$

**Model 2**

Usage of digital signature = $\alpha + \beta_1 Revenue + \beta_2 Staff +$
$\beta_3 Proximity\ to\ Business\ Partners$

**Model 3**

Usage of digital signature = $\alpha + \beta_1 Revenue + \beta_2 Staff +$
$\beta_3 Proxmity\ to\ Business\ Partners + \beta_4 Sector - Industry + \beta_5 Sector -$
$Commerce + \beta_6 Sector - services$

*Figure 30 Models tested in research*

The results of the SPSS computations run on the regression equations are presented in Table 10. In all three models, it is evident that there is a positive relationship between company size and the decision to use digital signature services. The relationship is statistically significant at the 1% and 5% levels. Considering that there is a strong, significant correlation between the proxies used to estimate company size (revenue and number of employees) (Table 8), it is not surprising that a similar direction and strength of relationship is observed for both indicators in each regression model. It is important to highlight that as the number of variables in the model increases, the strength of the relationship also increases. Overall, the results provide strong support for answering the first research question.

The coefficients related to the distance of business partners are negative, leading to the conclusion that companies with geographically distant customers and suppliers have a lower likelihood of using digital signatures. This contradicts previous findings, yet the relationship indicated by the regression model is not statistically significant at conventional levels.

When interpreting the results of the third model, it is important to note that if *n* binary variables are included among the explanatory variables, the software calculates *n*-1 regression coefficients. The last binary explanatory variable is treated as a reference category. Based on following Table, no coefficient was calculated for the "*Sector – Services*" variable, meaning the values for the "*Sector – Industry*" and "*Sector – Commerce*" variables must be evaluated against this reference variable. The negative

values indicate that both industrial and commercial companies are less likely to adopt digital signature solutions compared to service companies.

The increase A Cox & Snell $R^2$ and Nagelkerke $R^2$ values across the models suggests that more complex models with a higher number of independent variables account for a larger proportion of variance. This indicates improved model performance with the addition of explanatory variables.

| Dependent Variable: Decision to Use Digital Signatures (1 = Yes, 0 = No) | | | | |
|---|---|---|---|---|
| | | M1 | M2 | M3 |
| | | | | |
| Intercept | | -2.048**<br>(0.451)<br>(<.001) | -1.639**<br>(0.546)<br>(0.003) | -1.421*<br>(0.591)<br>(0.016) |
| | | | | |
| Independent Variables | | | | |
| | | | | |
| Proximity to Business Partners | | - | -0.158<br>(0.122)<br>(0.198) | -0.077<br>(0.130)<br>(0.551) |
| | | | | |
| Sector – Industry | | - | - | -2.232**<br>(0.516)<br>(<.001) |
| | | | | |
| Sector – Commerce | | - | - | -0.846*<br>(0.423)<br>(0.045) |
| | | | | |
| Sector – Services | | - | | - |
| | | | | |
| | | | | |
| Control Variables | | | | |
| | | | | |

| | | | |
|---|---|---|---|
| Revenue | 0.338*<br>(0.147)<br>(0.022) | 0.381*<br>(0.153)<br>(0.013) | 0.413*<br>(0.164)<br>(0.012) |
| Staff | 0.019**<br>(0.007)<br>(0.006) | 0.020**<br>(0.007)<br>(0.005) | 0.024**<br>(0.008)<br>(0.002) |
| | | | |
| Sample Size | 200 | 200 | 200 |
| Cox & Snell $R^2$ | 0.223 | 0.229 | 0.318 |
| Nagelkerke $R^2$ | 0.299 | 0.308 | 0.426 |
| | | | |
| ***Values in the table**: Regression coefficient (standard error) (p-value)* | | | |

*Table 10 The results of the regression equation for each model.*

**Model Fit and Goodness-of-Fit Statistics**

To assess the explanatory power and overall fit of the logistic regression models, several diagnostic statistics were examined. Table 11 presents the model fit statistics for all three models, including the -2 Log Likelihood, pseudo-$R^2$ measures, and the Hosmer-Lemeshow goodness-of-fit test.

| Model | -2 Log Likelihood | Cox & Snell $R^2$ | Nagelkerke $R^2$ | Hosmer-Lemeshow $\chi^2$ | df | p-value |
|---|---|---|---|---|---|---|
| Model 1 | 252.301 | 0.223 | 0.299 | 8.421 | 8 | .394 |
| Model 2 | 250.863 | 0.229 | 0.308 | 7.892 | 8 | .444 |
| Model 3 | 197.416 | 0.318 | 0.426 | 6.343 | 8 | .609 |

*Table 11 Model fit statistics for logistic regression models.*

The model fit statistics indicate progressive improvement across the three models. Model 3, which includes all predictor variables (company size, partner proximity, and sectoral orientation), demonstrates the strongest explanatory power with a Nagelkerke $R^2$ of 0.426, indicating that approximately 43% of the variance in digital signature adoption decisions is explained by the model. The Hosmer-Lemeshow test results ($\chi^2$=6.343, df=8, p=.609) suggest good model fit, as the non-significant p-value (p>.05) indicates no significant difference between observed and predicted values

across deciles of predicted probabilities. The decrease in -2 Log Likelihood from Model 1 (252.301) to Model 3 (197.416) further confirms improved model performance with the inclusion of additional predictors.

**Odds Ratios and Confidence Intervals**

To facilitate practical interpretation of the regression coefficients, Table 12 presents the odds ratios (Exp(B)) with 95% confidence intervals for Model 3, the full model. Odds ratios indicate the multiplicative change in the odds of digital signature adoption associated with a one-unit increase in the predictor variable, holding all other variables constant.

| **Variable** | **B** | **SE** | **Wald** | **p** | **Odds Ratio (OR)** | **95% CI** |
|---|---|---|---|---|---|---|
| Intercept | -1.421 | 0.591 | 5.782 | .016 | 0.242 | - |
| Revenue | 0.413 | 0.164 | 6.339 | .012 | 1.511 | [1.096, 2.083] |
| Staff | 0.024 | 0.008 | 9.000 | .002 | 1.024 | [1.008, 1.040] |
| Proximity to Business Partners | -0.077 | 0.130 | 0.351 | .551 | 0.926 | [0.718, 1.194] |
| Sector – Industry | -2.232 | 0.516 | 18.691 | <.001 | 0.107 | [0.039, 0.294] |
| Sector – Commerce | -0.846 | 0.423 | 4.000 | .045 | 0.429 | [0.187, 0.983] |

*Table 12 Logistic regression coefficients with odds ratio and confidence interval.*

*Reference category: Sector – Services*

The odds ratios reveal substantive effects for company size and sectoral orientation. Each additional employee increases the odds of digital signature adoption by 2.4% (OR=1.024, 95% CI [1.008, 1.040]), while each unit increase in revenue category increases adoption odds by 51.1% (OR=1.511, 95% CI [1.096, 2.083]). Most notably, sectoral differences are pronounced: industrial SMEs have 89.3% lower odds of adoption compared to service-oriented SMEs (OR=0.107, 95% CI [0.039, 0.294]), while commercial SMEs demonstrate 57.1% lower odds (OR=0.429, 95% CI [0.187, 0.983]). The confidence intervals for both sectoral variables exclude 1.0, confirming statistical significance at conventional levels. In contrast, the proximity to business partners shows no significant effect (OR=0.926, 95% CI [0.718, 1.194]), as the confidence interval includes 1.0.

## 5.5 FURTHER QUANTITATIVE ANALYSIS OF ENTERPRISES DATASET

In the second part of the quantitative research, the questionnaire dataset was explored to find answers to another of the main exploration research questions:

| |
|---|
| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES |

In this section, a separate analysis of enterprises utilizing digital signatures was conducted, considering potential differences relevant to the research question. Additionally, the analyzed SME sample was segmented into three categories based on the number of employees.

- Enterprises with 5–9 employees (referenced later on as small companies)
- Enterprises with 10–49 employees (referenced later on as medium-sized companies)
- Enterprises with 50–249 employees (referenced later on as larger companies)

### 5.5.1 ADVANTAGES ASSESSMENT AMONG ENTERPRISES

The listed benefits are of almost equal importance to the target group. The only exception is the importance of acceptance across the entire European Union, which is less relevant for them. The other benefits are considered of high importance by three quarters of the target group.

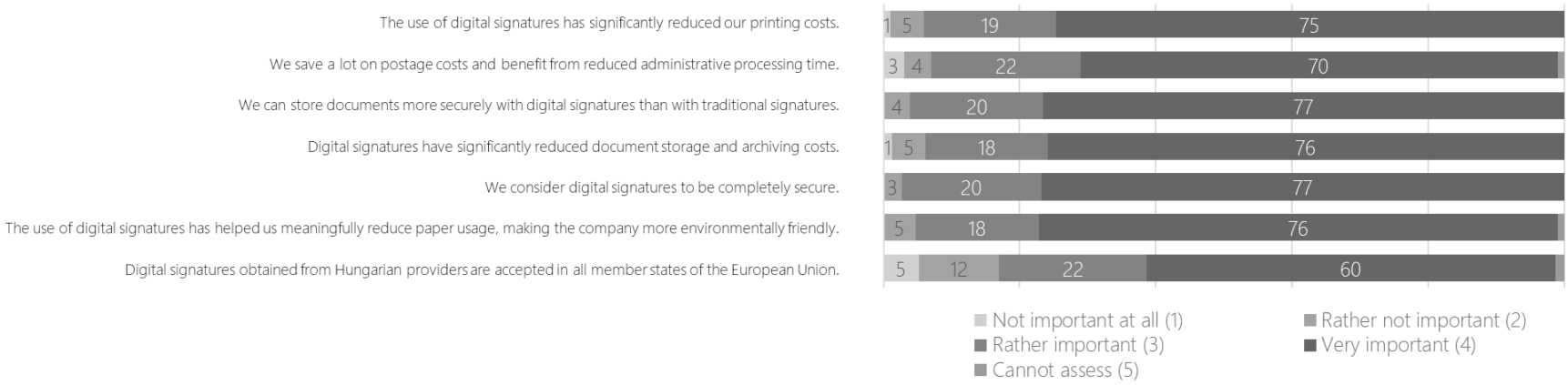



*Figure 31 Advantages assessment among enterprises*

The data presented reveals a strong positive perception of digital signatures among the respondents, with a notable emphasis on their security, environmental benefits, and cost-saving capabilities. The following analysis of each statement provides insight into the factors contributing to the high satisfaction and perceived value of digital signatures. The results suggest that enterprises highly value the benefits of digital signatures, with a particular emphasis on security, cost savings, and environmental impact.

### 5.5.2 PAPERLESS OPERATION

Larger companies prioritize paperless operations to a much greater extent. While full paperless operation is still characteristic of very few companies,

Most enterprises (58%) are still in the early stages of transitioning to paperless operations, indicating that while there is an intention to move towards digitalization, the full implementation is yet to be achieved.

A significant portion (31%) has made substantial progress in their paperless efforts, suggesting that they have already digitalized a significant part of their administrative processes.

A small proportion (4%) of enterprises have fully or almost fully eliminated paper usage, reflecting the highest level of digitalization.

Only a minority (7%) of enterprises do not strive to establish a paperless operation, suggesting that the concept of paperless operations is widely recognized and valued.

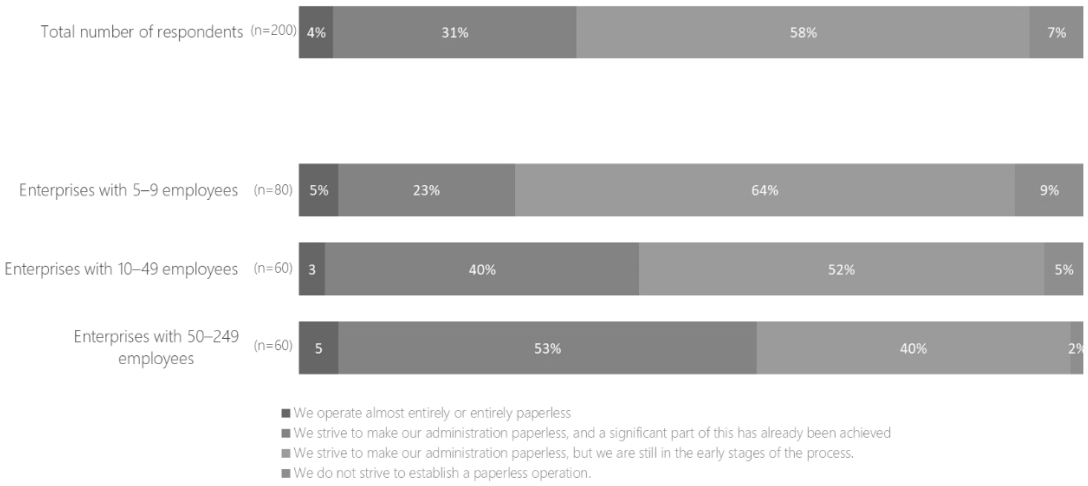



*Figure 32 Paperless operation*

Enterprises (5-9 employees) are generally in the early stages of digitalization. Enterprises (10-49 and 50-249 employees) have made more progress,

Despite the size of the enterprise, a notable portion of companies are still in the early stages of their paperless journey.

### 5.5.3 ANALYSIS OF ENTERPRISES USING DIGITAL SIGNATURE SOLUTIONS

I move on by presenting the findings from the sample of respondents using digital signature solutions.

.

### 5.5.3.1 ADVANTAGES ASSESSMENT AMONG ENTERPRISES USING DIGITAL SIGNATURE SERVICES

Users generally have a very positive opinion of digital signatures. They most (80%) strongly agree that digital signatures have significantly reduced their printing costs, saved considerable administrative time, and helped make their company more environmentally friendly. Similarly, the vast majority consider digital signatures to be secure (78%). Moreover, the adoption process was straightforward, with 91% of users expressing this view (48% + 43%).

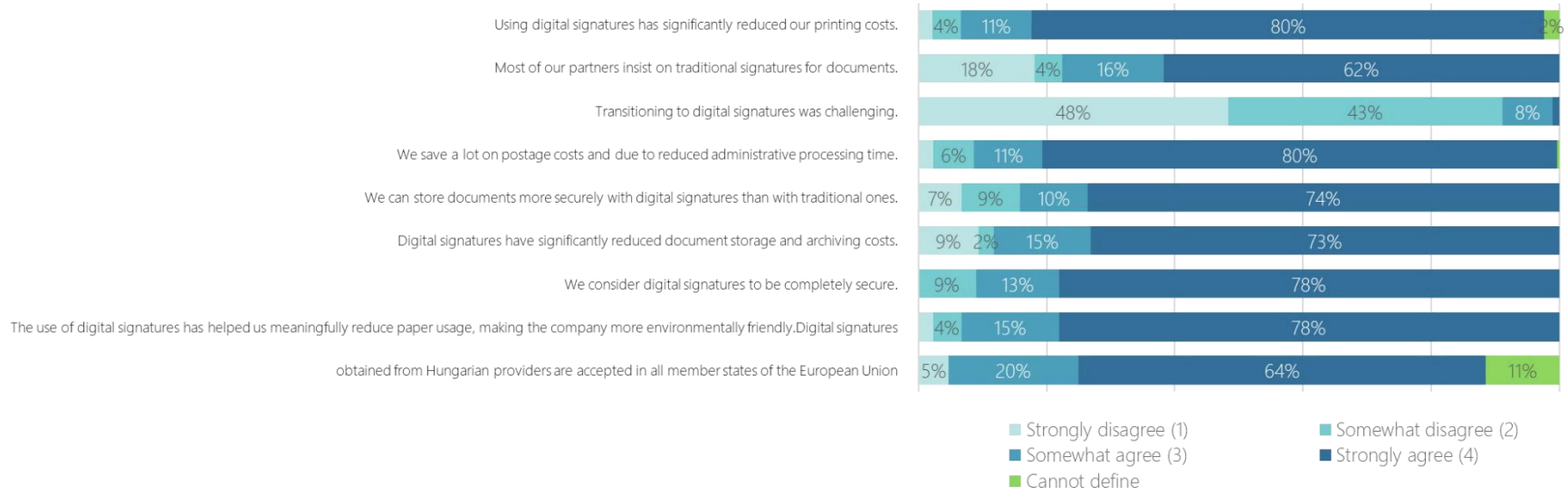



*Figure 33 Advantages assessment among enterprises Using Digital Signature*

The data presents satisfaction levels across several attributes of digital signatures, with respondents indicating their agreement on a scale of 1 to 4.

The highest level of satisfaction is seen in the acknowledgment of reduced paper usage and the environmental benefits, with 78% strongly agreeing and an additional 15% agreeing. This highlights the sustainability advantages of digital signatures.

A 91% agreement (78% strongly agree) that digital signatures are entirely secure and emphasize their substantial trustworthiness among users.

91% (80% strongly agree) report significant reductions in printing costs, Postage Costs, and Administrative Efficiency: 91% (80% strongly agree) agree that digital signatures save postage costs and reduce administrative time, reinforcing their operational value.

84% (64% strongly agree) affirm that digital signatures from Hungarian providers are accepted in all EU member states.

88% (73% strongly agree) agree that digital signatures reduce document storage and archiving costs.

84% (74% strongly agree) believe documents are more securely stored with digital signatures than traditional ones.

91% (48% strongly disagree, 43% somewhat disagree) found transitioning to digital signatures not challenging, which highlights that most organizations experienced a smooth adoption process.

Despite the overall positive reception, 78% (62% strongly agree) acknowledge that partners still prefer traditional signatures, suggesting this is a significant barrier to widespread adoption.

### 5.5.3.2 TYPE OF DIGITAL SIGNATURE SOLUTION

My research used this term to categorize and analyze the different types of electronic signature services respondents utilize.

Two-thirds of users utilize cloud-based services. Only larger companies employ both solutions simultaneously, albeit in a negligible proportion.

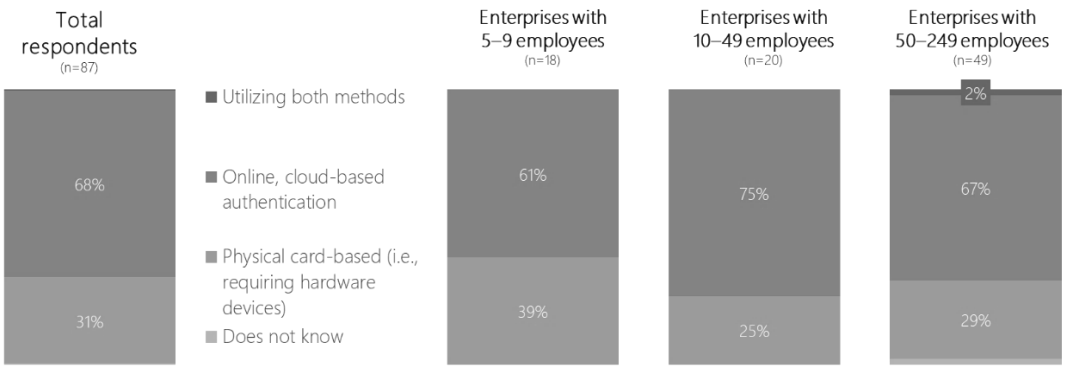



*Figure 34 Type of digital signature solution*

This finding is consistent with related research, confirming digital signature users' preference for cloud-based authentication solutions (Ege et al., 2025).

### 5.5.3.3 TOTAL SPENDING ON DIGITAL SIGNATURE SOLUTIONS

Half of the enterprises using these services reportedly utilize free solutions (53%). Larger spenders are primarily found among companies with more than 50 employees.

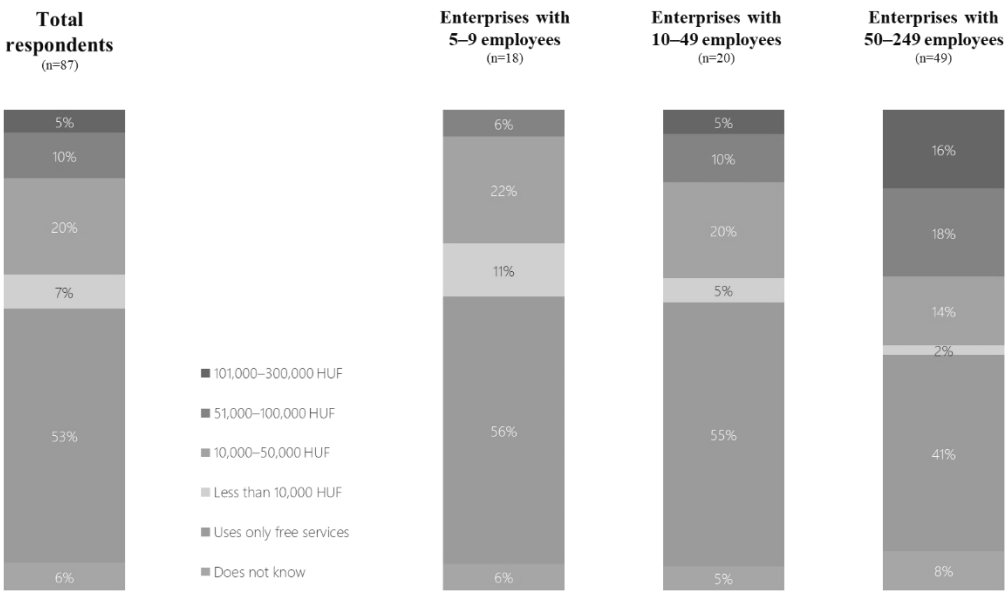



*Figure 35 Total spending on digital signature solutions*

A portion of respondents (6 % total) do not know the amount they are spending. The majority of companies use only free services (53 %); across all company sizes, the predominant choice is using only free services, indicating a general reluctance to spend on paid services, Larger companies (50-249 employees) show a higher willingness to invest in services, with a large proportion spending more than 100,000 HUF. Small companies (5-9 employees) are very conservative, with most respondents spending less than 10,000 HUF or using free services.

**Spending Behavior by Company Size**

- Small companies (5-9 employees)
  A majority (56%) use only free services, and a smaller proportion (22) spend between 10,000–50,000 HUF. There is a minimal trend towards higher spending categories, with no respondents in the 101,000–300,000 HUF range. This suggests that small companies are very cautious with their spending, likely focusing on low-cost or free tools to minimize expenses.
- Medium-sized companies (10-49 employees)
  Similar to the smaller companies, 55 % of respondents use only free services. However, there is a slightly more balanced distribution across the spending ranges, with 10 % of respondents spending between 51,000–100,000 HUF and 5% in the 101,000–300,000 HUF category. This could indicate that medium-

sized businesses are beginning to invest in paid services but still prioritize free services when possible.

- Larger companies (50-249 employees)

  This group shows a more diversified spending pattern. While 41% of respondents use only free services, a notable portion (18%) is spending between 51,000 – 100,000 HUF, and another (16%) in the 101,000–300,000 HUF category. Larger companies seem more willing to invest in higher-value services.

### 5.5.3.4 AUTOMATION HABIT OF DIGITAL SIGNATURE SERVICES

In this questionnaire section, I examined the habit of automation in the signature processes across different segments of SME representatives.

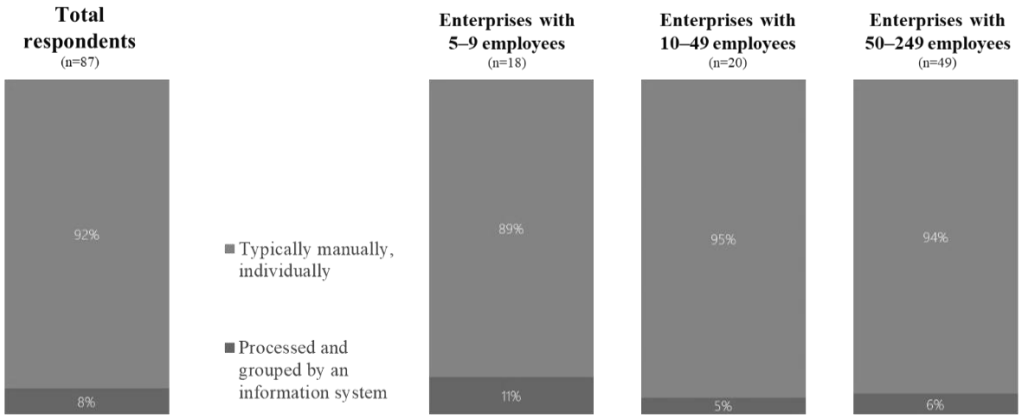



*Figure 36 Automation habit of digital signature services*

The overall sample shows a clear preference for manual, individual processing of digital signatures, with 92% of responses indicating this method, compared to just 8% of responses where the process is handled by an information system.

Across all company sizes, the majority of companies (ranging from 89% to 95%) continue to process digital signatures manually. This highlights a significant gap in the adoption of digital signature automation, suggesting that many companies, regardless of size, may not be fully utilizing available technological solutions. While larger companies show a slightly higher adoption of information systems for digital signatures (6%), the overall trend remains that digital signature automation is still in the early stages of adoption, even in companies with more resources.

**Automation habit by Company Size**

- Small companies (5-9 employees)
  A majority 89% of respondents from small companies still process signatures manually, while only 11% use an information system. This indicates that small businesses are highly dependent on manual processes
- Medium-sized companies (10-49 employees)

This group shows a slightly higher usage of information systems, with 5% of respondents indicating they use automated systems for digital signatures. However, the vast majority (95%) still rely on manual processes.

- Larger companies (50-249 employees)
  Similar to the other groups, the majority (94 %) of larger companies process digital signatures manually. 6% of respondents use an information system for automation. This indicates a minimal shift towards automation in larger companies

#### 5.5.3.5 USE OF BULK DIGITAL SIGNATURES

Bulk digital signatures refers to the practice of applying digital signatures to multiple documents or transactions in a streamlined, automated manner, often used by organizations for efficiency in handling large volumes of paperwork. The signer signs multiple prepared documents, such as invoices, with a single click rather than individually.

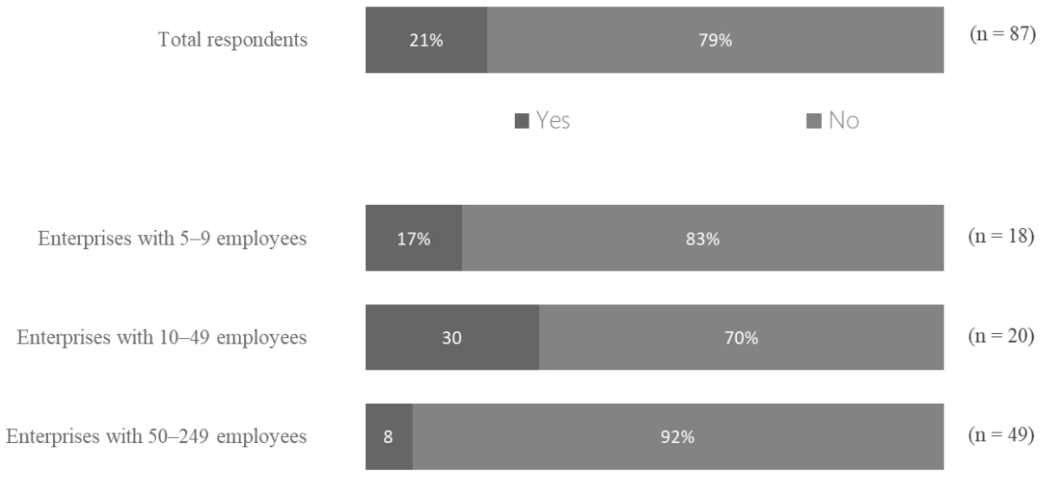



*Figure 37 Use of bulk digital signatures*

Total Respondents: 21% of respondents use bulk electronic signatures, while 79% do not. This indicates that bulk signing is relatively uncommon among the surveyed companies.

**Use of bulk digital signatures by Company Size**

- Small companies (5-9 employees)

Only 17% of these smaller companies use bulk electronic signatures, with 83% not adopting this method.

- Medium-sized companies (10-49 employees)
  30% of companies use bulk electronic signatures, and 70% do not. The adoption rate increases compared to smaller enterprises.
- Larger companies (50-249 employees)
  Only 8% of larger companies use bulk electronic signatures, with 92% not using them. This is a surprising result, as one might expect larger companies to be more likely to adopt bulk signing.

Among enterprises not currently utilizing bulk signature solutions, there appears to be little demand for such functionality, with only minimal interest (4%) observed in companies with more than 50 employees.

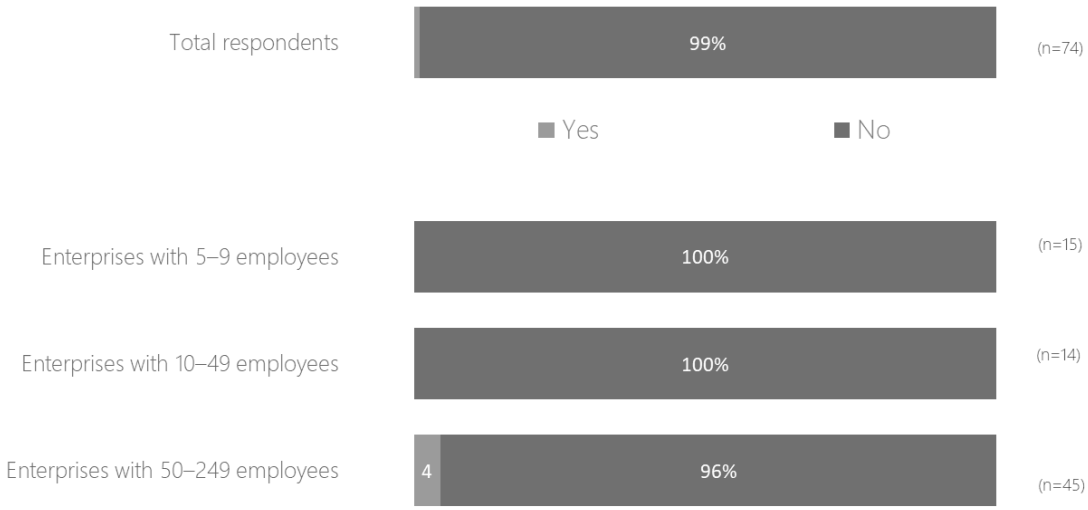



*Figure 38 Demand for using bulk signature solutions*

#### 5.5.3.6 SPECIFIC TYPES OF DOCUMENTS SIGNED BY DIGITAL SIGNATURE SYSTEMS

As the foundation of my thesis is a customer-centric approach, the survey questionnaire included targeted questions regarding the specific types of documents that could be involved in the use of digital signatures.

These findings highlight the varying adoption of digital signatures across different types of documents and company sizes. The data suggests that while smaller

companies are more inclined to use digital signatures for internal and operational documents, larger companies prioritize them for external, legal, and business-related documents.

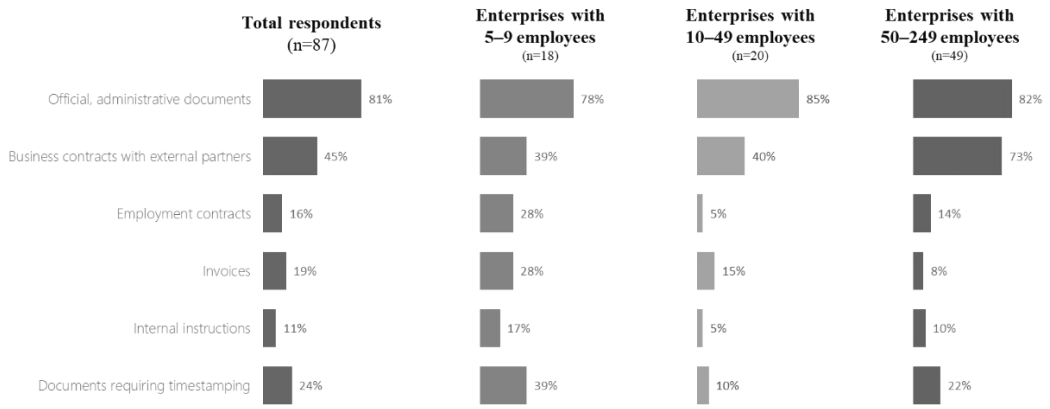



*Figure 39 Specific types of documents signed by digital signature systems*

**Official, Administrative Document**

The use of digital signatures for official, administrative documents is high across all company sizes, with 81% of the total sample using them for this purpose.

By Company Size:

- Small companies (5-9 employees): 78%
- Medium companies (10-49 employees): 85%
- Larger companies (50-249 employees): 82%

Official, administrative documents are the most commonly signed documents across all company sizes, with medium-sized businesses showing the highest usage. This suggests that these documents are likely the most critical for regulatory or legal compliance, prompting a higher adoption rate of digital signatures.

**Business Contracts with External Partners:**

45% of the total sample uses digital signatures for business contracts with external partners.

By Company Size:

- Small companies (5-9 employees): 39%
- Medium companies (10-49 employees): 40%

- Larger companies (50-249 employees): 73%

Larger companies show a significantly higher adoption of digital signatures for business contracts with external partners (73%) compared to smaller companies (39-40%).

**Employment Contract**

16% of the total sample uses digital signatures for employment contracts.

By Company Size:

- Small companies (5-9 employees): 28%
- Medium companies (10-49 employees): 5%
- Larger companies (50-249 employees): 14%

Small enterprises are more likely to use digital signatures for employment contracts (28%) compared to medium (5%) and large enterprises (14%).

**Invoices**

19% of the total sample uses digital signatures for invoices.

By Company Size:

- Small companies (5-9 employees): 28%
- Medium companies (10-49 employees): 15%
- Larger companies (50-249 employees): 8%

Smaller companies are more likely to use digital signatures for invoices (28%), while large companies use digital signatures the least (8%), which is also a surprising result.

**Internal Instructions**

11% of the total sample uses digital signatures for internal instructions.

By Company Size:

- Small companies (5-9 employees): 17%
- Medium companies (10-49 employees): 5%
- Larger companies (50-249 employees): 10%

Small businesses show a higher adoption of digital signatures for internal instructions (17%) compared to medium (5%) and large (10%) enterprises.

**Documents Requiring Timestamping**

24% of the total sample uses digital signatures for documents requiring timestamping.

By Company Size:

- Small companies (5-9 employees): 39%
- Medium companies (10-49 employees): 10%
- Larger companies (50-249 employees): 22%

Based on the questionnaire, small enterprises tend to show the highest adoption (39%) of digital signatures for timestamped documents.

#### 5.5.3.7 VARIOUS OTHER APPLIED USE-CASES

Analyzing use cases in my thesis is crucial for understanding the practical application, challenges, and acceptance of digital signatures in Hungarian SMEs. SMEs vary in size, structure, and industry, which means the way digital signatures are used can differ greatly.

Analyzing the distribution of use cases across different segments of SMEs allows me to assess how usability issues manifest in various contexts, and this provides a comprehensive understanding of the usability of digital signature systems across a range of business environments.

Among the listed services, the majority mentioned the creation of certified electronic copies as a service currently in use. This service is primarily used by larger companies (10+ employees). A relatively large number of companies also use online form authentication and electronically certified invoicing. The potential for adoption of new services is not considered high for any of the services.

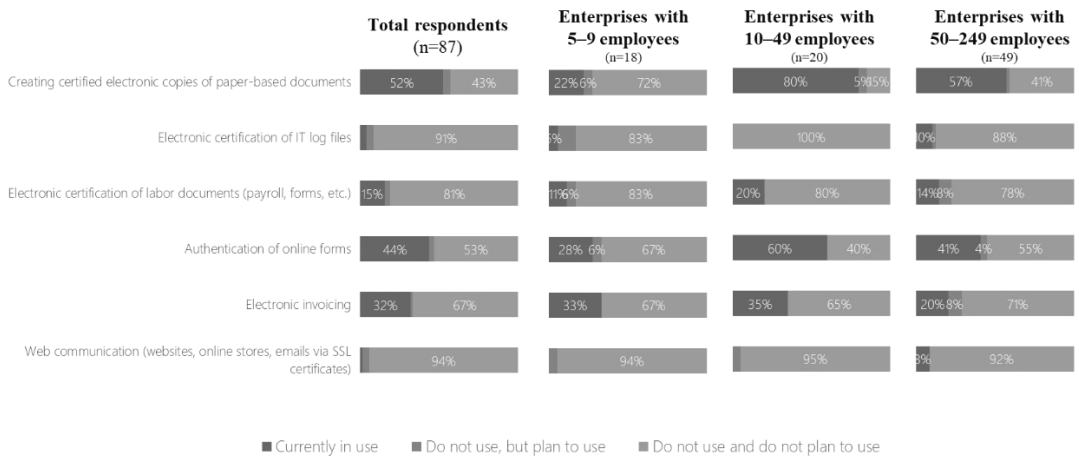



*Figure 40 Various other applied Use-Cases*

### 5.5.3.8 LEVEL OF SATISFACTION WITH CURRENT DIGITAL SIGNATURE SOLUTION PROVIDER

User satisfaction is notably high with the main service currently in use. Average scores between 4.8 and 4.9 were recorded on a 5-point scale for each of the criteria. The highest percentage of dissatisfaction (5% of actual ratings) was observed regarding the onboarding process. Additionally, 3-3% of users expressed dissatisfaction with acceptance by partners, error-free operation, and transparent pricing.

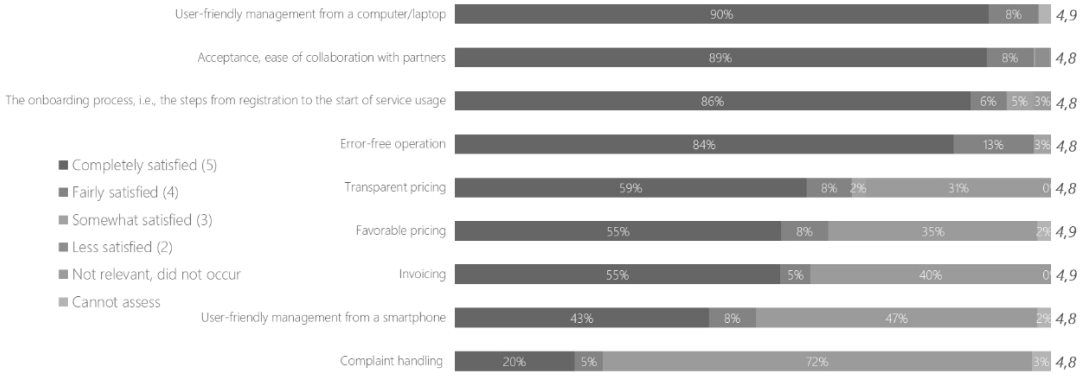



*Figure 41 Level of satisfaction with current digital signature solution provider*

### 5.5.3.9 IMAGE

The high level of satisfaction is also reflected in the fact that most of the listed image elements are considered characteristic of their current service provider by the respondents. Minimal percentages of ratings lower than 4 were given. The users

primarily could not assess whether the service provider offered them world-class service.

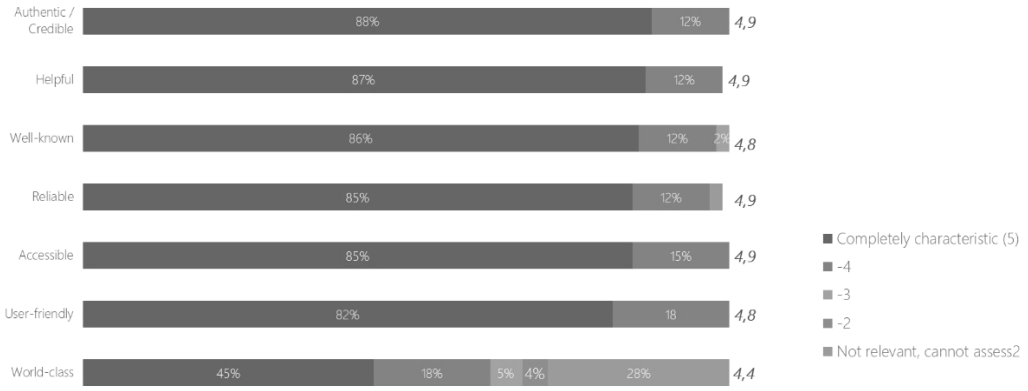



*Figure 42 Image*

### 5.5.3.10 TYPE OF USERS

48% of respondents report that both managerial and non-managerial employees use electronic signatures. 30% indicate that only employees authorized to sign on behalf of the company and other managerial positions use the service. 22% say that only employees authorized to sign on behalf of the company use electronic signatures.

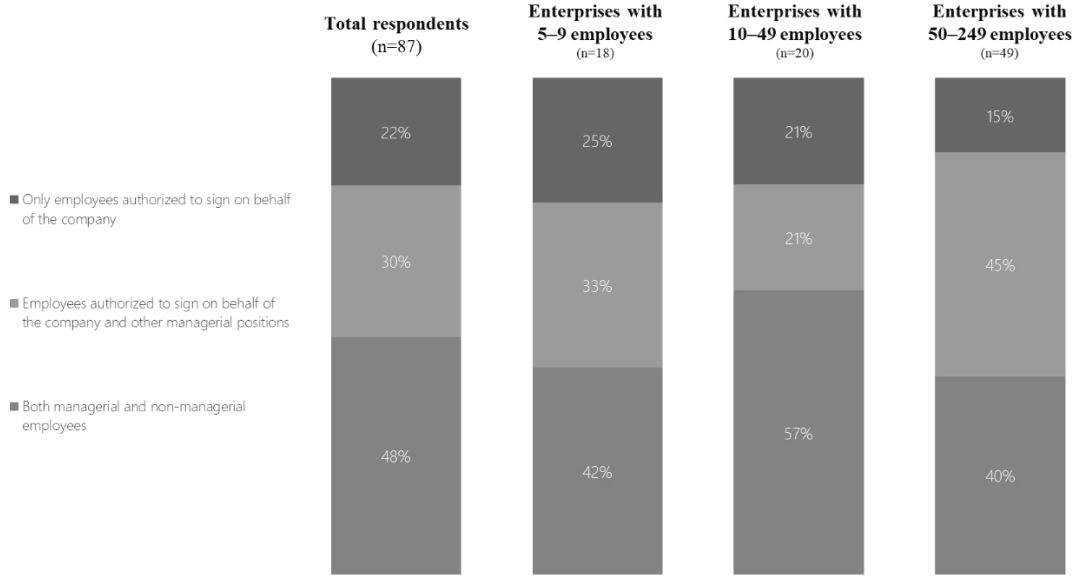



*Figure 43 Type of Users*

- Smaller companies (5-9 employees) tend to have a more balanced distribution of users, with both managerial and non-managerial employees involved in the use of electronic signatures.
- Medium-sized enterprises (10-49 employees) exhibit a more inclusive approach, with a higher percentage of both managerial and non-managerial employees using electronic signatures.
- Larger enterprises (50-249 employees) show a more hierarchical approach, with a greater concentration of electronic signature usage among employees authorized to sign on behalf of the company and other managerial positions.

#### 5.5.3.11 NUMBER OF USERS

The distribution of digital signature users across companies of different sizes reveals significant patterns in adoption and usage. The data is categorized into four groups based on the number of users: 1 user, 2 users, 3-5 users, and more than 5 users. This analysis provides insights into how company size influences the number of employees utilizing digital signatures.

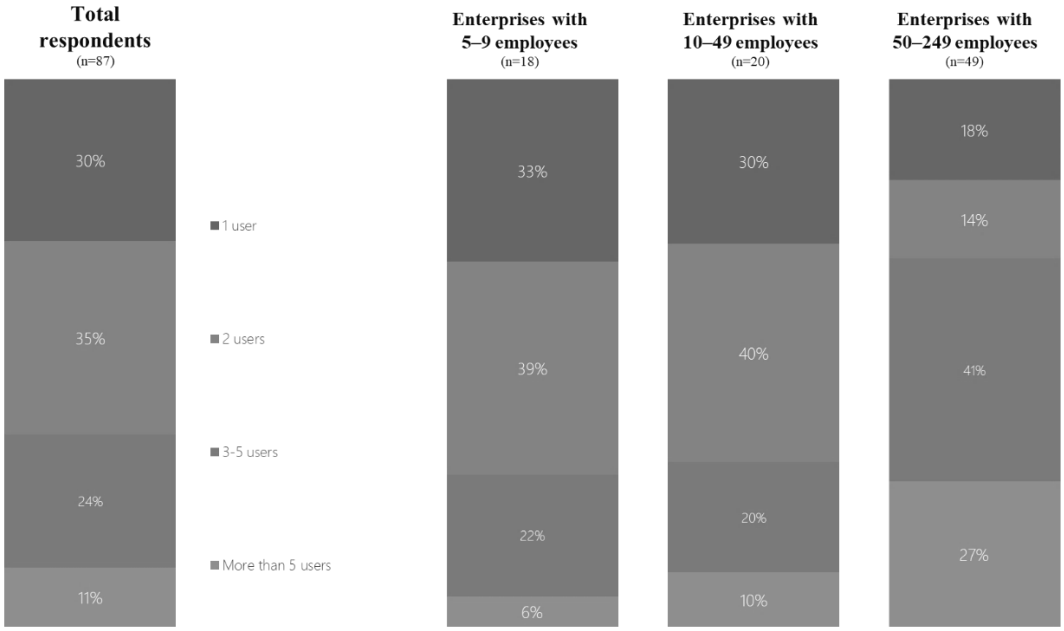



*Figure 44 Number of Users*

30% of all respondents reported having only one digital signature user. 35% of respondents have two users, making this the most frequent category overall. 24% of companies fall into 3-5 users category, showing a moderate level of adoption where

multiple employees use digital signatures. Only 11% of companies report having more than five users. Single or limited-user scenarios are less common in larger enterprises. A notable 27% of Enterprises with 50-249 Employees have more than 5 users,

#### 5.5.3.12 DEVICE

The next provides insights into the types of devices used for digital signatures by companies of varying sizes. The three categories analyzed are computer, phone, and tablet, with percentages representing the share of each device type among respondents

Computer: Universally dominant, with 100% of respondents across all company sizes (except for a slight dip to 98% in the larger enterprises) using computers for digital signatures. This highlights the centrality of computers in digital signature processes.

Phone: Secondary usage is noted, with 25% of overall respondents using phones for digital signatures. While not as prevalent as computers, phones represent an important supplementary tool.

Tablet: Marginal adoption, with only 2% of respondents using tablets. This indicates that tablets are not a preferred device for digital signatures.

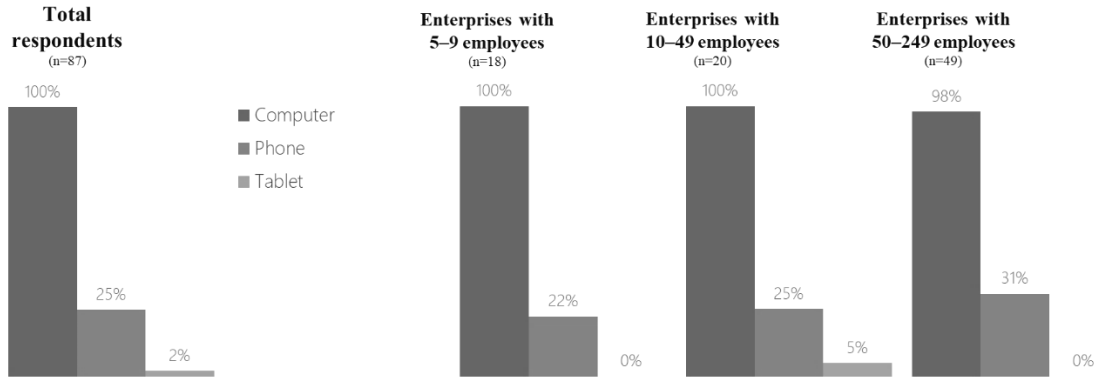



*Figure 45 Device*

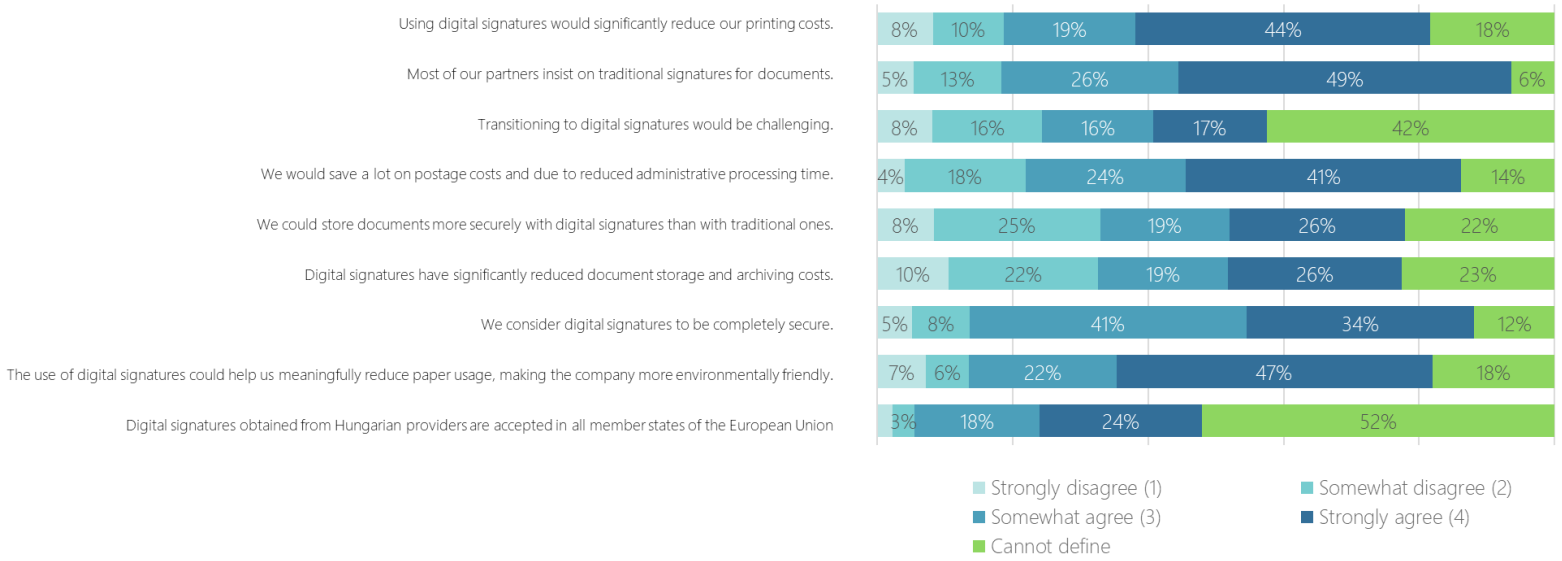
Computers are the undisputed primary device for digital signatures across all company sizes. Phones are gaining traction, especially in larger enterprises (50-249 employees), where 31% of companies use them for digital signatures. Tablets have negligible usage across all company sizes, with only 5% adoption in medium-sized enterprises.

### 5.5.4 ANALYSIS OF ENTERPRISES NOT USING DIGITAL SIGNATURE SOLUTIONS

I move on by presenting the findings from the sample of respondents not using digital signature solutions.

### 5.5.4.1 ADVANTAGES ASSESSMENT AMONG ENTERPRISES NOT USING DIGITAL SIGNATURE SERVICES

Among non-users, naturally—due to the lack of personal experience—a somewhat higher proportion could not form an opinion regarding certain statements. Opposing opinions are also more prevalent in this group. Nearly half of them (49%) believe that most of their partners insist on traditional signatures. However, they acknowledge that digital signatures make companies more environmentally friendly (47%), and the vast majority consider digital signatures to be secure.



These perceptions are shaped by a lack of direct experience, leading to higher proportions of uncertainty or inability to assess certain aspects, however, certain benefits are still recognized.

Across all statements, a significant proportion (12%-52%) of respondents indicate uncertainty, showing that non-users lack information or firsthand experience with digital signatures.

Despite limited use, many respondents acknowledge benefits like environmental sustainability (69%), security (75%), and cost savings (63%-65%).

Perceived Barriers: Partner resistance (75%) and challenges in transitioning (33%) are seen as the primary obstacles, which could deter potential adopters.

#### 5.5.4.2 AWARENESS OF ELECTRONIC SIGNATURES

In analyzing the awareness of digital signature solutions across different enterprise sizes, it is evident that a high percentage of enterprises have heard about digital signature solutions. Overall, 93% of the total sample is aware of digital signatures, with only 7% of enterprises reporting no awareness.

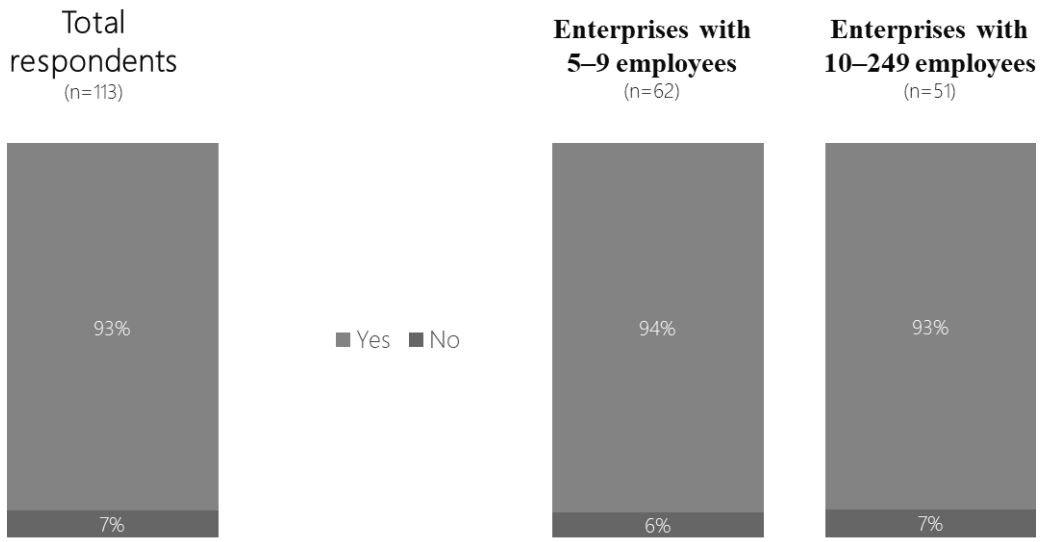



*Figure 46 Awareness of electronic signatures*

When broken down by enterprise size, awareness remains consistently high. Among enterprises with 5-9 employees, 94% have heard of digital signatures, while 6% have not. Similarly, among enterprises with 10-249 employees, 93% are aware of digital signature solutions, and 7% are not. This suggests that awareness of digital signature

solutions is widespread across all sizes of enterprises, with only a marginal difference in awareness between smaller (5-9 employees) and larger (10-249 employees) enterprises.

These results indicate that the concept of digital signatures has reached a broad audience, regardless of enterprise size, with only a small fraction of businesses remaining unaware of this solution. This could imply that digital signature solutions are gaining traction in the business community, and their adoption is likely to increase as businesses become more familiar with their benefits.

#### 5.5.4.3 FORMAL USAGE OF DIGITAL SIGNATURE

The analysis of occasional usage of digital signatures, specifically in cases where enterprises were required to sign documents received from external partners, reveals interesting insights into the adoption patterns across different enterprise sizes. According to the data, 41% of the total sample reported occasional previous use of digital signatures for this purpose, while 59% did not.

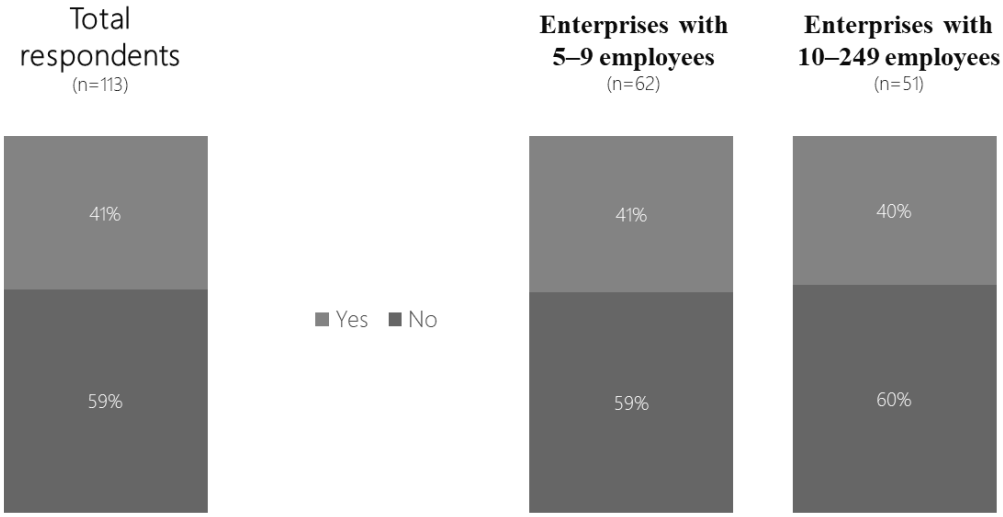



*Figure 47 Formal usage of digital signature*

When examining the data by enterprise size, the usage rate remains relatively consistent. Among enterprises with 5-9 employees, 41% reported occasional previus usage of digital signatures, while 59% did not. Similarly, in enterprises with 10-249 employees, 40% indicated that they occasionally used digital signatures for signing documents received from external partners, while 60% did not.

These findings suggest that the occasional use of digital signatures is prevalent among enterprises of various sizes, but the overall usage rate is still relatively low, with a great portion of enterprises not utilizing digital signatures. The uniformity in usage across different enterprise sizes indicates that the factor influencing occasional usage is not strongly dependent on the size of the enterprise but rather on the specific business practices or external requirements that drive the need for digital signatures.

#### 5.5.4.4 ENGAGEMENT OF USING DIGITAL SIGNATURES

The research highlights data on the planned usage of digital signatures, categorized by enterprise size, specifically focusing on the stages of engagement with potential service providers.

In the total sample, 2% of enterprises have already contacted potential service providers, while 5% have expressed interest. There is no data for enterprises that have started exploring options but have not yet contacted any providers.


*Figure 48 Engagement of using digital signatures*

Among enterprises with 5-9 employees, 2% have already contacted service providers, and 2% have expressed interest in adopting digital signatures but have not yet taken any steps toward implementation. No enterprises in this group have started exploring options.

For enterprises with 10-49 employees, 3% have already contacted service providers, and 11% have expressed interest but have not yet taken any steps toward implementation.

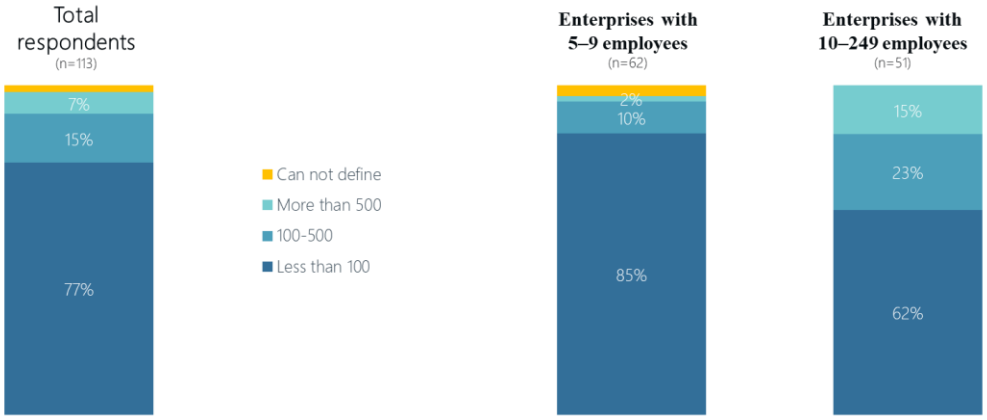
This analysis highlights that while there is some level of interest in adopting digital signatures, especially among larger enterprises, actual engagement with service providers is still limited. The data shows a clear gap between interest and action, with many enterprises yet to make significant progress toward implementation.

#### 5.5.4.5 PROGNOSTICATED NUMBER OF DOCUMENTS TO BE SIGNED DIGITALLY

The following table presents the estimated number of documents that enterprises plan to sign digitally, categorized by enterprise size. The data is expressed as percentages.

In the total sample:

- 77% of enterprises expect to sign fewer than 100 documents digitally.
- 15% plan to sign between 100 and 500 documents.
- 7% anticipate signing more than 500 documents.
- 2% could not define the number of documents they plan to sign digitally.




Among enterprises with 5-9 employees, 85% expect to sign fewer than 100 documents digitally, 10% plan to sign between 100 and 500 documents, and 2% expect to sign more than 500 documents. Additionally, 3% of these enterprises could not define the number of documents.

For enterprises with 10-249 employees, 62% expect to sign fewer than 100 documents digitally, 23% plan to sign between 100 and 500 documents, and 15% anticipate signing more than 500 documents. Notably, none of the enterprises in this group were able to define the number of documents.

This data indicates that smaller enterprises (with 5-9 employees) are more likely to sign fewer documents digitally, with a substantial proportion unable to define the exact number of documents. In contrast, larger enterprises (with 10-249 employees) anticipate signing more documents digitally, with a notable proportion planning to sign between 100 and 500 documents or more.

#### 5.5.4.6 PROGNOSTICATED TYPES OF DOCUMENTS TO BE SIGNED DIGITALLY

The following analysis examines the projected types of documents that enterprises anticipate signing if a digital signature solution were implemented. The data is categorized by the size of the enterprise (overall sample, 5-9 employees, and 10-249 employees). These insights can be valuable for understanding the adoption patterns and specific use cases for digital signature solutions across different types of documents.

Enterprises that do not currently use digital signature services – regardless of size – would primarily use this service to handle official matters, sign contracts with external partners, and authenticate invoices.

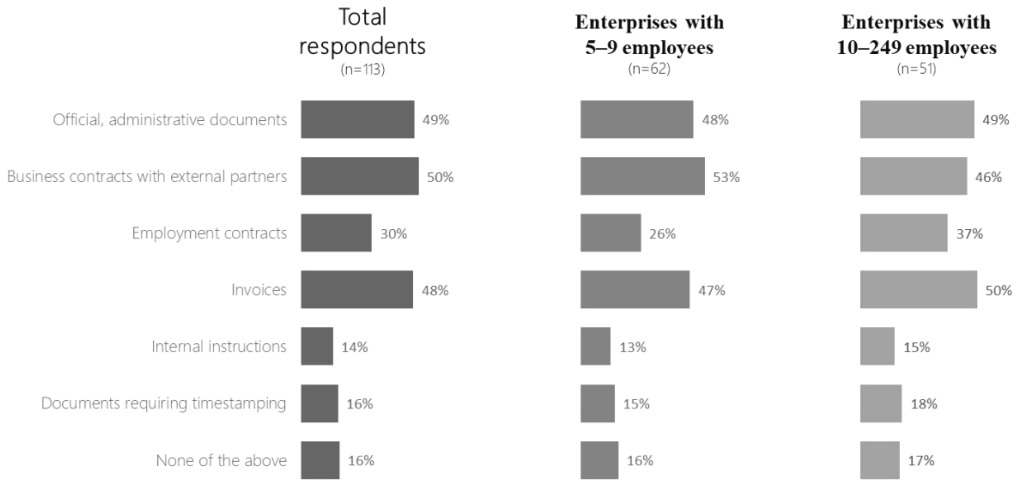



*Figure 49 Prognosticated types of documents to be signed digitally*

Enterprises (5-9 employees) prefer signing employment contracts digitally, with 53% of respondents indicating this document type.

Larger Enterprises (10-249 employees): Larger enterprises show a more balanced distribution across document types, with 46% indicating that business contracts with external partners and 49% indicating official, administrative documents would be signed digitally.

Common Document Types Across Sizes: Both small and large enterprises are aligned in their projections for signing official, administrative documents and business

contracts with external partners, with 49-53% of respondents in both categories identifying these documents as key candidates for digital signature adoption.

## 5.6 SUMMARY OF QUANTITATIVE RESEARCH

RQ2
WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES?

The processing of data aimed to explore the factors influencing the adoption and implementation of digital signatures among Hungarian small and medium-sized enterprises (SMEs). As part of this research, 200 respondents from domestic SMEs participated in a telephone-assisted survey. The SPSS analysis examined company size, revenue, the geographical location of business partners, and sectoral orientation. Through data analysis, the study sought to identify the factors that most significantly affect the adoption of digital signatures within this business group. The results provide insights into the acceptance of digital signatures, particularly regarding how specific organizational characteristics influence the adoption of innovative technologies. Statistically significant results were found, consistent with findings in the literature based on resource theory, as it was observed that companies with more employees and higher revenue were more likely to use digital signatures ($p<0.001$). The full logistic regression model (Model 3) explained approximately 43% of the variance in adoption (Nagelkerke $R^2=0.426$), demonstrating substantial explanatory power. One possible explanation for this relationship is that the implementation of digital signatures requires a more complex organizational infrastructure and greater financial resources. It is likely that these companies are capable of investing in the necessary technological developments, which provides an advantage in increasing the efficiency of administrative processes.

Based on literature findings, it could be assumed that the technology would be more prominently used by companies with business partners at a greater physical distance, realizing significant operational and financial benefits. Initial correlation analysis

suggested a relationship between business partner geographic distance and digital signature adoption. However, multivariate logistic regression controlling for company size, revenue, and sector revealed that geographic proximity was not a statistically significant predictor of adoption ($p=0.18$, $OR=0.926$, 95% CI [0.718, 1.194]). This indicates that while larger companies with distant partners may show higher adoption rates, distance itself does not independently drive adoption once organizational capacity factors are accounted for. Thus, the research found that partner proximity, unlike company size and sector, does not significantly influence digital signature adoption. Finally, it can be stated that a company's industry orientation significantly influences decisions related to using digital signatures ($p<0.01$).

Companies in the service sector showed a greater willingness to adopt digital signature technology compared to industrial and commercial enterprises. Industrial firms demonstrated 89% lower odds of adoption compared to service-sector firms ($OR=0.107$, 95% CI [0.039, 0.294], $p<0.001$), while commercial enterprises showed 57% lower odds ($OR=0.429$, 95% CI [0.187, 0.983], $p=0.045$). One possible explanation for this is that industry-specific characteristics and high document management needs are closely related to the use of the technology. For service companies, the transition to digital solutions may be especially justified in reducing paper-based documentation and providing faster customer service. Enterprises with 5-9 employees tend to adopt free solutions (56%) and prioritize official documents and internal operational documents (e.g., employment contracts and invoices). These companies are in the early stages of digitalization, with limited automation and relatively low document volumes. Enterprises with 10-49 employees show a balanced adoption of free and paid services, with a growing interest in external-facing use cases like business contracts. While they lag behind larger companies in automation, medium-sized businesses are beginning to experiment with paid solutions. Enterprises with 50-249 employees focus on external business contracts, while official administrative documents are still an essential part of usage. More willing to invest in premium services, with 16% spending over 100,000 HUF on digital.

Having identified the organizational characteristics that predict adoption, the research next examined specific usability and user acceptance requirements across different SME segments.

RQ3

WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES?

Digital signature users reported a high level of satisfaction with the simplicity and user-friendliness of the solutions. 91% of respondents indicated that transitioning to digital signatures was not challenging, reflecting the ease of adoption and integration into existing workflows. Despite this, the adoption of automated digital signature systems remains low, with only 8% of surveyed SMEs reporting the automation of their signature processes. Similarly, bulk digital signatures are underutilized, with just 21% of respondents implementing this feature, suggesting significant untapped potential for streamlining processes. Regarding device preferences, computers dominate as the primary tool for digital signature use across all SME segments, with nearly universal adoption rates of 98-100%. Mobile phones are secondary tools used by 25% of SMEs, particularly larger companies, while tablets remain marginally utilized, with only 2% adoption.

The perceived benefits of digital signatures are strongly valued, particularly their cost-saving, environmental, and security advantages. However, significant barriers to adoption persist. Partner resistance to digital signatures, mentioned by 75% of respondents, and a reliance on traditional paper-based signatures continue to hinder broader implementation, even though awareness levels are high at 93%.

Regarding document use cases, official administrative documents (81%) and business contracts with external partners (45%) dominate as the primary uses of digital signatures across SMEs. Employment contracts and invoices are increasingly signed digitally by smaller companies, a surprising finding that highlights segment-specific preferences. Looking ahead, SMEs indicate a focus on official documents and external contracts if digital signature adoption increases, with larger enterprises planning to expand their usage to accommodate higher volumes of documents. The quantitative findings highlight how the unique characteristics of Hungarian SMEs - size, sector, revenue, and geographic orientation affect - the adoption of digital signatures. Larger

SMEs, service-oriented sectors, and internationally connected firms lead to adoption due to greater operational and financial capacity. Usability and user acceptance hinge on cost-effectiveness, simplicity, and integration, with automation and bulk processing as underutilized opportunities. Addressing partner resistance, cost concerns, and cultural inertia will be crucial to driving broader adoption in this sector.

The sample and the indicators used limit the generalization of the results, as it is conceivable that different results would be obtained if the research were conducted with the involvement of large companies or the application of other independent variables.

# 6 QUALITATIVE RESEARCH

The literature review and quantitative research revealed global trends in the uptake of digital signatures and the specificities of Hungarian SMEs. It is important to highlight the limitations of the final results of quantitative research, which may, on the one hand, hinder the generalization of the conclusions and, on the other hand, offer an opportunity for further research in this area. The study processes the responses of 200 domestic SMEs, which were gathered through a telephone survey questionnaire. In addition to the advantages, it should not be overlooked that the method does not provide the opportunity to uncover knowledge that would require research of an interview.

The main focus of this dissertation is the user-centric approach, which aims to bridge the gap between digital signature technology and the practical needs of users. To this end, qualitative research will explore stakeholders' experiences, opinions, and expectations in the SME sector through semi-structured expert interviews.

The qualitative research aims to identify motivations and barriers to the adoption of digital signatures and to determine specific usability and acceptance requirements in different segments of SMEs in Hungary. The detailed interview guide used for this qualitative phase is documented in Appendix (16.2).

By conducting the interviews, I was looking for answers to two of my main exploratory research questions:

| |
|---|
| RQ2<br>WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES? |
| RQ3<br>WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES? |

During my literature review and quantitative research, I identified that the most relevant small and medium-sized enterprises (SMEs) from a customer-centric perspective might belong to the larger category of SMEs. This trend suggests that adopting digital signature technologies is closely tied to a company's organizational complexity and financial capacity. Larger SMEs tend to have more robust organizational infrastructures and greater resources, which positions them to better invest in the technological advancements necessary for digital transformation. Such investments enable these companies to improve the efficiency and reliability of their administrative processes, aligning with the principles of a customer-centric approach

The findings also revealed that the use of digital signatures is associated with revenue. Companies with larger workforces and higher revenues are more likely to adopt digital signatures

## 6.1 TARGET GROUP OF THE EXPERT INTERVIEW

Quantitative research identified potential users of digital signature solutions, forming the basis for selecting a target group for further analysis. During the pre-screening conversations, many companies indicated they already use digital signature solutions. However, to align with the research objective defined in the above question I wanted to understand barriers and boundaries to adoption specifically, these companies were

mostly excluded. Two enterprises in the dataset reported using digital signature solutions, both relying on DocuSign, a U.S.-regulated platform. These enterprises were still included in expert interviews to gain deeper insights into their adoption behavior and experiences.

By focusing now on SMEs that have not yet implemented digital signatures, the study aims to identify the factors preventing adoption and provide insights to enhance usability and acceptance.

Based on the results described in the quantitative research for the enterprises I characterized expectations to be in the 50–249 employees size, with greater net revenue than 200,000,000 HUF

To ensure a representative dataset for the study, substantial effort was invested in recruiting participants for expert interviews. This process included identifying and reaching out to over 100 companies, ultimately leading to 14 expert interviews. Of these, 12 are with companies that do not currently use digital signature solutions, while 2 are with companies that have adopted such solutions (yet, in Hungary not legally accepted solutions).

Basic characteristics of interviewed participant companies is presented in Table 13. I am not authorized to disclose the names of the enterprises or the respondents involved, or the raw transcripts of the interviews conducted. However, I was able to carry out the analysis and present the findings without including this sensitive information.

| **Staff #** | **Main Activity** | **Net Revenues Ft. (2023)** | **Uses Digital Signature** | **Position of Respondent** |
|---|---|---|---|---|
| 52 | 4633 Wholesale of dairy products, eggs and edible oils and fats | 15,793,836,000 | No | CEO |
| 4 | 4120 Construction of residential and non-residential buildings | 4,881,269,000 | No | COO |
| 9 | 5210 Warehousing and storage | 2,830,516,000 | No | CEO |
| 11 | 8299 Other business support service activities nec | 4,089,051,000 | Yes | CFO/COO |
| 12 | 8621 General medical practice activities | 4,081,564,000 | No | Owner |
| 11 | 4511 Sale of cars and light motor vehicles | 3,116,597,000 | No | CEO |

| | | | | |
|---|---|---|---|---|
| 24 | 4632 Wholesale of meat and meat products | 3,110,489,000 | No | CEO |
| 103 | 3811 Collection of non-hazardous waste | 2,121,175,000 | No | CTO |
| 11 | 0161 Support activities for crop production | 1,717,226,000 | No | CTO |
| 19 | 2562 Machining | 1,191,370,000 | No | CTO |
| 6 | 6920 Accounting, bookkeeping and auditing activities; tax consultancy | 1,017,275,000 | Yes | CEO |
| 74 | 5610 Restaurants and mobile food service activities | 394,150,000 | No | Head of office |
| 2 | 1721 Manufacture of corrugated paper and paperboard and of containers of paper and paperboard | 216,521,000 | No | Owner |
| 60 | 9499 Activities of other membership organisations nec | 206,282,000 | No | CTO |

*Table 13 Characteristics of interviewed SME companies (n=14)*

I begin the presentation of the expert survey results with an overview of the respondents' data.

The position of 14 respondents provide insight into organizational decision-making regarding technology adoption:

- C-level Executives (CEO, CFO, COO, CTO)
- Owners
- Other Roles (e.g., Head of Office)

C-level executives play a central role in technology adoption decisions, but their focus might prioritize other operational needs over digital signature solutions.

Each Of the 14 experts who participated in the survey, are leader of small- medium-sized enterprises with the following details (revenues in HUF)

The interviews were recorded and transcribed. The transcripts were coded and processed with the help of Taguette. Taguette is a free and open-source tool for qualitative research where you can import your research materials, highlight and tag quotes, and export the results.(*Taguette, the Free and Open-Source Qualitative Data Analysis Tool*, n.d.)

### 6.1.1 CODES USED

I have used the following codes to identify usability and user acceptance requirements

The dataset contains grouped feedback under various tags. Here's a summary of the content categories along with representative examples:

- **Acceptance**-Cost: Feedback on the costs associated with digital signatures. Example: *"I think it would be a few tens of thousands of forints."*
- **Advantage** of usage: Benefits of using digital signatures
  Example: "It's definitely faster, and much more traceable."
- **Bulk signature**: Comments on the use of bulk signing for documents.
  Example: "We don't sign that many contracts, maybe one or two per week."
- **Compatibility-Partners**: Issues or concerns about compatibility with partners.
  Example: "We have a few clients who don't accept it, for reasons I don't know."

- **Culture-Resistance**: Resistance or hesitation toward adopting digital signatures due to cultural habits.
  Example: "It has worked so far, and there's no big problem with it."
- **Device: Feedback** related to device preferences (e.g., mobile vs. computer).
  Example: "I sit in front of the computer all day anyway. It never even came up to use mobile."
- **General feedback**: General impressions or opinions about digital signatures.
  Example: "Personally, I really love these digital solutions."
- **Lack of knowledge**: Indications of insufficient understanding of the technology.
  Example: "I don't really understand this. We don't use time stamping or digital certificates."
- **Legal-NonAcceptance**: Issues about legal barriers or lack of acceptance.
  Example: "Every year I ask our lawyer why employment contracts don't accept this type of digital signature."
- **Processes**: Details about existing document-handling workflows.
  Example: "Documents are created, printed, signed with the manager's stamp and pen, and then stored as paper."

- **Prognosis for future usage**: Predictions or potential for broader adoption.
  Example: "If my children take over the company, they'll probably be more receptive to these things."
- Reason for not using digital signature: Barriers to adoption.
  Example: "There isn't such a volume of document circulation that would justify a more modern, electronic system."
- **Request for feature**: Suggestions for new features or improvements.
  Example: "It would be useful if this could be integrated with qualified Hungarian service providers."
- **Sectoral Variability**: Differences in adoption across industries.
  Example: "When goods leave us, there needs to be a signed delivery note, and this can't really happen digitally."
- **Trust and Security**: Concerns or confidence in the security of digital signatures.
  Example: "I trust digital signatures 100 percent. If it's based on cryptography, it has to be secure."
- **Types of documents**: Examples of documents that use or could use digital signatures.
  Example: "Contracts, quotes, material procurement, project preparation and follow-up."
- **Usability-Simplicity**: User experience feedback regarding ease of use
  Example: "It's easy. Save the PDF, upload it, add the signature, and two-three clicks and it's done."

Table 14 provides a detailed breakdown of qualitative codes derived from expert interviews, categorizing key themes related to digital signature adoption and its challenges among SMEs. A total of 261 coded responses were distributed across 17 categories, offering a nuanced perspective on adoption barriers and enablers.

| **Code** | **Quantity of Content** |
|---|---|
| Acceptance-Cost | 22 |
| Advantage of usage | 18 |
| Bulk signature | 1 |
| Compatibility-Partners | 12 |
| Culture-Resistance | 21 |
| Device | 2 |
| General feedback | 16 |
| Lack of knowledge | 25 |
| Legal-NonAcceptance | 13 |
| Processes | 25 |
| Prognosis for future usage | 20 |
| Reason for not using digital signature | 46 |
| Request for feature | 5 |
| Sectoral Variability | 4 |
| Trust and Security | 14 |
| Types of documents | 12 |
| Usability-Simplicity | 4 |
| **Sum** | **261** |

*Table 14 Frequency distribution of qualitative codes from interview transcripts.*

The most frequently coded category is "Reason for not using digital signature" (46 occurrences), capturing a broad spectrum of barriers that hinder adoption. This is closely followed by "Processes" (25) and "Lack of knowledge" (25), emphasizing the significance of operational hurdles and limited awareness as critical obstacles.

Categories like "Acceptance-Cost" (22) and "Advantage of usage" (18) reflect both the financial concerns and the perceived benefits of digital signatures, highlighting the duality of adoption drivers. "Culture-Resistance" (21) illustrates the impact of

organizational and generational attitudes, particularly resistance to change, as a major challenge.

Specific considerations, such as "Compatibility-Partners" (12) and "Types of documents" (12), underscore the importance of integration with external systems and applicability across various document types.

Less frequently mentioned but still relevant are categories like "Usability-Simplicity" (5) and "Request for feature" (5), which shed light on user experience and desired functionalities. These reflect emerging opportunities for improving user engagement and system adaptability. "Sectoral Variability" (4) points to differing adoption rates across industries, influenced by regulatory requirements and sector-specific needs.

This distribution of codes offers valuable insights into the multidimensional factors.

### 6.1.2 COHEN'S KAPPA AI VALIDATION OF CODING

To ensure the reliability and validity of the thematic analysis, the coding scheme was subjected to an inter-rater reliability (IRR) analysis. This process measures the degree of agreement between independent coders, and a high level of agreement indicates that the coding framework is robust, clearly defined, and consistently applicable.

As this study was conducted under the faculty of business and informatics, a novel approach was employed, utilizing an advanced Large Language Model (LLM) as an independent co-coder. The model chosen was a state-of-the-art generative AI on August 17, 2025, Claude 4,1 Opus thinking, selected for its documented strengths in complex analysis and text comprehension.

The advantages of using such a model for this purpose include:

- **High Accuracy and Nuance**: The model demonstrates near-human levels of comprehension, making it well-suited for understanding the nuanced context required for qualitative coding and outperforming other models on expert-level analytical benchmarks.
- **Consistency**: When guided by a precise prompt, the AI can apply a coding schema with a high degree of consistency across a large dataset, which is critical for reliable IRR calculations.
- **Bias Mitigation**: Using a non-human coder provides a valuable check against the primary researcher's potential biases, strengthening the objectivity of the findings.

To ensure the AI's performance was both independent and rigorously controlled, a detailed instructional prompt was developed. This prompt defined the AI's role, the specific coding schema, the required output format, and the critical constraint of ignoring the primary researcher's existing tags. I ran the prompt inside the Windsurf development tool.

#### 6.1.2.1 PROMPT

The following custom-developed prompt was used to guide the AI co-coder. Its formatting has been adjusted from markdown for readability.

### Prompt for AI Qualitative Co-Coder for Inter-Rater Reliability Analysis

**PERSONA**: You are a meticulous qualitative research assistant. Your expertise lies in the thematic analysis and coding of interview transcripts. You are precise, consistent, and adhere strictly to the provided coding schema. Your primary function is to act as an independent second coder to help establish inter-rater reliability for a research project.

**PROJECT CONTEXT**: I am analyzing semi-structured interview transcripts concerning the adoption of digital signatures in SMEs. I have already completed the first round of coding. I require you to perform a second, independent round of coding on the same data. Your coding will be compared against mine using the Cohen's Kappa statistic to measure the degree of agreement.

**CORE TASK**: For each text snippet I provide, you will independently assign the most appropriate code from the predefined Code Schema below. Your decision must be based solely on the content of the snippet. To ensure the statistical validity of the inter-rater reliability check, you must ignore the user_tag that I have already assigned to each snippet.

**CODE SCHEMA (PREDEFINED TAGS)**: You must use only the following codes. Do not invent new ones.

- Code 1 Name: Brief, precise definition of Code 1
- Code 2 Name: Brief, precise definition of Code 2
- Code 3 Name: Brief, precise definition of Code 3
- Example Code 1 - Advantage of usage: The snippet describes a benefit, time/cost savings, or efficiency gain from using the technology.
- Example Code 2 - Culture-Resistance: The snippet points to human factors, habits, legacy processes, or a "we've always done it this way" mentality as a barrier to adoption.
- Example Code 3 - Compatibility-Partners: The snippet discusses the challenge of partners, clients, or suppliers not accepting or using the same digital methods.
- UNCLEAR/AMBIGUOUS: Use this code ONLY if the content is too vague or does not clearly fit any other code in the schema.

**INSTRUCTIONS AND CONSTRAINTS**:

- Independence is Critical: Do not let my assigned tag (user_tag) influence your choice. Your primary value is in providing an unbiased, independent assessment.
- Adhere Strictly to the Schema: You must only use codes from the provided Code Schema.
- One Code Per Snippet: Assign only the single, most-fitting code to each snippet.
- Consistency: Apply the code definitions consistently across all snippets.
- Batch Processing: I will provide the data in batches. Please wait until you have received the full batch, then process all items and return one single, complete table as your output.

**CONFIRMATION**: Please confirm you have understood these instructions by summarizing your role and the primary goal of this task in one sentence. Then, await my first batch of data.

#### 6.1.2.2 RESULT

However, while LLMs excel at contextual understanding, they can be prone to inconsistencies in precise mathematical calculations. Therefore, to ensure the accuracy of the final Cohen's Kappa statistic, the comparison of the two sets of codes and the subsequent calculation were performed using a self-coded Python script dedicated to the task. This script programmatically generated the final agreement score and the confusion matrix, ensuring the result was both reproducible and mathematically sound.

**Results Summary of Python script**

Inter-rater Agreement Analysis:

- Cohen's Kappa (κ): 0.7550
- Agreement level: Substantial agreement

Interpretation

A Cohen's Kappa of 0.7550 indicates substantial agreement between the two raters (my coding vs. AI's coding) on the categorization of digital signature themes in my Hungarian SME research data.

Kappa interpretation scale (Landis & Koch, 1977):

- 0.61-0.80: Substantial agreement ← My result

This substantial inter-rater reliability ($\kappa = 0.7550$) strengthens the validity of my qualitative coding scheme for analyzing Hungarian SME perspectives on digital signature adoption. The agreement level supports the reliability of my thematic categories for dissertation analysis, so I proceed with my coding result

## 6.2 DISCUSSION OF THE CODED INTERVIEW

### 6.2.1 ACCEPTANCE-COST

The analysis highlights several key insights into the adoption of digital signatures among Hungarian SMEs, with cost perceptions playing a central role in decision-making. Many respondents perceive the solution as affordable, with comments such as *"I think it costs just a few tens of thousands of forints"* and *"It's even cheaper, as these costs are distributed."* These views indicate that digital signatures are considered a reasonable expense for some companies. However, there is notable variation in perspectives that might depend on company size and operational needs. For example, one respondent expressed concern, stating, *"We are not sure if this would be an affordable option for smaller companies,"* reflecting uncertainty about whether smaller enterprises could justify the cost.

Some organizations benefit from economies of scale, as indicated by statements like *"At the parent company, costs are distributed, and they inform us how much it will cost each branch before approval."* This centralized approach to cost-sharing appears to alleviate financial concerns for branches of larger entities. Still, there is skepticism about cost-effectiveness for companies with lower document volumes, with one participant explaining, *"In an optimal year, we sign 150 to 1,000 pages. It's not a significant amount."*

The lack of clear cost-benefit tradeoffs is a significant challenge for adoption. One respondent stated, *"The cost-benefit balance is not always clear, so the investment is*

*hard to justify."* This sentiment underscores the importance of demonstrating tangible savings or operational advantages to justify the investment. While some view longer-term subscriptions as potentially cost-saving, others point out that free options, such as government-provided AVDH solutions, meet basic needs: *"What we use for electronic signatures is the AVDH; it's the free government signature."*

The perception that costs align with benefits is reinforced by comments such as *"The price is definitely competitive, especially for larger packages."* However, there remains a need for greater clarity and transparency. This is particularly important for companies still transitioning from manual processes, as illustrated by *"We don't see significant savings compared to current manual processes."*

While many SMEs find digital signatures affordable, there is uncertainty about their cost-effectiveness for smaller companies. some organizations benefit from distributed costs, but smaller enterprises may struggle to justify the investment without clear benefits.

**Summary of code insights**

The findings align with the quantitative component of my research, where cost emerged as a moderate barrier but not the primary one. While many SMEs perceive digital signatures as affordable, concerns about scalability and unclear cost-benefit ratios remain significant.

### 6.2.2 ADVANTAGE OF USAGE

The analysis highlights the numerous advantages of digital signatures, as perceived by respondents, emphasizing operational efficiency, environmental benefits, and usability improvements. These insights underscore the transformative potential of e-signatures for Hungarian SMEs and align with the broader digital transformation goals.

**Operational Efficiency**

One of the most prominent advantages of digital signatures is their ability to streamline processes and reduce administrative burdens. As one respondent noted, *"Digital signatures speed up processes and reduce paperwork."* This efficiency extends to document management, where the ability to electronically archive and retrieve

documents saves significant time and effort. A participant explained, *"It's so much easier to pull up an electronic, well-archived document than to find a 20-year-old contract in the basement."* The durability and reliability of digital documents were also highlighted, with another stating, *"Printed documents yellow, and signatures can fade. They can even physically deteriorate, but electronic documents don't have these problems."*

Additionally, respondents emphasized how digital signatures improve tracking and workflow transparency, with one sharing, *"It's faster and definitely more trackable."* The mobility offered by digital solutions was another critical factor, as illustrated by the comment, *"If they have a tablet, they can read the document and sign it digitally on the spot, which is a definite advantage."* This ease of use, particularly for executives and employees frequently on the move, strengthens the appeal of digital signatures.

**Environmental and Practical Benefits**

The environmental impact of digital signatures is a recurring theme, with several respondents recognizing their role in reducing paper use. One noted, *"It's a more environmentally friendly solution because we don't use paper."* Practical benefits also emerged, with respondents appreciating the reduced need for printing and physical storage. As one respondent explained, *"We definitely print less. The storage method has changed too—previously, we worried about where to put paper and how to find it later. Now, we use cloud or local servers and organize everything for easy searchability."*

**Usability and Accessibility**

Digital signatures also simplify work processes for employees. Respondents highlighted how e-signatures eliminate the need for repetitive manual tasks, such as printing, signing, and scanning documents. One participant stated, *"If I have a document, I don't need to print it and sign it manually; I can sign it electronically in a provable way and send it via email or another method, avoiding postage."* This ease of use extends to organizational workflows, as another remarked, *"This makes my job so much easier; it's much more transparent."*

While there are initial challenges in adoption, such as learning the process, these hurdles appear surmountable. A participant shared their experience: *"It was quite difficult at first because it required help, but now that I understand the steps, it has made my work much easier."* This indicates that employees quickly adapt to the system with adequate support and training.

**Mobility and Collaboration**

The enhanced mobility provided by digital signatures is another key benefit, allowing work to continue seamlessly regardless of location. One respondent commented, *"Mobility means I don't need to be physically present."* This flexibility also facilitates smoother collaboration with partners and clients. A respondent noted, *"It's easier to work with partners when using this solution."*

**Integration with Existing Workflows**

Respondents also appreciated how digital signatures align with existing processes, such as electronic document sharing and storage. As one participant noted, *"We have digitized contracts—though they are scanned versions—but it still simplifies the process."* Another highlighted the role of digital signatures in modernizing workflows: *"Now I'm looking for tasks at the labor center, and it's so much simpler with this system."*

**Summary of code insights**

Qualitative data underscores the broad appeal of digital signatures among SMEs, focusing on their efficiency, usability, and sustainability.

### 6.2.3 COMPATIBILITY-PARTNERS

The dataset analysis highlights SMEs' multiple-aspect experiences when adopting digital signatures, emphasizing both the seamless integrations and the persisting challenges in collaboration with partners. These insights reveal the complex dynamics of digital transformation compatibility and reliance on external stakeholder readiness and preferences.

**Seamless Integrations and Quick Fixes**

Many respondents reported positive experiences in integrating digital signatures into their existing systems. One respondent remarked, *"The integration was simple with our existing systems."* This indicates that modern digital signature solutions often align well with current workflows, minimizing disruption. Even when compatibility issues arose, these were resolved efficiently, as noted by another respondent: *"There were minor compatibility issues, but they were quickly fixed."* These smooth integrations underline the potential of digital signatures to become a natural extension of organizational processes.

**Partner Resistance and Variability**

Despite internal successes, respondents frequently highlighted the resistance or variability in adoption among partners. A participant explained, *"We have a few clients who do not accept it, for reasons I don't know."* This lack of acceptance is often rooted in traditional practices or limited familiarity with digital signatures, creating hurdles in broader adoption.

The challenge of implementing digital signatures across international and domestic partnerships is also apparent. One respondent shared, *"Cross-border signatures happen, especially since we mostly work with international companies or those with foreign parent companies."* While digital signatures are often accepted abroad, domestic adoption remains inconsistent, with one participant noting, *"So far, no partner has raised the idea of having a digital signature on any document."*

**Cultural and Practical Misalignments**

The cultural resistance to digital signatures also manifests in peculiar scenarios. One participant shared an ironic experience: *"A partner specifically requested that the document be digitally signed or sealed in a tamper-proof manner. The biggest joke was that they then returned it printed and signed on paper."* This illustrates the gap between theoretical acceptance of digital methods and practical implementation.

Similarly, the back-and-forth in partner expectations adds complexity. A respondent noted, *"Initially, the impression was that it needed to be signed digitally. Then, practically an hour later, they said, absolutely not."* Such instances highlight the fluctuating expectations that complicate widespread adoption.

**Compatibility in Domestic vs. International Contexts**

The dataset also emphasizes the difference in digital signature acceptance between domestic and international contexts. Respondents working with international partners noted greater openness to digital methods, with one explaining, *“For our foreign partners, it is often completely acceptable to have a scanned, signed document; these usually work.”* However, collaborating with domestic clients or end-users presented challenges, as described by one participant: *“It’s hard to contract electronically with private individuals because there could be issues on the other side.”*

This discrepancy often forces organizations to adopt hybrid approaches. One respondent shared, *“We have a contract where one side signs electronically while we still sign on paper.”* Another added, *“When we got a recent order, the other partner asked whether to sign it on paper or electronically. I said, whatever’s convenient for them—we still only work with paper.”*

**Summary of code insights**

This analysis underscores a critical barrier to the widespread adoption of digital signatures: their dependence on external stakeholders. Even when SMEs integrate digital signatures seamlessly into their systems, the success of these efforts hinges on the readiness and willingness of partners and clients to adopt similar practices. The variability in domestic and international partner acceptance creates a fragmented adoption landscape that SMEs must navigate.

### 6.2.4 REASON FOR NOT USING DIGITAL SIGNATURES

The dataset analysis focusing on Reasons for Not Using Digital Signatures provides a comprehensive understanding of SMEs' barriers to adopting this technology. Through respondents' feedback, I can discern resistance patterns, practicality, perceived need, and cultural and systemic limitations.

**Perceived Lack of Necessity**

A prevalent theme is the perception that digital signatures are unnecessary for current operations. One respondent stated, *"I don’t feel the need for digital signatures in our current operations,"* while another shared, *"I don’t see any problems with signing documents manually."* These statements underscore that SMEs often perceive their

manual processes as sufficient, with no immediate benefits from transitioning to digital signatures.

Similarly, the frequency of document signing plays a role in shaping this perception. As one participant explained, *"In a whole month, there are only one or two things I sign. It's hard to assume we need digitization here."* For businesses with low document turnover, the time and cost investment required for digital signature solutions seems unjustifiable.

**Partner and Customer Demand**

The limited demand from partners and customers is another significant barrier. Many SMEs noted the absence of external pressure to adopt digital signatures, as one respondent stated, *"There has been no demand from partners to transition to digital signatures."* Others echoed this sentiment, highlighting that even multinational clients rarely impose such requirements. Another respondent elaborated, *"Our partners have not insisted on receiving documents this way, although we occasionally receive such requests ourselves."*

This external dynamic is reinforced by the lack of mutual understanding in digital adoption. One participant noted, *"Our clients wouldn't understand the digital signature process,"* indicating that even if SMEs adopted digital signatures, broader acceptance would remain an obstacle.

**Cultural and Practical Resistance**

Cultural attitudes and deeply ingrained practices also hinder adoption. A telling example is, *"It's ingrained in people; this practice works well, everything is in place, and everyone knows what to do."* Age, demographics, and leadership attitudes compound this resistance to change. For instance, *"The one in charge here is 68 years old. There's no way they'd transition to digital signatures,"* reflects generational reluctance.

For many, traditional methods feel more reliable. As one respondent explained, *"We prepare documents on paper and store them in folders. Everything is in order and easy to find when needed."* Others pointed out that manual methods are simple and effective: *"We hand out the documents to the signatories, and they sign them on paper. This is the easiest solution for now."*

**Perceived Complexity and Misconceptions**

Complexity, both real and perceived, deters SMEs from adopting digital signatures. Respondents highlighted that while electronic documentation exists in their processes, signing remains manual. One participant shared, *"Technically, we handle electronic documents, but when you consider the process, it doesn't save work time."* Another added, *"To even try the system, we'd need a catalyst event to justify why to use it in the first place."*

Such feedback reflects misconceptions about the efficiency and integration of digital solutions. For some, digital signatures seem to overcomplicate simple tasks: *"It would just complicate our lives."*

**Systemic and Administrative Barriers**

SMEs also face systemic hurdles. The reliance on physical presence for operations during the COVID-19 pandemic exemplifies this: *"We sent home half to two-thirds of our team during COVID, but many processes still required physical presence."* These operational realities make digital signatures less relevant in certain contexts.

Administrative practices further limit adoption. For example, *"We still sign employment-related documents manually because they require two signatures or need to be signed locally,"* demonstrates that some processes are hardwired for paper.

**Future Generational and Strategic Shifts**

While immediate demand is low, some SMEs recognize potential future benefits. Generational shifts could play a role, as one respondent noted, *"If my children take over the company, they will likely adopt such innovations because they will approach everything differently."* This reflects a gradual but inevitable shift toward modernization driven by younger leadership.

**Summary of code insights**

This dataset highlights a range of factors that hinder SMEs' adoption of digital signatures, with common themes of cultural inertia, perceived sufficiency of manual processes, and limited external demand. These findings resonate with the quantitative portion of this study, where the perceived lack of utility and low document turnover emerged as facts. Generational shifts and increasing external requirements could

catalyze future adoption, emphasizing the need for tailored advocacy efforts that address misconceptions and highlight tangible benefits.

### 6.2.5 LACK OF KNOWLEDGE

The dataset vividly illustrates Hungarian SMEs' challenges in adopting digital signatures, particularly the lack of knowledge and confidence in the technology. Many responses reflect a sense of unfamiliarity with the practicalities of implementation and the legal frameworks governing digital signatures. These sentiments resonate with my quantitative research's study's focus on cultural, practical, and systemic barriers.

Participants often expressed their struggle with understanding the processes involved, exemplified by one respondent who stated, *"I am uninformed about the legal acceptance of digital signatures."* This lack of clarity regarding the legal framework suggests a pressing need for awareness campaigns or educational initiatives tailored to SMEs.

Furthermore, the perceived complexity of digital signature tools emerged as a recurring concern. One individual noted, *"I don't really understand this. We don't use time-stamping or digital certificates provided by external service providers."* Similarly, another respondent reflected, *"I only know Adobe Reader, where I think you can set these parameters with a few clicks to include a timestamp."* While this reflects some level of familiarity with a basic tool, it also highlights the limited exposure to more advanced digital signature systems.

**Practical Challenges and Systemic Constraints**

Many participants identified practical barriers, such as the compatibility of digital signatures with their current practices and the perceived necessity for physical documentation. For instance, one respondent mentioned, *"The documents we sign now are fully legally valid when printed."* This reflects a deep-rooted trust in traditional, paper-based methods, which are seen as reliable and universally accepted. Another echoed this sentiment, saying, *"Signed documents are also printed to avoid any issues."* These practices indicate a systemic reliance on paper documentation, which digital signature solutions must address to gain wider acceptance. Legal uncertainties also emerged as a significant theme. One participant shared, *"Every year I ask our lawyer why this type of digital signature is not accepted for*

*employment contracts, and every year we find that it's not at that level yet."* This recurring doubt about legal sufficiency adds another layer of complexity to adoption efforts. Additionally, the use of mixed systems, such as scanning signed documents and exchanging them via email, further demonstrates a transitional state where businesses are yet to embrace digital solutions fully.

**Generational and Cultural Factors**

Generational differences also play a role in the adoption of digital signatures. A respondent observed, *"There is a greater lack of knowledge among older generations."* This aligns with broader trends suggesting that younger, more tech-savvy generations may be more open to digital innovations while older professionals may require additional training or reassurance

In another example, cultural preferences for in-person, paper-based transactions were evident: *"Technically, the request is to print, have the client sign, and then upload it back. The company considered this an electronically suitable document."* Such practices reinforce the perception that digital solutions are supplementary rather than replacements for traditional methods.

**Summary of code insights**

This dataset provides rich qualitative evidence of SMEs' barriers to adopting digital signatures. From knowledge gaps and legal uncertainties to entrenched paper-based habits and generational divides, these insights offer valuable guidance for my customer-centric exploratory study.

### 6.2.6 PROCESSES

This dataset delves into the operational processes surrounding document handling and signing practices in Hungarian SMEs. It reveals a hybrid environment where digital and traditional paper-based methods coexist, illustrating these organizations' transitional phases.

The reliance on traditional practices remains strong, as one participant highlighted, *"These documents are still managed by preparing them electronically, printing them, having them signed by the executive with a seal, and then they exist in paper form."* This statement underscores the deep-rooted preference for physical documentation,

which often serves as a fallback even when initial steps are digital. Another respondent elaborated on the inefficiencies of paper-based processes: *"Depending on how many papers accumulated weekly or bi-weekly, we sent out a batch and waited for it to return. It was very tedious and lengthy."*

**Practical and Systemic Barriers**

The systemic reliance on paper persists even in organizations that have adopted partial digital workflows. For instance, one participant noted, *"Even if the administration is done electronically, for some reason, we still send paper back and forth, even with partners who we know operate fully digitally."* This illustrates a lack of alignment between internal processes and external partner capabilities, creating inefficiencies and missed opportunities for streamlining operations.

Legal and procedural constraints also play a significant role in slowing adoption. A respondent shared, *"Unfortunately, for employment contracts, authorities do not accept digital signatures, so these contracts are still handled through postal mail."* This highlights how external regulatory requirements can dictate internal practices, often forcing organizations to maintain dual systems.

**Incremental Adoption of Digital Tools**

The dataset also reveals instances where digital tools are beginning to take root, albeit unevenly. One participant mentioned, *"We subscribed to DocuSign around 4-5 years ago for signing contracts, but employment contracts are still handled by mail."* This illustrates a selective approach to adoption, where digital tools are used for specific tasks while others remain firmly entrenched in traditional methods. Another respondent reflected on growing familiarity with digital signing systems, stating, *"Over time, digital signatures and movements are becoming more frequent, and Adobe's electronic signing system is regularly used."*
The role of foreign partnerships in driving digital adoption is evident. One participant highlighted, *"With foreign partners, it is very often fully acceptable to use a simple scanned signed contract, and these arrangements usually work."* This reflects a divergence in practices influenced by international norms, suggesting that SMEs with more global exposure may be more inclined to experiment with digital solutions.

**Cultural and Organizational Dynamics**

Cultural factors and organizational structures also influence the adoption process. For example, one participant explained, *"At the company, there is one lawyer who has the right to use an electronic signature."* This centralized approach can create bottlenecks and limit the broader implementation of digital tools. Additionally, the ingrained habit of printing, signing, and scanning documents remains prevalent, as expressed by another respondent: *"What I prepare, I print, sign, scan, and upload."*

**Summary of code insights**

This dataset highlights the complex interplay of traditional and digital processes within Hungarian SMEs, underscoring both progress and persistent barriers. The cultural attachment to physical documentation and centralized signing authority further complicates adoption efforts.

### 6.2.7 PROGNOSIS FOR FUTURE USAGE

This dataset provides insights into the projected adoption and attitudes toward the future use of digital signatures within Hungarian SMEs. The responses demonstrate optimism and a sense of inevitability about the increasing integration of digital signatures in business practices.

A forward-looking perspective is evident in statements such as, *"The system's usage is expected to spread even more in the coming years,"* and, *"Digital signatures will become the standard in the business world."* These responses highlight a shared belief among participants that digital signatures are poised to transition from a novel innovation to a default method, driven by both external factors such as regulatory support and internal pressures from clients and stakeholders.

**Generational and Cultural Dynamics**

Generational shifts are seen as a catalyst for adoption. One respondent remarked, *"For the new generations, this will be the default method."* This reflects the expectation that younger, more technologically adept leaders and employees will naturally gravitate toward digital solutions, accelerating their widespread implementation. Another participant noted, *"If the younger generation moves into company leadership positions, they will likely be more innovative."*

**Systemic and External Influences**

External factors, such as customer demand and regulatory developments, also play a key role in the anticipated growth of digital signature usage. *"More customers are demanding these kinds of solutions,"* a respondent observed, emphasizing the growing external pressure on SMEs to adopt digital tools. Similarly, another participant noted, *"Regulatory frameworks will likely support its spread,"* pointing to the enabling role that legal and institutional support can play in normalizing digital signatures.

The ripple effect of peer adoption is also highlighted as a motivator. One individual stated, *"If more companies start using it, especially within our partnership circle, the idea would certainly come up for us as well."* This reflects the role of network effects in fostering broader acceptance.

**Pragmatic Views on Implementation**

Despite the optimism, several responses indicate a measured approach to adoption. *"It will likely be a multi-step implementation process,"* one participant noted, suggesting that gradual integration and pilot testing will be key strategies for many organizations. Another echoed this sentiment, stating, *"We plan to implement it, but we don't have a fully concrete plan yet."* These remarks underscore the importance of clear, phased strategies for successful adoption.

A practical view of the learning curve is also evident. *"I think this could be easily mastered by all involved within a few days after a short crash course,"* a respondent stated, confident that the technical and operational barriers can be overcome with proper training.

**Summary of code insights**

The dataset paints an optimistic picture of the future of digital signature adoption in Hungarian SMEs. Respondents believe that technological advancements, generational leadership shifts, and increasing customer demand will drive widespread integration. External factors such as regulatory support and peer influence are also seen as critical enablers.

While enthusiasm for digital signatures is high, there is recognition of the need for strategic planning and phased implementation.

### 6.2.8 TRUST AND SECURITY

This dataset provides insights into perceptions of trust and security surrounding digital signatures in Hungarian SMEs. Trust and security are foundational for adopting digital signature solutions, especially in environments dealing with sensitive or confidential information. The responses reflect a mix of confidence in technology and concerns over human factors and systemic vulnerabilities, aligning with my research focus on usability and acceptance barriers.

One participant expressed strong confidence in the technology, stating, *"We've dealt with encryption, so I trust digital signatures one hundred percent; they need to be secure."* This highlights the belief that when properly implemented, digital signatures offer a robust security level. Another respondent echoed this sentiment, saying, *"I don't think this poses significant security risks. Every technical application generates some risk, but I don't think this creates extra risk for us."* These statements demonstrate a general trust in the technical integrity of digital signatures, which is a positive indicator for their broader acceptance.

**Concerns Over Vulnerabilities**

Despite the confidence in technical security, participants raised concerns about potential vulnerabilities. For instance, one individual remarked, *"Questions arise, first about whether what is signed with it is legally valid, and second about how hackable the system is, or whether someone could interfere and sign fraudulently. But I don't consider either of these concerns serious."* While this reflects a moderate level of concern, it also indicates that the perceived risks do not constitute major adoption barriers for most respondents.

Another participant provided a compelling example of the risks inherent in traditional methods: *"A photocopier was repaired at our office two or three weeks ago, and they copied something for me that looked exactly like I had signed it. A paper signature can be easily forged, perhaps even more easily than a digital one."* This comparison underscores the relative advantage of digital signatures over traditional paper-based methods in terms of forgery prevention, a key point for promoting their adoption.

**Human and Organizational Factors**

Human behavior and organizational practices also emerged as significant themes. One respondent shared, *"On the human side, I can give a bad example. I go to the office across the hall, open a laptop, and there's a password stuck to it."* This example highlights the risks posed by poor password management and underscores the need for better training and stricter enforcement of security policies. Another respondent added, *"People don't usually misbehave, thank God, but when someone goes on vacation, they share their password with a colleague."* Such practices undermine the security of even the most robust systems, highlighting the need for comprehensive organizational policies and user education.

A related concern is the lack of security awareness among employees, as one participant noted, *"I see many colleagues whose phones aren't secured. It's not an issue when it's just their passwords, but when it involves company data, it's a concern."* This reflects a gap in the implementation of corporate security policies, which can erode trust in digital systems if not addressed.

**Summary of code insights**

The dataset reveals a dual perspective on trust and security in digital signatures within Hungarian SMEs. While confidence in technology is generally high, concerns persist about human factors, systemic vulnerabilities, and poor security practices. Respondents also highlighted the comparative advantages of digital signatures over traditional methods in terms of Documentum archiving.

These insights reinforce the importance of addressing both technical and human factors to build trust and ensure the secure adoption of digital signatures.

### 6.2.9 CULTURE-RESISTANCE

This dataset provides a comprehensive view of cultural resistance to adopting digital signatures within Hungarian SMEs. It highlights key barriers, including employee reluctance, generational divides, and entrenched practices favoring traditional paper-based methods. These cultural factors align closely with my research focus on usability and acceptance barriers.

One significant theme is the perceived complexity and lack of readiness among employees. A respondent stated, *"The employees do not feel skilled enough to use it,"*

reflecting a widespread lack of confidence in adopting digital tools. Another noted, *"The system implementation seems too complicated for them,"* indicating that the perception of complexity creates a psychological barrier, even if the technology itself is user-friendly.

**Generational and Leadership Resistance**

Generational differences within SMEs are evident in the reluctance of older leaders and employees to embrace digital methods. One participant shared, *"My supervisors are not interested; they're a bit older, and they prefer reading and signing things on paper. They'd rather mail it, whether it's an electricity contract, gas contract, or anything else."*

This resistance also manifests in workplace habits. *"The manager likes to hand over employment contracts to employees personally,"* a respondent explained, underscoring the symbolic and procedural significance attached to physical interactions. Such practices not only delay digital adoption but also highlight the need to address emotional and psychological attachments to traditional methods.

**Employee Reluctance and Familiarity**

Employee resistance to digital solutions is another recurring theme. *"Many colleagues are wary of technology,"* one respondent observed, reflecting a broader hesitation among employees to move beyond familiar paper-based systems. Another noted, *"They don't feel that the digital solution would be simpler for them,"* illustrating a disconnect between the perceived and actual efficiency of digital tools.

Entrenched habits also hinder adoption. *"They tend to print every page, sign it individually, and then store it in a binder,"* one participant explained, revealing how ingrained paper-based processes continue to dominate despite the availability of digital alternatives.

**Organizational Culture and Hesitation**

The dataset also highlights a broader cultural resistance to change within SMEs. A participant shared, *"We don't usually jump into new things first; we wait until it's absolutely necessary."* This cautious approach reflects a reactive rather than proactive mindset, which can slow the pace of technological transformation. Another respondent

remarked, *"I think we're not that open,"* reinforcing the notion that organizational culture can serve as a significant barrier to innovation.

The status quo often feels sufficient to many employees and leaders, as one respondent explained, *"It has worked so far, and we don't have too many issues with it."* This resistance to change is compounded by the perception that digital solutions do not provide enough immediate benefits to justify the adoption effort. *"The fact that employees would have fewer tasks is not a consideration,"* one respondent noted, highlighting a lack of emphasis on operational efficiency.

**Summary of code insights**

This dataset underscores the deep cultural resistance to digital signature adoption in Hungarian SMEs, shaped by generational divides, entrenched habits, and a cautious organizational culture. While digital tools promise efficiency and security, they are often perceived as complex and unnecessary, especially by older leadership and employees accustomed to paper-based methods.

### 6.2.10 GENERAL FEEDBACK

This dataset provides general feedback on attitudes toward digital signature adoption within Hungarian SMEs. It reflects various perspectives, ranging from enthusiasm for digital solutions to cautious skepticism. These responses contribute valuable insights into the readiness and perceived value of adopting digital signatures, aligning with my research on usability, cultural acceptance, and organizational barriers.

**Mixed Readiness and Perceived Timing**

Several responses suggest that while the concept of digital signatures is acknowledged, it is not yet seen as an immediate necessity. One respondent stated, *"I know this exists, but it hasn't come to our desk yet,"* indicating low urgency and priority within their organization. Another remarked, *"I think this is still in its infancy,"* reflecting the perception that the technology or its adoption is not yet mature enough for widespread use.

Conversely, there is awareness of the potential benefits for specific business environments. A participant noted, *"Small companies probably don't have much demand for this, but medium-sized businesses, especially those with a lot of*

*paperwork, could need it."* This highlights how the demand for digital signatures correlates with the size and administrative complexity of the organization.

**Enthusiasm for Digital Solutions**

Despite cautious attitudes, there are signs of enthusiasm among respondents. One stated, *"Personally, I really like these digital solutions,"* demonstrating individual openness to innovation. Another shared, *"It could be simpler if we used it, with less paperwork, for sure,"* recognizing the practical advantages of digital signatures in reducing administrative burdens.

Organizations characterized by a forward-thinking culture are particularly receptive. As one participant described, *"Innovation characterizes the organization anyway, so we are quite open to anything that makes life easier or reduces waste production."* This suggests that companies with a culture of innovation are more likely to adopt digital tools, especially when environmental benefits are also a factor.

**Generational and Cultural Factors**

Generational dynamics are also evident in the dataset. One respondent noted, *"Looking at those signing contracts, it's usually not young people buying new property; it's older people who come in."* This observation implies that digital solutions may face slower adoption in contexts where older generations dominate decision-making processes. In contrast, younger individuals tend to prefer digital channels, as seen in the remark, *"Young people often handle these things via email or phone."*

**Adoption Lag and External Influence**

The dataset also highlights a perceived lag in adoption compared to peers. One respondent commented, *"I think others use it better than us; we're below average,"* reflecting a sense of underperformance relative to other businesses. However, there is also recognition that this lag has not yet caused significant disadvantage: *"We're not really behind, I think, but it hasn't really been a disadvantage for us either, as there hasn't been a situation where it was absolutely necessary."*

External influences, such as regional trends and peer practices, play a role in shaping attitudes. *"As far as I know, many companies around here already use it, and some even send pay slips electronically,"* one participant observed, illustrating how exposure to peers' practices can gradually normalize digital signature adoption.

**Summary of code insights**

The general feedback indicates a mix of readiness and hesitation toward digital signature adoption in Hungarian SMEs. While some organizations and individuals are enthusiastic about the potential benefits of digital solutions, others view the technology as premature or non-essential. Key barriers include generational dynamics, low perceived urgency, and a lack of immediate disadvantage from not adopting digital signatures.

### 6.2.11 LEGAL-NONACCEPTANCE

This dataset sheds light on the challenges of legal non-acceptance as a barrier to adopting digital signatures in Hungarian SMEs. It highlights systemic legal and regulatory obstacles, partner concerns, and limitations in international and local contexts.

**Legal and Regulatory Constraints**

A prominent issue is the inconsistency in legal acceptance across jurisdictions. One respondent stated, *"In some countries, digital signatures are still not accepted,"* illustrating how international operations can complicate adoption. Similarly, a participant noted, *"Local laws do not always support this solution,"* reflecting the variability in legal frameworks even within national contexts. These disparities create uncertainty for SMEs, particularly those engaged in cross-border transactions.

Legal acceptance by authorities is another major concern. A respondent shared, *"Authorities do not always accept these signatures,"* highlighting that even within countries where digital signatures are legally recognized, practical implementation can lag behind.

**Practical Challenges in Specific Contexts**

Certain contractual and operational contexts necessitate paper-based signatures despite digital alternatives. As one participant explained, *"Some contracts still require paper-based signatures,"* pointing to legacy practices and entrenched workflows. Another respondent provided a detailed example, stating, *"Since we are ISO certified, there are certain documents that must also be signed according to ISO standards. Recently, this was the case with our insurance policy, which both of us had to sign and*

*upload to the internal portal."* This indicates that compliance with international standards can also reinforce reliance on traditional methods.

**Partner and Stakeholder Concerns**

Partner hesitation and uncertainty about legal validity further complicate adoption. A respondent observed, *"Some partners worry about the legal validity,"* indicating that the perceived reliability of digital signatures among stakeholders is crucial for widespread implementation. This aligns with the broader theme that trust in the system, including its legal robustness, is a prerequisite for acceptance.

The financial sector, in particular, demonstrates resistance to digital signatures. *"The bank does not accept it,"* one respondent noted, emphasizing the persistence of paper-based processes in industries where legal and regulatory compliance is paramount. The participant added, *"It's alarming that in the 21st century, everything is still so paper-based,"* reflecting frustration with the slow pace of modernization in certain sectors.

**Operational and Procedural Frictions**

Practical implementation issues also emerged as barriers. One respondent highlighted inefficiencies in document handling, stating, *"We send scanned and twice-signed documents back and forth via email, but we don't even know how the document was filled out."* This suggests that incomplete adoption of digital solutions leads to inefficiencies and confusion, further deterring full implementation.

Another shared a hypothetical legal concern: *"If it comes to court, it becomes more challenging, but none of us intend for that to happen."* This highlights apprehensions about the perceived strength of digital signatures in legal disputes, even if such situations are rare.

**Summary of code insights**

This dataset underscores the significant role of legal non-acceptance as a barrier to digital signature adoption in Hungarian SMEs. Key challenges include inconsistent legal frameworks, sector-specific resistance (e.g., banking), and partner hesitancy about legal validity. These factors combine to create uncertainty, slowing adoption and reinforcing reliance on traditional paper-based methods.

### 6.2.12 REQUEST FOR FEATURES

The feedback highlights specific features that SMEs consider essential for digital signature solutions.

One recurring need is localization and customization. A respondent stated, *"We would like to have more language options in the system,"* emphasizing the importance of multilingual support to accommodate diverse user bases. Another participant highlighted the need for automation, saying, *"An automatic signature validation feature would be useful."* Such functionality could build confidence in the system by simplifying verification processes.

Integration with existing systems is another critical demand. One respondent explained, *"A key consideration during implementation will be how we can integrate it into our document management system."* This reflects the importance of compatibility with current IT infrastructures to streamline workflows and minimize disruption during adoption.

Legal compliance also emerged as a priority. A participant noted, *"It would be acceptable if integrated with the two Hungarian service providers that handle time-stamping and are trusted,"* indicating the need for systems that align with local legal and regulatory standards.

**Sectoral Variability**

The dataset underscores differences in digital signature adoption across industries. In international logistics, one respondent observed, *"The level of acceptance varies,"* reflecting diverse practices influenced by global standards and regional norms. In finance, traditional practices persist, as noted by another participant: *"Invoices still move a lot on paper."*

The public sector poses unique challenges. A respondent remarked, *"In the public sector, implementation is cumbersome due to regulations,"* highlighting the systemic resistance created by strict legal frameworks. Furthermore, certain operational contexts, such as shipping, continue to rely on paper-based systems. One participant noted, *"When any goods leave us, it is necessary to have a signed delivery note, and this cannot really happen digitally."* These findings suggest that sector-specific strategies are essential for promoting adoption.

The dataset identifies a wide range of documents suitable for digital signatures, including *"employment contracts," "project documentation," "invoices,"* and *"quarterly data reporting to the Hungarian National Bank."*

A respondent emphasized the burden of traditional documentation processes, stating, *"Entering employees generates a lot of paperwork,"* suggesting that digital tools could significantly reduce administrative workloads.

### 6.2.13 PROCESS MATURITY AND IT INTEGRATION CONSIDERATIONS

In this section I address process maturity levels and IT integration requirements that emerged from the expert interviews, responding to the observation that examining these factors more deeply would provide valuable insights for the IT sector and digital transformation initiatives.

#### 6.2.13.1 PROCESS MATURITY LEVELS IN DOCUMENT MANAGEMENT:

The interviewed SMEs demonstrated varying levels of digital process maturity, which can be conceptualized across four distinct stages:

**Level 1 - Fully Manual Processes**

Several respondents described entirely paper-based workflows. One participant explained, *"We hand out the documents to the signatories, and they sign them on paper. This is the easiest solution for now."* Another elaborated, *"Documents are created, printed, signed with the manager's stamp and pen, and then stored as paper."* These organizations maintain traditional filing systems with physical folders and manual archiving.

**Level 2 - Hybrid Print-Scan Workflows**

A substantial proportion of SMEs operate in a transitional state, creating documents electronically but reverting to paper for authentication. As one respondent described, *"I prepare documents, print them, sign them, scan them, and upload them."* Another noted, *"Even when the transaction is electronic, we still move paper back and forth with partners who we know operate fully digitally."* This hybrid approach combines digital creation with physical authentication, representing an inefficient intermediate stage.

**Level 3 - Basic Digital Authentication**

Some enterprises have adopted government-provided electronic signature solutions for specific use cases. One participant stated, *"We use AVDH [government e-signature] for supported employee-related documentation."* However, these implementations remain limited in scope, with most business processes continuing on paper.

#### 6.2.13.2 IT INTEGRATION REQUIREMENTS AND BARRIERS

The transition between maturity levels depends heavily on IT integration capabilities. Respondents identified several critical technical considerations:

**Document Management System Compatibility**

Multiple participants emphasized the importance of integration with existing IT infrastructure. As one respondent explained, *"We have a document management system, which is one factor, but actively using it is another. Implementation will be a key consideration, how we can integrate digital signatures into our document management system."*

**Multi-Signature and Geographic Distribution**

Organizations with multiple signatories face specific technical challenges. One participant described their situation: *"We have three authorized signers, but two signatures are required. Depending on who is available, one is in Bratislava, another in Vienna, we route documents accordingly."* This distribution necessitates cloud-based solutions with role-based access controls.

**Authentication Method Selection**

The choice between authentication mechanisms emerged as a practical concern. One respondent noted, "We will need to decide on signature type—mobile application-based, card-based, etc. The technical side is still under consideration." This reflects uncertainty about which authentication approach best balances security, usability, and organizational workflows.

The qualitative analysis reveals that digital signature adoption among Hungarian SMEs is shaped by five primary barrier categories: knowledge deficits and legal uncertainty, cultural resistance rooted in generational divides, partner ecosystem

dependencies, perceived lack of necessity among low-volume firms, and hybrid operational realities where parallel paper-digital processes persist. These findings, synthesized with quantitative patterns in the following chapter, illuminate the mechanisms underlying adoption disparities across company sizes and sectors.

# 7 SUMMARY

HOW DO THE SPECIFIC CHARACTERISTICS OF HUNGARIAN SMES INFLUENCE THE INTRODUCTION OF DIGITAL SIGNATURES, AND WHAT ARE THE DISTINCT USABILITY AND USER ACCEPTANCE REQUIREMENTS

This thesis investigates the adoption, usability, and user acceptance of digital signature solutions within the Hungarian small and medium-sized enterprise (SME) sector through a customer-centric lens, examining how organizational characteristics, technological infrastructure, and institutional context shape adoption patterns.

## 7.1 THEORETICAL FRAMEWORK AND RESEARCH DESIGN

The research builds upon the Technology Acceptance Model (TAM; Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT), extending these frameworks to account for the regulatory nature of digital signatures and the resource constraints characteristic of SMEs. The study employs a mixed-methods exploratory design, integrating three complementary research phases: (1) systematic literature review with text mining analysis of 1,469 Scopus articles, (2) structured telephone survey of 200 Hungarian SMEs (5–249 employees) with chi-square tests and logistic regression modeling, and (3) semi-structured interviews with 14 SME decision-makers analyzed through thematic coding.

## 7.2 LITERATURE REVIEW FINDINGS

The systematic literature review reveals that while digital signature technology has achieved technical maturity and regulatory recognition globally, a significant research gap exists in understanding user acceptance patterns, particularly within resource-constrained SME environments. Text mining analysis identified the prevailing academic conceptualization as "security-based signature" or "signature-based security," emphasizing technical authentication over user experience. The review

synthesizes three research streams—technological infrastructure (PKI, cryptography, timestamps), regulatory frameworks (eIDAS in EU, UETA/ESIGN in US, Hungarian Act XXXV/2001), and usability considerations—revealing that most research addresses the first two dimensions while neglecting the third, particularly in SME contexts. This research gap is particularly significant in Hungary, where (Kis, 2010) identified that while technology adoption studies have examined infrastructure development and regulatory frameworks extensively, customer-centric and usability-focused research remains limited, especially concerning SME-specific barriers and acceptance patterns.

## 7.3 QUANTITATIVE FINDINGS: DETERMINANTS OF ADOPTION

Survey analysis of 200 Hungarian SMEs revealed that 44% currently use digital signatures (n=87), with adoption significantly influenced by company size and sectoral orientation. Chi-square tests demonstrated strong statistical associations between adoption and revenue ($\chi^2$=44.780, p<.001), employee count ($\chi^2$=52.440, p<.001), and sectoral focus ($\chi^2$=13.653, p=.001). Logistic regression modeling (Model 3: Cox & Snell $R^2$=0.318, Nagelkerke $R^2$=0.426) identified company size as the strongest predictor, with larger enterprises (50–249 employees) exhibiting adoption rates exceeding 70%, compared to approximately 30% among smaller firms (5–9 employees).

Sectoral analysis revealed that service-oriented companies demonstrate significantly higher adoption propensities than industrial (β=-2.232, p<.001) or commercial (β=-0.846, p=.045) enterprises. This pattern aligns with TAM's perceived usefulness (PU) construct: service firms' document-intensive workflows and frequent client interactions increase the perceived utility of digital authentication. Conversely, industrial firms' reliance on embedded ERP systems and stringent quality assurance protocols may reduce perceied ease of use (PEOU), creating adoption barriers. This sectoral variation aligns with broader patterns observed in Hungarian technology adoption research. Kis (Kis, 2010) found similar sectoral disparities in broadband infrastructure utilization, where service sectors demonstrated higher ICT integration compared to industrial and commercial sectors, suggesting persistent structural differences in Hungarian business digitalization across industries.

Contrary to initial expectations, the geographic distribution of business partners showed no significant association with adoption ($\chi^2$=8.891, p=.180). This finding suggests that regulatory infrastructure and institutional support (UTAUT's facilitating conditions) may supersede geographic factors, as trust service providers and legal frameworks enable digital authentication regardless of partner location.

Among adopters, **70%** utilize cloud-based solutions compared to 30% using hardware tokens, with user satisfaction ratings averaging 4.8–4.9 out of 5. However, automation remains underutilized: only 8% report automated signature workflows, and 21% employ bulk signing functionality. Cost barriers are minimal, with 56% of small firms using free solutions and 80% of all adopters reporting total costs below 50,000 HUF annually. Document management patterns differ markedly: **more than 60%** of adopters operate partially or fully paperless, compared to approximately 75% of non-adopters remaining in early digitalization stages.

## 7.4 QUALITATIVE FINDINGS: BARRIERS AND MECHANISMS

RQ2

WHAT IS THE IMPACT OF THE SPECIFIC CHARACTERISTICS OF THE HUNGARIAN SMALL AND MEDIUM-SIZED ENTERPRISE (SME) SECTOR ON THE INTRODUCTION OF DIGITAL SIGNATURES?

Semi-structured interviews with 14 SME stakeholders revealed five primary barrier categories, illuminating the mechanisms underlying quantitative patterns:

**Knowledge Deficits and Legal Uncertainty:** Respondents frequently cited confusion regarding legal validity: *"Every year I ask our lawyer why this type of digital signature is not accepted for employment contracts."* This reflects weak facilitating conditions (FC) in UTAUT terms, where regulatory ambiguity undermines perceived usefulness. Legal and regulatory uncertainties have historically constrained Hungarian enterprise technology adoption. Kis (Kis, 2010) documented how regulatory framework inconsistencies and unclear state policy guidance created barriers to infrastructure investment and technology utilization among Hungarian businesses, a pattern that persists in digital signature adoption contexts.

**Cultural Resistance and Generational Divides:** Older leadership demonstrates strong preference for tangible documentation: *"My supervisors are not interested; they're a bit older, and they prefer reading and signing things on paper. They'd rather mail it."* This pattern suggests low PEOU among certain demographic segments, where technology is perceived as complex rather than simplifying.

**Partner Ecosystem Dependencies:** Network effects emerged as critical: *"We can't fully transition because our clients still request paper signatures."* Seventy-five percent of respondents identified partner resistance as a primary obstacle, revealing that adoption decisions extend beyond organizational boundaries. One respondent described regulatory constraints: *"For employment contracts, authorities do not accept digital signatures, so these contracts are still handled through postal mail."*

**Perceived Lack of Necessity:** Smaller firms with low document volumes question technology relevance: *"In a whole month, there are only one or two things I sign. It's hard to assume we need digitization here."* This reflects insufficient PU for firms below a critical transaction threshold.

**Hybrid Operational Realities:** Transitional practices are common: *"We have a contract where one side signs electronically while we still sign on paper."* Even adopters maintain parallel processes: *"Signed documents are also printed to avoid any issues."*

Despite barriers, future outlook remains optimistic. Respondents anticipate generational leadership transitions: *"If my children take over the company, they will likely adopt such innovations because they will approach everything differently."* This suggests adoption may accelerate through demographic succession rather than current leadership conversion.

# 8 PRACTICAL IMPLICATIONS AND SEGMENT-SPECIFIC REQUIREMENTS

RQ3

WHAT ARE THE SPECIFIC USABILITY AND USER ACCEPTANCE REQUIREMENTS FOR DIGITAL SIGNATURE SOLUTIONS WITHIN DIFFERENT SEGMENTS OF HUNGARIAN SMES?

The research identifies distinct adoption profiles requiring tailored strategies:

**Small Enterprises (5–9 employees):** Prioritize simplicity and zero-cost entry. Current 56% reliance on free solutions indicates price sensitivity. Barriers center on knowledge gaps and perceived irrelevance for low document volumes. Recommended approach: freemium models with guided onboarding and use-case education demonstrating efficiency gains at small scale.

**Medium Enterprises (10–49 employees):** Face partner ecosystem coordination challenges. Require integration with existing systems and evidence of network adoption. Barriers include cultural resistance and hybrid workflow complexity. Recommended approach: industry-specific solutions emphasizing peer adoption and compatibility demonstrations.

**Larger Enterprises (50–249 employees):** Demand advanced functionality, compliance features, and automation capabilities. Currently underutilizing bulk signing (21%) and automated workflows (8%), suggesting feature awareness gaps. Barriers shift toward regulatory compliance and security concerns. Recommended approach: enterprise solutions with compliance certification, API integration, and workflow automation.

# 9 CONCLUSION

Digital signature adoption among Hungarian SMEs reflects a complex interplay of organizational capacity (size), operational context (sector), institutional infrastructure (regulation), and technological readiness (digital maturity). The Technology Acceptance Model's core constructs perceived usefulness and ease of use operate within boundaries set by company resources, industry workflows, and legal frameworks.

By synthesizing quantitative adoption patterns with qualitative barrier mechanisms, this customer-centric research bridges the gap between digital signature technology's technical maturity and its practical acceptance. The findings demonstrate that successful adoption requires not only usable technology but also regulatory clarity, partner ecosystem coordination, and segment-appropriate implementation strategies addressing the distinct needs of small, medium, and larger enterprises within the SME spectrum.

# 10 METHODOLOGICAL CONSIDERATIONS AND LIMITATIONS

This research provides valuable insights into digital signature adoption among Hungarian SMEs; however, several limitations should be acknowledged when interpreting the findings.

**Sample and Generalizability.** The quantitative findings derive from 200 Hungarian SMEs employing 5-249 people. While disproportionate stratification ensured adequate representation across size categories, the findings are primarily specific to the Hungarian SME context. The exclusion of large enterprises (250+ employees) from the sample may limit understanding of how organizational scale influences adoption patterns beyond the SME segment. Different results might emerge if the research included large companies, which typically possess greater resources and different organizational dynamics. Additionally, the distinct regulatory frameworks, cultural attitudes toward digitalization, and economic conditions of the Hungarian market limit the transferability of findings to other national contexts.

**Methodological Constraints.** The telephone-assisted survey methodology, while achieving higher response rates than self-administered questionnaires, inherently limits the depth of exploration possible through in-depth interviews. This method does not provide opportunities to uncover deeper insights that would require more nuanced, interview-based investigation. The methodology may have also introduced selection bias toward less digitally mature enterprises, as digitally advanced firms might prefer online communication channels. The cross-sectional design captures adoption patterns at a single point in time, precluding insights into adoption trajectories or the temporal sequence necessary to establish causal relationships between variables.

**Endogeneity and Causal Inference.** While logistic regression modeling identifies statistically significant associations between company size, sectoral orientation, and digital signature adoption, the cross-sectional design cannot definitively establish causality. Reverse causality remains theoretically possible. For instance, that digital signature adoption might drive company growth rather than size enabling adoption. However, this risk is minimal given that more than half of adopters use exclusively

free solutions and approximately 75% report annual costs below 50,000 HUF, making it implausible that digital signature adoption materially affects revenue trajectories or organizational scale in the short term. Additionally, the potential for omitted variable bias exists, as unobserved factors such as leadership innovation orientation or organizational culture may influence both company characteristics and technology adoption decisions. The VIF analysis mitigates multicollinearity concerns, but unmeasured constructs could still confound the observed relationships.

**Data Collection Limitations.** The reliance on self-reported data from SME representatives introduces potential recall bias and social desirability effects. Respondents may have overestimated their digitalization progress or underreported implementation challenges to present their organizations favorably. The qualitative phase comprised 14 semi-structured interviews, which, while providing rich insights, represents limited coverage across the diverse segments within the Hungarian SME landscape. The choice of independent variables and indicators used may also constrain the findings—different variables or operational definitions might yield alternative results and reveal unexplored relationships.

**Literature Review Scope.** The systematic literature review filtered exclusively for open-access publications, potentially excluding relevant proprietary research, industry reports, or publications behind paywalls. This constraint may have introduced selection bias, particularly regarding cutting-edge commercial solutions or region-specific studies that could provide additional context for understanding adoption patterns.

Despite these limitations, the mixed-methods approach provides robust insights into digital signature adoption patterns within the Hungarian SME context. The triangulation of quantitative survey data, qualitative interview insights, and systematic literature review strengthens confidence in the findings while acknowledging the associative rather than causal nature of the identified relationships. Future research should address these limitations through longitudinal designs tracking adoption trajectories over time, expanded samples including large enterprises, international comparative studies to assess regulatory and cultural influences, and panel data analysis to disentangle bidirectional effects between digital maturity and technology adoption.

# 11 CONTRIBUTIONS

This research makes principal contributions to the understanding of digital signature adoption in SME contexts:

**1. Empirical Foundation**

First comprehensive study of digital signature adoption in the Hungarian SME sector, combining quantitative evidence from 200 SMEs with qualitative insights from 14 expert interviews. The mixed-methods approach reveals that 44% of Hungarian SMEs currently use digital signatures, with adoption significantly influenced by company size ($\chi^2 = 52.440, p < .001$) and sectoral orientation ($\chi^2 = 13.653, p = .001$). Logistic regression modeling (Nagelkerke $R^2$=0.426) demonstrates that service-oriented companies exhibit significantly higher adoption propensities than industrial ($\beta = -2.232, p < .001$) or commercial ($\beta = -0.846, p = .045$) enterprises. The research identifies that larger enterprises (50–249 employees) achieve adoption rates exceeding 70%, while smaller firms (5–9 employees) reach approximately 30%, with 56% of the smallest firms relying exclusively on free solutions.

**Practical Framework**

Identification of segment-specific adoption barriers and requirements through integration of quantitative patterns and qualitative mechanisms. The research reveals three distinct SME adoption profiles (5–9, 10–4 9, 50–249 employees), each with unique barriers, priorities, and recommended implementation approaches (detailed in Section 8).

This segmentation enables tailored strategies addressing knowledge gaps and cost sensitivity in smaller firms (56% rely on free solutions), partner ecosystem dependencies and cultural resistance in medium enterprises (hybrid workflows dominate), and automation underutilization in larger organizations (only 8% report automated workflows despite high satisfaction of 4.8–4.9 out of 5).

# 12 FUTURE RESEARCH DIRECTIONS

The findings and frameworks developed in this research open several promising avenues for future investigation:

**1. Digital Maturity-Implementation Complexity Matrix:** Building upon the segment-specific findings, future research could develop a practical assessment tool, a **Digital Maturity-Implementation Complexity Matrix**, designed to guide SMEs in evaluating their readiness for digital signature adoption. This matrix would operate along two dimensions (Figure 50)

- **Dimension 1: Digital Maturity Assessment**s: Evaluating the SME's current level of digital readiness using established frameworks (e.g., Pirola et al., 2019), creating a calculable 5-stage readiness categorization ranging from "initial digitalization" to "advanced digital integration."
- **Dimension 2: Implementation Complexity**: Assessing the technical, organizational, and regulatory complexity requirements specific to digital signature solutions, considering factors such as document volume, automation needs, compliance requirements, and partner ecosystem demands.

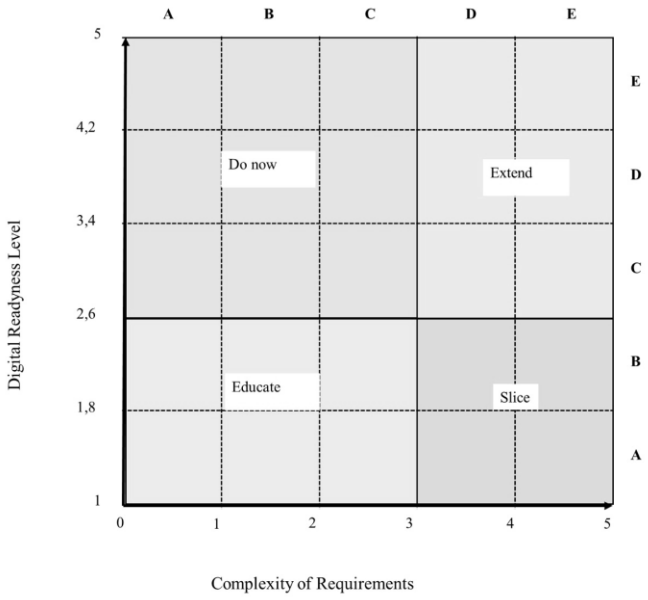



*Figure 50 Digital Ingenuity complexity map*

By positioning an SME within this matrix, decision-makers could identify appropriate solution types, required preparatory steps, expected implementation challenges, and realistic adoption timelines. Empirical validation through implementation studies where SMEs use the tool to guide adoption would measure outcomes (adoption success, user satisfaction, process efficiency) and demonstrate the framework's practical utility.

**2. Longitudinal Studies:** Tracking digital signature adoption trajectories over time would enable causal inference and reveal how SMEs progress through digital maturity stages. Panel data analysis could disentangle bidirectional effects between digital maturity and technology adoption, addressing the co-evolution dynamics identified in this research.

**3. International Comparative Studies:** Examining how regulatory regime differences (e.g., eIDAS in EU vs. ESIGN/UETA in US) influence adoption patterns would reveal context-specific factors influencing adoption across different regulatory and cultural contexts.

**4. Contextual TAM Extensions**: The empirical analysis revealed adoption patterns influenced by organizational size, sectoral orientation, regulatory thresholds, and digital maturity—factors extending beyond traditional TAM constructs. Based on these empirical observations, future research could formalize a Contextual Technology Acceptance Model (C-TAM):

*C-TAM = TAM + Size(central) + Sector(structural) + Regulation(threshold) +*

*Digital_Maturity(co-evolution)*

Where:

- Size(central): organizational resources and absorptive capacity

- Sector(structural): workflow compatibility determinants

- Regulation(threshold): legal infrastructure prerequisites

- Digital_Maturity(co-evolution): recursive digitalization dynamics

Future studies could operationalize these dimensions through structural equation modeling and test explanatory power improvements across multiple national and technology contexts.

**5. Generational Leadership Transition:** Qualitative investigations of how leadership succession impacts technology adoption could illuminate the mechanisms behind the generational divide identified in interviews (*"If my children take over the company, they will likely adopt such innovations"*), potentially revealing strategies to accelerate adoption through change management.

**6. Sector-Specific Deep Dives:** Given the significant sectoral differences identified (service firms vs. industrial firms), industry-specific studies could reveal unique adoption patterns and develop tailored implementation guidelines for high-potential sectors.

# 13 CLOSING REFLECTION

This research demonstrates that digital signature adoption among Hungarian SMEs reflects a complex interplay of organizational capacity, operational context, institutional infrastructure, and technological readiness. The findings underscore that successful technology adoption requires not only usable technology but also regulatory clarity, partner ecosystem coordination, and segment-appropriate implementation strategies addressing the distinct needs of small, medium, and larger enterprises within the SME spectrum.

By combining rigorous empirical evidence with practical recommendations, this research contributes to both academic understanding and practitioner guidance, thereby bridging the gap between the technical maturity of digital signature technology and its practical acceptance within the Hungarian SME sector.

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# 15 PUBLICATIONS ON THE TOPIC

## 15.1 JOURNAL ARTICLES

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# 16 APPENDIX

## 16.1 DIGITAL SIGNATURE TELEPHONE SURVEY (CATI)

SZŰRÉS

**VÁLASZADÓK: MINDENKI**

**S01 – EGY VÁLASZ**
**Elsőként megmondaná, hogy mi az Ön cégének a gazdasági formája?**
*KÉRD.: Segítse a válaszadást!*

1. Betéti társaság (Bt.)
2. Korlátolt felelősségű társaság (Kft.)
3. Nyilvánosan vagy zártkörűen működő részvénytársaság (Nyrt./Zrt.)
4. Egyéb
9. Nem tudja / nem válaszol

**VÁLASZADÓK: MINDENKI**

**S02 – ÉRTÉK: 1-9998**
**Jelenleg hány állandó teljes munkaidős (legalább heti 30 órát dolgozó) alkalmazottja van a cégének Önt is beleértve?**
*KÉRD.: Ha nem tudja pontosan, becslés is elfogadható.*

… fő
9999. Nem tudja / nem válaszol

*PROG.: Ha S02 <5 vagy (S02>249 és S02 <>9999)* → *VÉGE AZ INTERJÚNAK!*

**VÁLASZADÓK: HA S02=9999**

**S03 – EGY VÁLASZ**
**Ha nem is tudja pontosan vagy nem szeretné pontosan megmondani, a következő kategóriák közül melyik igaz a cége állandó, teljes munkaidős (legalább heti 30 órát dolgozó) alkalmazottainak számával kapcsolatban?**
*KÉRD.: Segítse a válaszadást!*

1. 1-4 fő
2. 5-9 fő
3. 10-49 fő
4. 50-249 fő
5. 250 fő vagy több
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

*PROG.: Ha S03=1 vagy 5 vagy 9* → *VÉGE AZ INTERJÚNAK!*

**VÁLASZADÓK: MINDENKI**

**S04 – EGY VÁLASZ, REJTETT KÉRDÉS**
**Alkalmazottak száma**

2. 5-9 fő *[PROG.: S02>4 és S02<10 vagy S03=2]*
3. 10-49 fő *[PROG.: S02>9 és S02<50 vagy S03=3]*
4. 50-249 fő *[PROG.: S02>49 és S02<250 vagy S03=4]*

**VÁLASZADÓK: MINDENKI**

**S05 – EGY VÁLASZ**
**Mekkora volt vállalkozásának 2022. évi nettó árbevétele?**
*KÉRD.: Segítse a válaszadást: „Ha nem tudja pontosan vagy nem szeretné megmondani pontosan, akkor a következő kategóriák közül melyikbe esett a cég tavalyi árbevétele?”*

1. 1 - 50 millió Ft
2. 51 - 100 millió Ft
3. 101 - 200 millió Ft
4. 201 - 500 millió Ft
5. 501 - 1000 millió Ft
6. 1 - 20 milliárd Ft
7. 20 milliárd Ft felett
9. Nem tudja/nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: MINDENKI**

**S06 – EGY VÁLASZ**
**Melyik vármegyében van a cégének a székhelye?**

1. Budapest
2. Bács-Kiskun
3. Baranya
4. Békés
5. Borsod-Abaúj-Zemplén
6. Csongrád-Csanád
7. Fejér
8. Győr-Moson-Sopron
9. Hajdú-Bihar
10. Heves
11. Jász-Nagykun-Szolnok
12. Komárom-Esztergom
13. Nógrád
14. Pest
15. Somogy
16. Szabolcs-Szatmár-Bereg
17. Tolna
18. Vas
19. Veszprém
20. Zala

**VÁLASZADÓK: MINDENKI**

**S07a – EGY VÁLASZ**

**Főtevékenysége alapján vállalkozása melyik szektorba tartozik?**

*KÉRD.: Segítse a válaszadást!*

1. Ipar, építőipar
2. Kereskedelem
3. Szolgáltatás
4. Egyéb

*PROG.: Ha S09=4 → VÉGE AZ INTERJÚNAK!*

**VÁLASZADÓK: MINDENKI**

**S07b – NYITOTT**

**Mi a vállalat fő tevékenysége? Elmondaná pár szóban?**

**VÁLASZADÓK: MINDENKI**

**S08 – TÖBB VÁLASZ**

**A következők közül mely régiókból vannak Önöknek üzleti partnerei? Kérjük most olyan partnerekre gondoljon, akikkel szerződéses viszonyban állnak, vagy egyéb hivatalos dokumentumokat szoktak cserélni.**

*KÉRD.: Olvassa fel a válaszokat, és jelölje!*

1. Saját település
2. Saját megye
3. Szomszédos megye
4. Az ország távolabbi részei
5. Szomszédos országok
6. Egyéb európai országok
7. Nem európai országok
9. Nem tudja/nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: MINDENKI ---**

**S09 – EGY VÁLASZ**

**A következők közül melyik jellemző az Önök cégére?**

*KÉRD.: Olvassa fel a válaszokat, és jelölje!*

1. Teljesen, vagy szinte teljesen papírmentesen működünk
2. Törekszünk az adminisztrációnkat papírmentessé tenni és ez jelentős részben már meg is valósult
3. Törekszünk az adminisztrációnkat papírmentessé tenni, de még a folyamat elején járunk
4. Nem törekszünk papírmentes működést kialakítani.
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: MINDENKI ---**

**S10 – EGY VÁLASZ**

**Vesznek igénybe külső partnert dokumentumok tárolására és logisztikájára?**

1. Igen
2. Nem
9. Nem tudja / nem válaszol

**VÁLASZADÓK: MINDENKI**

**S11 – EGY VÁLASZ**

**Mindent egybe véve mekkora költséget jelent cégének a különféle dokumentumok nyomtatása, logisztikája, tárolása, archiválása jelenleg?**

*KÉRD.: Olvassa fel a válaszokat, és jelölje!*

1. Egyáltalán nem jelent érdemi költséget
2. Érezhető, de nem jelentős költséget jelent
3. Jelentős költséget jelent
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

FŐ KÉRDŐÍV

**VÁLASZADÓK: MINDENKI ---**

**A01 – EGY VÁLASZ**

**Használ jelenleg vállalkozásuk olyan digitális aláírási szolgáltatást, mely alkalmas joghatással bíró dokumentum-hitelesítésre?**

**Kérem, itt most csak arra gondoljon, hogy az Önök cége áll-e kapcsolatban ilyen szolgáltatóval. Ha csak úgy írnak alá digitálisan, hogy más, külső partner indítja a dokumentumot, akkor ezt most ne vegye figyelembe!**

*KÉRDEZŐ: HA A VÁLASZADÓ NEM TUDJA MIRŐL BESZÉLÜNK SEGÍTSEN NEKI: Az digitális aláírás egy olyan szolgáltatás, mellyel a hitelesítendő dokumentumok nem kerülnek kinyomtatásra és fizikailag aláírásra, hanem egy informatikai eljárás segítségével kerül rá az aláírót azonosító digitális aláírás, mely nyomtatás nélkül is joghiteles.*

1. Igen
2. Nem
9. Nem tudja / nem válaszol -> VÉGE AZ INTERJÚNAK

AKIK HASZNÁLNAK JELENLEG IS

**VÁLASZADÓK: HA A01=1 –**

**H01a – TÖBB VÁLASZ**

**Melyik szolgáltatótól veszik igénybe az digitális aláírás szolgáltatást?**

1. NETLOCK
2. Ügyfélkapu
3. Microsec (e-Szignó)
4. Signi
5. DocuSign
6. Adobe Sign
98. Egyéb, éspedig…….
99. Nem tudja / nem válaszol *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA H01a-ban több választ is jelöl –**

**H01b – EGY VÁLASZ**

**Önöknek tehát több digitális aláírás szolgáltatója is van. Melyiket tartják ezek közül a legfontosabbnak?**

1. NETLOCK
2. Ügyfélkapu
3. Microsec (e-Szignó)
4. Signi
5. DocuSign
6. Adobe Sign
98. Egyéb, éspedig…….
99. Nem tudja / nem válaszol

**VÁLASZADÓK: HA A01=1 ---**

**H01c – EGY VÁLASZ**

**Mióta vesznek Önök igénybe digitális aláírás szolgáltatást?**

1. Kevesebb, mint 1 éve
2. 1-2 éve
3. 3-5 éve
4. Több, mint 5 éve
9. Nem tudja / nem válaszol

**VÁLASZADÓK: HA A01=1 –**

**H01d – TÖBB VÁLASZ**

**Van esetleg olyan szolgáltató, mellyel régebben kapcsolatban álltak, de most már nem veszik igénybe? Ha igen, melyik ez, melyek ezek?**

1. NETLOCK
2. Ügyfélkapu
3. Microsec (e-Szignó)
4. Signi
5. DocuSign
6. Adobe Sign
98. Egyéb, éspedig…….
99. Nem tudja / nem válaszol *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA A01=1 –**

**H01e – TÖBB VÁLASZ**
**Milyen egyéb digitális aláírás szolgáltatót ismer azokon kívül, amelyekkel most vagy korábban kapcsolatban álltak?**

1. NETLOCK
2. Ügyfélkapu
3. Microsec (e-Szignó)
4. Signi
5. DocuSign
6. Adobe Sign
98. Egyéb, éspedig…….
99. Nem tudja / nem válaszol *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA A01=1 ---**

**H02 – EGY VÁLASZ**
**A jelenleg igénybe vett digitális aláírás szolgáltatásuk melyik megoldást alkalmazza?**

1. Fizikai kártyás (azaz hardvereszközt igénylő)
2. Online, felhőalapú azonosítást alkalmazó
3. Mindkettővel rendelkeznek
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA A01=1 –**

**H03a – SORONKÉNT EGY VÁLASZ, RANDOMIZÁLD A SOROKAT**

**Kérem, értékelje most jelenlegi szolgáltatóját – több szolgáltató esetén a fő szolgáltatóját - a következő szempontok szerint. Értékeléséhez használjon egy 1-től 5-ig terjedő skálát, ahol az 1-es azt jelenti, hogy egyáltalán nem (volt) elégedett, az 5-ös pedig, hogy teljes mértékben elégedett!**

1. Az onboarding folyamata, azaz a regisztrációtól a szolgáltatás használatának megkezdéséig tartó lépések
2. Felhasználóbarát kezelés okostelefonról
3. Felhasználóbarát kezelés számítógépről/laptopról
4. Hibamentes működés
5. Elfogadás, partnerekkel való együttműködés egyszerűsége
6. Számlázás
7. Panaszkezelés
8. Átlátható árazás
9. Kedvező árazás

VÁLASZOK OSZLOPOKBAN:
1. Egyáltalán nem elégedett
2. 2
3. 3
4. 4
5. Teljes mértékben elégedett
6. Nem releváns, nem történt ilyen
9. Nem tudja megítélni, nem válaszol

**VÁLASZADÓK: HA A01=1 –**

**H03b – SORONKÉNT EGY VÁLASZ, RANDOMIZÁLD A SOROKAT**

**Néhány jelzőt sorolok fel. Kérem, mondja meg, Ön szerint mennyire jellemzőek ezek az Önök szolgáltatójára – több szolgáltató esetén a fő szolgáltatójára. Értékeléséhez használjon egy 1-től 5-ig terjedő skálát, ahol az 1-es azt jelenti, hogy egyáltalán nem jellemző rá, az 5-ös pedig, hogy teljes mértékben jellemző rá!**

1. Világszínvonalú
2. Felhasználóbarát
3. Segítőkész
4. Megbízható
5. Hiteles
6. Elérhető
7. Ismert

VÁLASZOK OSZLOPOKBAN:
1. Egyáltalán nem jellemző
2. 2
3. 3
4. 4
5. Teljes mértékben jellemző
6. Nem releváns, nem történt ilyen

**VÁLASZADÓK: HA A01=1 ---**

**H04a – ÉRTÉK: 1-9998**

**Hány személy használ digitális aláírás szolgáltatást a cégnél? Ha nem tudja pontosan, kérem, becsülje meg!**

… fő
9999. Nem tudja / nem válaszol

**VÁLASZADÓK: HA H04a>1 ÉS H04A<9999 ---**

**H04b – EGY VÁLASZ**

**Az Önök cégénél tehát többen is használnak digitális aláírást. Milyen szinten dolgozók használnak ilyen szolgáltatást?**

1. Csak cégjegyzésre jogosult munkatársak
2. Cégjegyzésre jogosult és egyéb vezető pozícióban lévő munkatársak
3. Vezető és nem vezető beosztású munkatársak is
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA A01=1 ---**

**H05 – TÖBB VÁLASZ**

**Milyen eszközön használja Ön az digitális aláírás szolgáltatást?**

1. Számítógépen
2. Okostelefonon
3. Tableten
8. Egyéb, éspedig…….
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!] *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA A01=1 ---**

**H06 – TÖBB VÁLASZ, RANDOMIZÁLD (KIV. 8, 9)**

**Több lehetséges dokumentumtípust olvasok fel. Ezek közül mely dokumentumtípusok hitelesítésére szoktak digitális aláírást használni?**

1. Hivatalos, közigazgatási ügyek dokumentumai
2. Üzleti szerződések külső partnerekkel
3. Munkaszerződések
4. Számlák
5. Belső utasítások
6. Időbélyegzést igénylő dokumentumok
8 Ezek egyikére sem [KÉRD.: Ne olvassa fel!] *[KIZÁRÓLAGOS]*
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!] *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA A01=1 –**

**H07 – EGY VÁLASZ**

**Meg tudja mondani, hogy éves szinten mennyit költ cége digitális aláírás szolgáltatásra? Nem szükséges pontosan megmondani, csak amennyire emlékszik.**

1. Csak ingyenes szolgáltatást vesznek igénybe
2. Kevesebb, mint 10 ezer forintot
3. 10-50 ezer forint
4. 51-100 ezer forintot
5. 101-300 ezer forintot
6. 301-500 ezer forintot
7. Több, mint 500 ezer forintot
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA A01=1 ---**

**H08 – EGY VÁLASZ**

**Használják Önök tömegesen az digitális aláírást? Ez alatt azt értjük, hogy az aláíró nem egyesével, hanem egy gombnyomással tömegesen ír alá előkészített dokumentumokat, például számlákat?**

1. Igen
2. Nem
9. Nem tudja / nem válaszol

**VÁLASZADÓK: HA H08=2**

**H09 – EGY VÁLASZ**
**És tervezik ilyen jellegű tömeges aláírás alkalmazását az digitális aláírásoknak?**

1. Igen
2. Nem
9. Nem tudja / nem válaszol

**VÁLASZADÓK: HA A01=1 --**

**H10a – EGY VÁLASZ**
**Az aláírandó dokumentumokat jellemzően egyesével megnyitva manuálisan írják alá, vagy rendelkeznek olyan rendszerrel, mely ezeket feldolgozza és így juttatja el az aláíróhoz.**

1. Jellemzően manuálisan, egyesével
2. Informatikai rendszer által feldolgozva, csoportosítva
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA H10a=1**

**H10b – NYITOTT**
**Mi ez az automatikus rendszer? El tudná mondani néhány szóban?**
**VÁLASZADÓK: HA A01=1 --**

**H11 – SORONKÉNT EGY VÁLASZ, RANDOMIZÁLD A SOROKAT**
**A szolgáltatók általában az digitális aláírás mellett más szolgáltatásokat is kínálnak. Felsorolunk néhányat ezek közül. Kérem, mondja meg ezek esetében, hogy használnak-e jelenleg ilyet vagy nem, és amennyiben nem, akkor terveznek-e ilyet igénybe venni?**

VÁLASZOK OSZLOPOKBAN:
1. Jelenleg is használnak
2. Nem használnak, de terveznek igénybe venni
3. Nem használnak és nem is terveznek igénybe venni

SOROKBAN:
1. Hiteles digitális másolatok készítése papíralapú dokumentumokról
2. Informatikai naplóállományok digitális hitelesítése
3. Munkaügyi dokumentumok (bérjegyzék, nyomtatványok stb.) digitális hitelesítése
4. Online űrlapok hitelesítése
5. Digitális számlázás
6. Webes kommunikáció (weboldalak, webshopok, levelezések SSL tanúsítványok segítségével)

**VÁLASZADÓK: HA A01=1**

**H12 – NYITOTT**
**Miben nyújtja a legnagyobb segítséget Önöknek az digitális aláírás használata? Meg tudná fogalmazni röviden?**

AKIK JELENLEG NEM HASZNÁLNAK

**VÁLASZADÓK: HA A01=2 --**

**N01 – EGY VÁLASZ**
**Hallott Ön már ilyen digitális aláírási szolgáltatásról, mely segítségével Ön hivatalos dokumentumok kinyomtatása és aláírása nélkül joghatással bíró dokumentumokat állíthat elő és küldhet el?**

1. Igen
2. Nem
9. Nem tudja / nem válaszol

**VÁLASZADÓK: HA N01=1 --**

**N02 – EGY VÁLASZ**

**Vettek már úgy igénybe digitális aláírás szolgáltatást, hogy külső partnertől kaptak dokumentumot, amit aláírtak?**

1. Igen
2. Nem
9. Nem tudja / nem válaszol

**VÁLASZADÓK: HA N01=1 --**

**N03 – EGY VÁLASZ**

**Tervezi az Önök cége, hogy a következő 1 évben igénybe vesz saját előfizetéssel digitális aláírás szolgáltatást?**

1. Igen, már fel is vették lehetséges szolgáltatókkal a kapcsolatot
2. Igen, már elkezdtek utánajárni a lehetőségeknek, de még nem vettek fel a kapcsolatot egy szolgáltatóval sem
3. Igen, de még nem tettek semmit ez ügyben
4. Nem tervezik
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA N01=1**

**N04 – TÖBB VÁLASZ**

**Tudna említeni olyan szolgáltatókat, akiktől digitális aláírás szolgáltatást lehet igénybe venni? Melyek ezek**

1. NETLOCK
2. Ügyfélkapu
3. Microsec (e-Szignó)
4. Signi
5. DocuSign
6. Adobe Sign
88. Egyéb, éspedig…….
98. Nem tud egyet sem említeni *[KIZÁRÓLAGOS]*
99. Nem tudja / nem válaszol *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: HA N01=2 --**

**N05 – CSAK SZÖVEG**

**Az digitális aláírás alatt olyan <u>kriptográfiai</u> eljárást értünk, amelynek segítségével joghatás kiváltására alkalmas, akár a kézzel írott aláírással vagy a közjegyző előtt tett aláírással egyenértékű bizonyító erejű dokumentum hozható létre a hatályos jogszabályok szerint. Az digitális aláírással számítógépen vagy mobileszközön, a dokumentum kinyomtatása nélkül tudnak a társaság nevében arra jogosultak hivatalos jognyilatkozatot tenni.**
**A következőkben erről a lehetőségről tennék fel Önnek néhány kérdést.**

**VÁLASZADÓK: HA N01=2 --**

**N06 – EGY VÁLASZ**

**Mit gondol, fog az Önök cége a következő 1 évben ilyen szolgáltatást igénybe venni?**

4. Igen, biztosan
3. Igen, elképzelhető
2. Nem valószínű
1. Biztosan nem
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA A01=2 --**

**N07 – EGY VÁLASZ**

**Mit gondol, ha igénybe vennének ilyen szolgáltatást, akkor éves szinten hány dokumentum esetében tudnák ezt használni?**

1. Kevesebb mint 100
2. 100-500
3. 501-1000
4. 1001-5000
5. Több mint 5000
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!]

**VÁLASZADÓK: HA A01=2 --**

**N08 – TÖBB VÁLASZ, RANDOMIZÁLD (KIV. 8, 9)**

**Több lehetséges dokumentumtípust olvasok fel. Ezek közül mely dokumentumtípusok hitelesítésére tudja elképzelni, hogy használnának digitális aláírást, ha rendelkezésükre állna ilyen szolgáltatás?**

1. Hivatalos, közigazgatási ügyek dokumentumai
2. Üzleti szerződések külső partnerekkel
3. Munkaszerződések
4. Számlák
5. Belső utasítások
6. Időbélyegzést igénylő dokumentumok
8 Ezek egyikére sem [KÉRD.: Ne olvassa fel!] *[KIZÁRÓLAGOS]*
9. Nem tudja / nem válaszol [KÉRD.: Ne olvassa fel!] *[KIZÁRÓLAGOS]*

**VÁLASZADÓK: MINDENKI --**

**M1a – SORONKÉNT EGY VÁLASZ, RANDOMIZÁLD A SOROKAT**

**Felolvasok néhány olyan előnyt, melyet mások említettek az digitális aláírások használata kapcsán. Mennyire ért egyet ezekkel az állításokkal? Kérem, a következő válaszlehetőségekkel mondja el a véleményét: (1) Egyáltalán nem ért egyet; (2) inkább nem ért egyet, (3) inkább egyetért, (4) Teljes mértékben egyetért.**

1. Az digitális aláírások használatával jelentősen csökkent a nyomtatási költségük
2. A partnereik nagy része ragaszkodik a dokumentumok hagyományos aláírásához
3. Nehéz volt váltani digitális aláírásra
4. Sokat spórolnak a postázási költéseken és az ügyintézési idő csökkenésén
5. A dokumentumokat biztonságosabban tudják tárolni digitális aláírással, mint hagyományossal
6. Az digitális aláírással jelentősen csökkentek a dokumentumok tárolási és archiválási költségei
7. Teljes mértékben biztonságosnak tartja az digitális aláírásokat
8. Az digitális aláírások használata segített érdemben csökkenteni a papírfelhasználást és így zöldebbé tenni a céget
9. A magyarországi szolgáltatóktól igénybe vett digitális aláírásokat az Európai Unió minden tagországában elfogadják

VÁLASZOK OSZLOPOKBAN:
1. Egyáltalán nem ért egyet
2. Inkább nem ért egyet
3. Inkább egyetért
4. Teljes mértékben egyetért
9. Nem tudja megítélni, nem válaszol

**VÁLASZADÓK: MINDENKI --**

**M1b – SORONKÉNT EGY VÁLASZ**

**Azon előnyöket, melyekkel Ön egyetértett, ismét felolvasom. Kérem, mondja meg, hogy mennyire tartja ezeket fontos előnynek. Kérem, a következő válaszlehetőségekkel mondja el a véleményét: (1) Egyáltalán nem fontos; (2) inkább nem fontos, (3) inkább fontos, (4) nagyon fontos.**

1. Az digitális aláírások használatával jelentősen csökkent a nyomtatási költségük
4. Sokat spórolnak a postázási költéseken és az ügyintézési idő csökkenésén
5. A dokumentumokat biztonságosabban tudják tárolni digitális aláírással, mint hagyományossal
6. Az digitális aláírással jelentősen csökkentek a dokumentumok tárolási és archiválási költségei
7. Teljes mértékben biztonságosnak tartja az digitális aláírásokat
8. Az digitális aláírások használata segített érdemben csökkenteni a papírfelhasználást és így zöldebbé tenni a céget
9. A magyarországi szolgáltatóktól igénybe vett digitális aláírásokat az Európai Unió minden tagországában elfogadják

VÁLASZOK OSZLOPOKBAN:
1. Egyáltalán nem fontos
2. Inkább nem fontos
3. Inkább fontos
4. Nagyon fontos
9. Nem tudja megítélni, nem válaszol

KÉRDŐÍV VÉGE

**Köszönöm, hogy részt vett a kutatásban!**

## 16.2 DEEP INTERVIEW THEMATIC QUESTIONNAIRE

### Az interjú keretében vizsgálandó kutatási kérdések:

1. Mi a digitális aláírással kapcsolatos megítélés és funkcionális követelmény a kkv-k szektor felhasználói és nem felhasználói között?
2. A főbb iparágakon belül melyek azok a megkülönböztetett használhatósági és felhasználói elfogadottsági követelmények, amelyeknek egy digitális aláírási megoldásnak meg kell felelnie?

### Bevezető kérdések

1. Le tudná írni, hogy az Ön vállalata jelenleg milyen folyamatokat és rendszereket használ a dokumentumok aláírására és hitelesítésére?
2. Milyen kihívásokkal vagy fájdalompontokkal találkozott a hagyományos papír alapú aláírásokkal kapcsolatban?
3. Használ jelenleg vállalkozásuk olyan elektronikus aláírási szolgáltatást, mely alkalmas joghatással bíró dokumentum-hitelesítésre?

Kérem, itt most csak arra gondoljon, hogy az Önök cége áll-e kapcsolatban ilyen szolgáltatóval. Ha csak úgy írnak alá elektronikusan, hogy más, külső partner indítja a dokumentumot, akkor ezt most ne vegye figyelembe!

### Használ elektronikus aláírást

1. Milyen tényezők befolyásolták a digitális aláírási megoldás kiválasztását (pl. költség, könnyű használhatóság, biztonság)?
2. Le tudja írni a digitális aláírás szervezeten belüli bevezetésével kapcsolatos tapasztalatait?
3. A digitális aláírási platformok mely konkrét jellemzőit vagy funkcióit tartják a legértékesebbnek az alkalmazottai?
4. Volt-e olyan eset, amikor a digitális aláírás nem felelt meg az elvárásainak vagy követelményeinek?
5. Hogyan jellemezné a digitális aláírásokkal és azok lehetséges előnyeivel kapcsolatos tudatosság vagy megértés szintjét az Ön szervezetén belül?
6. Véleménye szerint melyek azok a kulcsfontosságú tényezők, amelyek befolyásolják a digitális aláírások felhasználói elfogadottságát az Ön szervezetén belül?
7. Tudna-e beszélni a digitális aláírások bevezetése óta a felhasználók szokásaiban vagy a papírmunkával kapcsolatos hozzáállásban bekövetkezett változásokról?

8. Vannak-e olyan konkrét kihívások vagy korlátok a jelenlegi dokumentum-aláírási folyamatukkal kapcsolatban, amelyeket a digitális aláírás Ön szerint potenciálisan megoldhana?

9. Meg tudna osztani olyan sikertörténeteket vagy előnyöket, amelyeket cége a digitális aláírások bevezetése eredményeként tapasztalt?

10. Előre tekintve, hogyan képzeli el a digitális aláírás jövőjét az Ön iparágában vagy vállalatánál?

## Nem használ elektronikus aláírást

1. Voltak-e a szervezetén belül korábban egyeztetések a digitális aláírás bevezetéséről? Ha igen, melyek voltak a fő okok, amiért nem léptek előre a bevezetés felé?

2. Vannak-e olyan konkrét kihívások vagy korlátok a jelenlegi dokumentum-aláírási folyamatukkal kapcsolatban, amelyeket a digitális aláírás potenciálisan megoldhatna?

3. Milyen funkciókat vagy fejlesztéseket látna szívesen a digitális aláírási megoldásokban, hogy jobban megfeleljenek a vállalata igényeinek?

4. Végeztek-e bármilyen felmérést vagy elemzést a digitális aláírások szervezeten belüli bevezetésének potenciális megtérülésének (ROI) felmérésére?

5. Milyen elvárásai vannak a digitális aláírások használhatóságával és felhasználói elfogadottságával kapcsolatban az alkalmazottai körében?

6. Milyen aggályai vagy fenntartásai vannak a digitális aláírások biztonságával kapcsolatban a hagyományos papír alapú aláírásokhoz képest?

7. Vannak-e olyan szabályozási vagy megfelelési megfontolások, amelyek befolyásolták a digitális aláírás bevezetésének mellőzésével kapcsolatos döntését?

8. Hogyan jellemezné a digitális aláírással és annak lehetséges előnyeivel kapcsolatos tudatosság vagy megértés szintjét az Ön szervezetén belül?

9. Ön szerint melyek azok a legfontosabb kihívások vagy akadályok, amelyek megakadályozzák a kis- és középvállalkozásokat a digitális aláírási megoldások bevezetésében?

10. Van-e egyéb olyan tényező vagy megfontolás, amelyet fontosnak tart megemlíteni az Ön szervezetének a digitális aláírás bevezetésével kapcsolatos álláspontját illetően?