Providing a Digital Service Model within the Framework of Industry 4.0 in the Banking Sector

Heidar Abbasi [1], Hakimeh Niki Esfahlan[2*] Mortaza Honarmand Azimi [1]

[1] Department of Management, Ta.C., Islamic Azad University, Tabriz, Iran
[2] Department of Management, Ara.C., Islamic Azad University, Jolfa, Iran

*** Corresponding author email address**: Ha.Niky@iau.ac.ir

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Abstract

The purpose of this study was to develop a digital service model within the framework of Industry 4.0 in the banking sector using a qualitative meta-synthesis approach. The statistical population included all valid domestic and international scientific studies published in the fields of digital banking, digital transformation, Industry 4.0 technologies, and financial service innovation within the selected time frame, indexed in national and international scientific databases. Using a systematic search strategy and based on the PRISMA logic, 212 studies were identified in the initial screening stage. After removing duplicate records and conducting a multi-stage screening process (title, abstract, full text, and methodological quality assessment), 55 studies were ultimately selected as the final sample for analysis. Data were collected through a library-based method and systematic searches of specialized keywords in scientific databases. Data analysis was conducted using a three-stage coding process including open, axial, and selective coding. Qualitative data management was performed using MAXQDA software, and Cohen's kappa coefficient was calculated to assess coding reliability. In addition, Shannon entropy was employed to determine the relative weights of the components, and the DEMATEL method was used to analyze causal relationships among the dimensions of the model. The findings led to the extraction of 17 key components categorized into five major dimensions, including Industry 4.0 technologies, organizational capabilities and readiness, banking service transformation, customer experience and value, and performance and sustainability outcomes. Causal analysis demonstrated that Industry 4.0 technologies and organizational capabilities function as driving factors and, through banking service transformation, influence customer digital experience, trust, and ultimately financial performance and sustainability. This framework provides a theoretical and empirical foundation for structural modeling in subsequent stages of the research.

Keywords: *Industry 4.0; Digital Banking; Digital Transformation; Dynamic Capabilities; Smart Technologies*

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1. Introduction

The banking sector is undergoing a profound transformation as digital technologies, Industry 4.0 architectures, and new forms of service innovation reshape the foundations of financial value creation. Unlike earlier waves of computerization that primarily automated back-office operations or expanded electronic channels, the current transformation involves the systemic integration of artificial intelligence, big data analytics, cloud computing, blockchain, the Internet of Things, robotic process automation, and platform-based digital ecosystems into banking service design and delivery [1-4]. This transformation is not merely technological; it also affects organizational capabilities, governance structures, customer relationships, business models, financial inclusion, operational resilience, and sustainability-oriented value creation [5-8]. Therefore, developing a digital service model within the framework of Industry 4.0 in the banking sector requires an integrative understanding of how technological infrastructure, organizational readiness, service innovation, and performance outcomes interact within a coherent conceptual system.

Industry 4.0 initially emerged as a paradigm for smart manufacturing, but its underlying logic has expanded to service sectors, including banking and financial services. The core of Industry 4.0 lies in cyber-physical integration, data-driven decision-making, automation, connectivity, interoperability, and real-time intelligence, all of which are increasingly relevant to financial institutions seeking to redesign their services and operations [3, 9-11]. In banking, this paradigm supports the transition from branch-centered and transaction-centered models toward intelligent, personalized, embedded, and platform-based services. Prior studies have emphasized that Industry 4.0 maturity in banking depends not only on technological adoption but also on strategic alignment, organizational readiness, digital culture, governance mechanisms, and the capability to integrate digital tools across the service supply chain [12-15]. Thus, the Industry 4.0 framework provides a valuable theoretical lens for explaining the new architecture of banking services.

Digital transformation in banking involves a multilevel shift from digitization of existing processes to full digital banking models. Digitization refers to the conversion of analog data and processes into digital formats, whereas digital transformation involves deeper changes in organizational routines, customer interfaces, business logic, and value propositions [8, 16, 17]. Digital banking transformation includes mobile banking, virtual banking, open banking, digital payment ecosystems, digital customer experience management, data-driven marketing, automated compliance, and intelligent risk assessment [18-21]. The increasing role of digital entrants has intensified the pressure on incumbent banks to transform, while corporate governance factors influence how effectively traditional banks respond to digital disruption [22]. Consequently, banks must develop models that explain not only technology adoption but also the organizational and market mechanisms through which digital services create value.

A key pillar of Industry 4.0-based digital banking is advanced data infrastructure. Big data analytics enables banks to analyze large volumes of structured and unstructured data, identify customer behavior patterns, improve credit scoring, detect fraud, personalize services, and support strategic decision-making [1, 23]. In accounting, auditing, and financial reporting, big data and related Industry 4.0 technologies enhance transparency, monitoring, predictive analytics, and real-time decision-making [24-27]. Similarly, machine learning and artificial intelligence are increasingly used for fraud detection, risk assessment, regulatory compliance, customer segmentation, portfolio optimization, and financial modeling [28-31]. These developments show that data infrastructure is not a technical support function but a central strategic resource for the digital transformation of banking services.

Artificial intelligence has become one of the most important technologies in the transformation of financial and accounting services. In banking, AI supports automated customer interaction, predictive risk assessment, fraud detection, credit evaluation, intelligent advisory services, and process optimization [32-34]. The diffusion of AI also requires digital competence, technological readiness, ethical awareness, and organizational learning, particularly because human capital remains essential for interpreting and governing intelligent systems [34, 35]. Furthermore, the emergence of generative AI and large language models creates new possibilities for automated reporting, intelligent compliance, customer support, and knowledge-intensive banking processes [30, 36]. However, the benefits of AI depend on data quality, governance, institutional readiness, and integration with broader digital transformation strategies rather than isolated implementation.

Blockchain and distributed ledger technologies represent another important dimension of Industry 4.0 in banking. Blockchain can strengthen transparency, traceability, transaction security, smart contracts, real-time auditing, fraud prevention, and inter-organizational trust in financial ecosystems [37-39]. In open banking and platform finance, distributed ledger technologies may support new models of decentralized verification and secure data exchange, especially when combined with regulatory innovation and digital governance [18, 40]. At the same time, the adoption of blockchain requires careful attention to scalability, interoperability, cybersecurity, legal accountability, and institutional acceptance. Therefore, blockchain should be positioned within a broader digital service model that connects technological potential to governance, service architecture, customer trust, and financial performance.

Cloud computing, automation, and digital process redesign also play a central role in banking transformation. Cloud infrastructure enables flexibility, scalability, cost efficiency, remote service deployment, and rapid integration of digital platforms, while process automation improves operational efficiency, reduces human error, and supports real-time service delivery [41, 42]. Digital accounting systems and automated financial information systems have also been shown to influence banking performance, transparency, and decision quality [43, 44]. However,

automation must be aligned with service innovation and customer value rather than being treated only as a cost-reduction mechanism. In this regard, digital servitization provides a useful framework for understanding how firms move from product- or transaction-centered logic toward digitally enabled service ecosystems [5, 45]. For banks, this means that operational automation must be connected to customer experience, personalization, responsiveness, and service integration.

Organizational capabilities are essential for converting digital technologies into sustainable service outcomes. The resource-based view and dynamic capabilities perspective suggest that digital transformation depends on the ability of organizations to sense technological opportunities, seize them through strategic investment, and reconfigure resources, structures, and processes in response to environmental change [46-48]. Dynamic managerial capabilities are particularly important in banking because managers must coordinate technological investments, regulatory constraints, risk control, customer needs, and competitive pressures [47]. Absorptive capacity and innovation capability further determine whether banks can transform digital knowledge into new services, improved performance, and long-term competitive advantage [35, 46]. Therefore, any model of digital services in the Industry 4.0 banking context must include organizational readiness, digital maturity, governance, and dynamic capability as core dimensions.

Digital governance is another critical component of Industry 4.0-based banking transformation. Banks operate in highly regulated environments where privacy, cybersecurity, compliance, risk management, transparency, and consumer protection are essential. Regulatory innovation and digital finance governance influence how banks balance experimentation with stability and accountability [40, 49]. The broader literature on digitalization and institutional quality also indicates that digital transformation is shaped by financial freedom, industrial development, governance quality, and institutional capacity [50, 51]. In addition, digital technologies affect democratic processes, public participation, and institutional trust, highlighting the broader societal implications of digital governance [52]. In the banking sector, digital governance therefore functions as a bridge between technological innovation, regulatory legitimacy, customer trust, and sustainable value creation.

From the customer perspective, digital banking transformation is meaningful only when it improves experience, trust, access, and perceived value. Digital customer experience includes usability, personalization, speed, transparency, omnichannel integration, responsiveness, and emotional confidence in digital interactions [20, 53]. Trust is particularly important because banking services involve sensitive personal, financial, and behavioral data; therefore, digital trust depends on security, privacy, reliability, and institutional credibility [21]. Digitalization can also reshape financial inclusion by reducing geographical barriers, enabling mobile services, and expanding access to underserved groups, although digital barriers and branch closures may also create exclusion risks for certain customers [7, 19]. Accordingly, a comprehensive digital service model must conceptualize customer experience and value not as peripheral outcomes but as central evaluative criteria of transformation success.

Digital banking also changes business models and competitive dynamics. Digitalization can lead to convergence across industries as platform logics, data ecosystems, and service integration reshape traditional sector boundaries [54, 55]. In banking, digital entrants, FinTech firms, open banking providers, and PayTech solutions challenge incumbent institutions and force them to revise their market strategies, revenue models, and service architectures [18, 22, 56, 57]. Studies on future drivers of the banking industry and virtual banking business models indicate that the sector is moving toward scenario-based, platform-oriented, and digitally integrated models that require strategic foresight and institutional adaptation [58-61]. These shifts demonstrate the need for a model that integrates technological foundations with business model innovation, market penetration, and social banking innovation.

Sustainability is increasingly connected to Industry 4.0 and digital banking. Sustainability 4.0 refers to the use of advanced digital technologies to support long-term value creation, efficiency, inclusion, transparency, and alignment with sustainable development goals [6, 62]. In banking services, Industry 4.0 technologies can support sustainability through paperless processes, energy-efficient digital operations, financial inclusion, responsible lending, data-driven risk assessment, and more transparent reporting systems [6, 36]. Although some sustainability studies focus on other sectors such as construction, their findings show that Industry 4.0 and digital technologies can improve sustainability performance by integrating data, automation, and intelligent management systems [63]. Thus, sustainability should be regarded as a strategic consequence

of digital service transformation rather than as an external or secondary outcome.

Despite the growing body of research on digital banking, Industry 4.0, FinTech, AI, blockchain, digital governance, and sustainability, the literature remains fragmented. Some studies focus on technological readiness and maturity [9, 11, 12, 15]; others examine customer experience, mobile banking adoption, trust, and inclusion [19-21, 53]; and another group emphasizes digital accounting, auditing, compliance, and analytics [24, 27, 43, 44]. Additional studies explore quantum computing, portfolio optimization, and emerging financial technologies that may shape the next stage of intelligent finance [31, 64-66]. While each stream contributes valuable insights, there is still a need for an integrated model that synthesizes these dispersed concepts into a coherent framework for digital services in banking under the Industry 4.0 paradigm.

Therefore, the present study aims to develop an integrated digital service model within the framework of Industry 4.0 in the banking sector by identifying, synthesizing, and structuring the key technological, organizational, service-related, customer-oriented, and performance-based components extracted from the existing literature.

2. Methodology

Given the nature of the problem, the research objectives, and the necessity of developing a new model, the present study adopted a systematic and integrated approach. In terms of purpose, this study is categorized as applied-basic research. Regarding the method of data collection and analysis, the study employed a qualitative approach. The selection of this approach was due to the multidimensional and complex nature of the research topic, as designing and validating a digital service model within the framework of Industry 4.0 requires the integration of conceptual, structural, and analytical examinations. The qualitative phase contributes to the exploration and conceptualization of the underlying constructs.

To identify the components and dimensions of the digital service model within the Industry 4.0 framework, the meta-synthesis method was employed. Meta-synthesis is a qualitative and systematic approach for analyzing and integrating findings from previous studies, enabling researchers to consolidate dispersed concepts in the literature and develop a coherent framework. At this stage, the researcher systematically searched reputable scientific sources and extracted and analyzed studies related to digital banking and Industry 4.0. Subsequently, through coding and categorization of concepts, the key components of digital services were identified and classified into conceptual dimensions. The output of this stage was the development of the initial conceptual model of the study, consisting of a structured set of related components and dimensions.

The study population included all scientific research articles, specialized books, theses, and dissertations related to "digital services within the framework of Industry 4.0 in the banking sector" published during the recent sixteen-year period (2010–2026). This time frame was selected to focus on recent literature aligned with the developments of the Fourth Industrial Revolution.

To collect valid scientific resources, a systematic search was conducted based on keywords such as "digital banking services," "digital banking," "Industry 4.0 in banking," "banking digital transformation," and related combinations in reputable international scientific databases, including Elsevier, Springer, Emerald, ScienceDirect, and Google Scholar.

The sampling method in this section was purposive and based on inclusion and exclusion criteria determined according to the PRISMA framework. Accordingly, all relevant studies were initially identified, duplicate articles were removed, and final resources were selected based on criteria such as direct relevance to the research topic, scientific quality, accessibility of the full text, and focus on the banking sector.

3. Findings and Results

In this study, the meta-synthesis process was conducted based on the seven-stage model proposed by Sandelowski and Barroso, which is considered one of the most comprehensive frameworks in this field. In the first step, guiding research questions were formulated to determine the direction of the systematic analysis of the literature. Subsequently, systematic searches were carried out in reputable national and international scientific databases, and relevant studies within the specified time period were identified. Specialized keywords related to digital banking services and Industry 4.0 were extracted, and the search process was conducted in databases such as Web of Science, Elsevier, Springer, Emerald, ScienceDirect, and Google Scholar. Following the initial collection of sources, a screening process was conducted based on title, abstract, research methodology, and full-text review, and the final eligible studies were selected.

At the data extraction stage, the content of the selected articles was carefully examined, and concepts, indicators, and underlying categories were extracted through systematic note-taking and coding. The extracted codes were subsequently categorized and classified, and through comparative analysis and interpretive synthesis, the principal dimensions and components of the model were identified. To improve analytical accuracy and control coding quality, qualitative data analysis software was utilized, and coding agreement was assessed using indicators such as Cohen's kappa coefficient. Finally, the findings obtained from this process were integrated into a preliminary conceptual model.

Step One: Formulation of Research Questions

The first stage in conducting the meta-synthesis involved the precise and purposeful formulation of the research questions. Since the aim of this study was to identify and explain the components of digital banking services within the framework of Industry 4.0 and to extract an integrated conceptual framework, the meta-synthesis questions were designed to encompass both the technological dimensions of the Fourth Industrial Revolution and the service, organizational, and institutional dimensions of digital banking.

In the meta-synthesis approach, the initial question is generally formulated around the concept of "What?" because the primary objective is to extract concepts, indicators, and key constructs from the existing literature. However, to achieve a theoretical and structural framework, the questions should also extend to the levels of "How?" and "What relationships?" in order to enable the classification of concepts and the explanation of relationships among them.

Accordingly, answering these questions makes it possible to extract an integrated conceptual framework explaining the linkage between Industry 4.0 and digital banking services within the form of an analytical model. Based on the above considerations, the principal meta-synthesis research question was formulated as follows:

"What are the key components and constructs of digital banking services within the framework of Industry 4.0, and how can these constructs be conceptually explained within an integrated and structured framework based on evidence from the literature?"

Step Two: Systematic Literature Review

Following the formulation of the research questions, the second stage of the meta-synthesis was devoted to the systematic and structured review of scientific literature. The purpose of this stage was to comprehensively, transparently, and reproducibly identify studies related to "digital banking services within the framework of Industry 4.0" in order to provide a reliable basis for concept extraction and synthesis.

At this stage, the search strategy was designed in a way that ensured maximum coverage of the relevant literature while maintaining the focus of the research on valid and relevant studies through the application of inclusion and exclusion criteria.

Considering the formal introduction of the Industry 4.0 concept in 2011 and the expansion of the digital banking literature during the past decade, the search period was defined from 2010 to 2026. This time frame enabled the inclusion of pioneering studies in banking digitalization as well as recent research related to advanced technologies, FinTech, artificial intelligence, blockchain, digital governance, and Sustainability 4.0.

To ensure comprehensiveness, reputable national and international databases were selected.

International databases included Scopus, Web of Science, ScienceDirect, SpringerLink, Emerald Insight, Wiley Online Library, and Google Scholar.

National databases included SID, Civilica, Magiran, Noormags, and IranDoc.

These databases were selected based on their indexing coverage of scientific journals in management, banking, information technology, digital transformation, and Industry 4.0.

The search strategy was designed based on the combination of three principal conceptual clusters: Industry 4.0 and advanced digital technologies; digital banking and financial services; and digital transformation, service innovation, and value creation. Within each cluster, primary keywords and their synonyms were extracted in both Persian and English. The keywords were identified through the combination of research questions and a preliminary review of the literature.

Table 1. Search Keywords in National and International Databases

Conceptual Cluster	Persian Keywords	English Keywords
Industry 4.0	Industry 4.0, Fourth Industrial Revolution, advanced digital technologies, smart automation	Industry 4.0, Fourth Industrial Revolution, Advanced Digital Technologies, Smart Automation
Key Technologies	artificial intelligence, big data, Internet of Things, blockchain, cloud computing, data analytics	Artificial Intelligence, Big Data, Internet of Things, Blockchain, Cloud Computing, Data Analytics
Digital Banking	digital banking, smart banking, virtual banking, digital financial services	Digital Banking, Smart Banking, Virtual Banking, Digital Financial Services
Digital Transformation	digital transformation, digital maturity, digital readiness, digitization	Digital Transformation, Digital Maturity, Digital Readiness, Digitization
Services and Experience	digital services, service innovation, digital customer experience, electronic service quality	Digital Services, Service Innovation, Digital Customer Experience, E-Service Quality
Governance and Risk	digital governance, cybersecurity, privacy, digital risk	Digital Governance, Cybersecurity, Data Privacy, Digital Risk
Ecosystem and FinTech	FinTech, digital ecosystem, open innovation	FinTech, Digital Ecosystem, Open Innovation

The inclusion criteria included publication in reputable peer-reviewed journals or recognized scientific conferences, direct relevance to Industry 4.0, digital transformation, or digital banking services, publication within the specified time period, and accessibility of the full text of the article.

The exclusion criteria included non-scientific or non-peer-reviewed articles, duplicate studies, purely technical research lacking connections to service, managerial, or banking dimensions, and studies lacking conceptual relevance to banking or financial services.

The search process and extracted studies were documented to facilitate the subsequent stages of screening and flowchart development. Through the use of a systematic, multilingual, and multi-database search strategy, a comprehensive set of studies related to Industry 4.0 and digital banking services was identified. The application of conceptual clusters, logical keyword combinations, and inclusion and exclusion criteria established the basis for the formation of the initial study database used in the screening and quality assessment stages.

Step Three: Search and Review of Relevant Articles

Following the determination of keywords and the implementation of systematic searches in selected scientific databases, the third stage of the meta-synthesis focused on the screening and evaluation of the retrieved studies. The purpose of this stage was the gradual refinement of articles and the selection of final studies that were relevant, valid, and aligned with the research questions.

At this stage, the screening process was conducted in a multi-stage and structured manner to preserve comprehensiveness while excluding irrelevant or low-quality studies. The screening logic was based on a funnel approach in which a large number of initial articles were progressively reduced to a limited yet accurate and relevant set of studies.

The first stage involved the removal of duplicate studies.

The second stage involved screening based on article titles.

The third stage involved abstract review.

The fourth stage involved full-text review.

The fifth stage involved methodological quality assessment.

The screening process can be represented through a flowchart similar to the PRISMA framework, including the following stages:

Identification of initial studies from databases

Removal of duplicate records

Title screening

Abstract screening

Full-text review

Final selection of studies for analysis

This approach ensured the transparency and reproducibility of the article selection process and minimized researcher bias in source selection.

Table 2. Numerical Summary of the Study Screening Process Based on the PRISMA Framework

Screening Process Stage	Number of Articles
Initial identification of studies from scientific databases	212
Removal of duplicate records	-36
Remaining articles for title and abstract screening	176
Excluded during title and abstract screening	-82

Articles entered into the full-text review stage	94
Excluded during full-text and methodological quality assessment	-39
Final studies included in the meta-synthesis	55

As shown in the table, out of a total of 212 studies identified during the systematic search stage, 176 articles entered the initial screening stage after the removal of 36 duplicate records. Subsequently, 82 articles were excluded during the title and abstract review phase due to conceptual inconsistency with the research topic. Among the remaining 94 articles, 39 studies were excluded after full-text evaluation and methodological quality assessment. Ultimately, 55 eligible articles entered the coding and conceptual synthesis stage.

Table 3. Characteristics of Selected Studies Included in the Meta-Synthesis

No.	Author / Year	Article Title	Journal / Source
1	Bahrami et al. (2024)	Evaluation of Industry 4.0 Maturity in Iranian Banking	Sepehr Eghtesad
2	Bahrami et al. (2025)	Analysis of Industry 4.0 Maturity in Banking	Systems Engineering and Productivity
3	Shahabi et al. (2021)	The Impact of the Fourth Industrial Revolution on the Banking Service Supply Chain	International Business Management
4	Nistani et al. (2024)	Digital Transformation Model in Specialized Banks	Strategic Policies
5	Rashidi et al. (2023)	Barriers to Digital Banking in Iran	Modern Management Approaches
6	Esmaeili Niri et al. (2024)	Digital Marketing Model in Banking	Technology in Entrepreneurship
7	Milanloo et al. (2024)	Digital Customer Experience Model in Banking	Marketing Management
8	Moomivand et al. (2022)	Future Drivers of Banking with an Emphasis on FinTech	Financial Economics
9	Ajli and Saberifard (2021)	The Fourth Industrial Revolution and Digital Banking	Digital Transformation Conference
10	Mahmoudi et al. (2027)	Social Banking Innovation Model	Investment Knowledge
11	Ouyarhossein et al. (2022)	Digital Transformation in Corporate Banking	Investment Knowledge
12	Zeinati et al. (2025)	Maturity of the Fourth Industrial Revolution in Banking Services	Civilica
13	Fallah et al. (2020)	Business Process Reengineering in Banking	Modern Marketing Research
14	Farhadi Kotenai et al. (2025)	Digital Governance Model in Iranian Banking	Entrepreneurship Knowledge
15	Safajou et al. (2025)	Model for Measuring Digital Transformation Maturity in Banking	Management, Education, and Digital Development
16	Chaychian et al. (2024)	Meta-Synthesis of Barriers to Banking Digital Transformation	Strategic Management Thought
17	Askari et al. (2024)	Future Studies of the Banking Industry in the Transition to the Fourth Industrial Revolution	Monetary and Banking Research
18	Malekan et al. (2024)	Industry 4.0 Technologies and Customer Experience	Business Management Conference
19	Aravan and Akhavan Ghanadi (2025)	Modern Digital Banking Model	National Oil-Free Conference
20	Norki and Kosari (2025)	Virtual Banking Business Model	Value Creation in Management
21	Joghtaei et al. (2025)	Adoption of Generative Artificial Intelligence in Banking	Technology and Entrepreneurship
22	Najafi et al. (2019)	Relationship Between Banks and FinTech Firms	Commercial Strategies
23	Radsaeid et al. (2022)	Open Digital Innovation in Banking	Technology Development Management
24	Felipe et al. (2025)	Digital Transformation in Commercial Banks	Digital Business
25	Masitoh and Sylvia (2025)	From Digitisation to Full Digital Banking	IJBGE
26	Kornarius et al. (2025)	Industry 4.0 Technologies in Services	Journal of Technology Management
27	Thanasas et al. (2026)	Big Data and Industry 4.0 in Accounting	Journal of Risk and Financial Management
28	Maziriri et al. (2026)	Intention to Use Mobile Banking Applications	Computers in Human Behavior Reports
29	Martínez de Ibarreta et al. (2025)	Banking Digitalization and Inclusion	Digital Business
30	Said et al. (2026)	Blockchain in Banking	Asia and Global Economy
31	Wu et al. (2026)	Digital Entrants and Transformation	Information and Management
32	Aydin et al. (2026)	Digitalization and Institutional Quality	Central Bank Review
33	Al-Hattami (2025)	Digital Accounting Systems and Performance	IJIIT
34	Czechowska and Paduszyńska (2024)	Digital Banking Performance	Procedia Computer Science
35	Saleh and Ijab (2025)	Industry 4.0 Readiness Model	Results in Engineering
36	Purwanto et al. (2025)	Digital Banking Transformation	Arthatama Journal
37	Tabares et al. (2023)	Revenue Models for Digital Services	Journal of Business Research
38	Papathomas and Konteos (2024)	Stages of Digital Transformation in Banking	Journal of Financial Services Marketing

39	Al-Okaily et al. (2024)	Digital Accounting Transformation	Journal of Financial Reporting
40	Asamoah et al. (2026)	Dynamic Managerial Capabilities in Banking	Scientific African
41	Mpofu (2024)	Industry 4.0 and Financial Inclusion	IJEFI
42	Rupeika-Apoga et al. (2025)	Regulation and Innovation in Digital Finance	Digital Business
43	Mai Xuan et al. (2025)	Bibliometric Analysis of Digital Banking	IJKSS
44	Bueno et al. (2024)	Digitization and Operational Efficiency	IJIM Data Insights
45	Abdurrahman et al. (2024)	Dynamic Capabilities and Banking Performance	Journal of Innovation
46	Faro et al. (2024)	Digital Transformation and Resilience	JEIM
47	Ononiwu et al. (2024)	Digital Transformation and Agility	World Journal
48	Upadhyay (2024)	Blockchain Business Models	Digital Business
49	Xie and Hu (2024)	Open Banking Review	Journal of Internet and Digital Economics
50	Filgueiras et al. (2024)	Sustainability 4.0 in Banking Services	Sustainability
51	Filgueiras and Melo (2024)	Sustainability 4.0 Systematic Review	Benchmarking
52	Amiri et al. (2023)	Digital Banking Implementation Indicators	Axioms
53	Singh et al. (2022)	Industry 4.0 in Banking	De Gruyter
54	Vial (2019)	Understanding Digital Transformation	Journal of Strategic Information Systems
55	Thakor (2020)	FinTech and Banking	Journal of Financial Intermediation

Following the implementation of the systematic screening process, 55 studies were selected as the final sources for the meta-synthesis stage. Examination of the temporal distribution of these studies indicates that the majority of the research was published between 2023 and 2026, reflecting the growing scientific attention devoted to digital transformation, Industry 4.0, and digital banking in recent years.

From the perspective of geographical distribution and publication source, the final sample included a combination of domestic and international studies, which enhanced conceptual richness and reduced local bias in the extraction of components. Domestic studies mainly focused on digital maturity, transformation barriers, digital governance, and indigenous banking models, whereas international studies emphasized advanced Industry 4.0 technologies such as artificial intelligence, blockchain, big data, Internet of Things, dynamic capabilities, digital business models, and Sustainability 4.0.

Regarding research type, the selected studies included quantitative and qualitative research, structural modeling studies, systematic reviews, bibliometric analyses, and conceptual frameworks. This methodological diversity strengthened the validity of the conceptual synthesis process.

Overall, the integration of these studies provided a suitable foundation for the comprehensive extraction of digital banking transformation components within the context of Industry 4.0.

Step Four: Extraction of Information and Key Indicators From Selected Articles

Following the completion of the systematic identification and screening stages and the determination of the final set of eligible studies, the fourth stage of the meta-synthesis focused on “data extraction.” The purpose of this stage was to transform the selected studies from a dispersed textual collection into a structured and analyzable database, enabling the systematic identification, coding, synthesis, and integration of concepts, indicators, and key constructs related to the research topic, namely digital banking services within the framework of Industry 4.0.

At this stage, the content of each article was examined carefully and line by line, and the relevant information was recorded using a standardized “data extraction form.” Standardization of data extraction reduced researcher bias and enhanced the transparency and reproducibility of the meta-synthesis process because reviewers could trace the extraction logic and verify that the codes and categories were grounded in the actual data of the studies rather than subjective interpretations.

The data extraction form was designed based on a dual “descriptive–analytical” approach. Accordingly, both bibliographic and methodological information and conceptual data and theoretical indicators were extracted. This distinction is important because, in meta-synthesis, the quality and significance of each concept are partially dependent on the study type, methodology, population, and level of analysis. Therefore, contextual information from each article needed to be recorded alongside the conceptual findings.

In the fourth stage of the meta-synthesis, the selected articles were comprehensively reviewed, and the essential indicators related to the research topic were extracted. This extraction process was conducted using a standardized form containing bibliographic, methodological, and conceptual information. The output of this stage consisted of a set of initial codes and raw indicators that formed the basis for axial coding, conceptual integration, and ultimately the construction of the conceptual research model in the subsequent stages.

Step Five: Analysis and Synthesis of Qualitative Findings

The fifth stage represents the most important and analytical phase of the meta-synthesis because, at this stage, the data extracted from the selected studies are elevated from the descriptive level to the level of theoretical explanation. The purpose of this stage was the systematic integration of initial codes, identification of recurring patterns, recognition of conceptual relationships, and ultimately the development of an integrated theoretical framework for explaining digital banking services within the framework of Industry 4.0.

At this stage, the researcher employed a combined approach consisting of "structured qualitative analysis" and "statistical support for qualitative analysis" in order to preserve the interpretive nature of the meta-synthesis while ensuring analytical rigor and validity.

During this phase, the qualitative data extracted from the selected studies were transformed into an integrated conceptual structure through a multi-stage process involving within-study analysis, cross-study comparison, axial coding, and frequency analysis. The output of this stage consisted of a set of organized categories and macro dimensions that formed the basis for designing the conceptual model of the research.

This stage constitutes the distinguishing feature of meta-synthesis compared with traditional literature reviews because, within this process, existing knowledge is not merely described but rather theoretically reconstructed and synthesized.

Step Six: Reliability and Validity of the Model (Meta-Synthesis Quality Control)

In qualitative research, validity and reliability are concepts that go beyond classical statistical measures and refer to criteria such as credibility, dependability, confirmability, and reflexivity of the results. In the meta-synthesis method, since the output of the research is a synthesized conceptual model, quality control is performed at two levels:

Qualitative level: interpretive validity and theoretical coherence

Supporting quantitative level: assessment of agreement and coding reliability

At this stage, the validity and reliability of the conceptual model derived from the meta-synthesis were evaluated through a combination of qualitative criteria, including credibility, dependability, confirmability, and reflexivity, and quantitative measures, including Cohen's kappa coefficient. In addition, to strengthen structural validity, the possibility of testing the model through structural equation modeling was considered. Accordingly, the final research model possesses the required theoretical, interpretive, and statistical coherence and robustness.

Step Seven: Presentation of the Final Meta-Synthesis Findings

After completing the stages of data extraction, open coding, axial aggregation, and model quality control, the final meta-synthesis findings are presented at this stage. In this section, the extracted components of the model are organized into a hierarchical structure consisting of "code," "concept," and "category."

The logic of presenting the findings is as follows:

Codes are the initial semantic units extracted from the selected studies;

Concepts are formed by integrating codes with similar meanings or functions;

Categories are broader dimensions that organize related concepts at a higher level of abstraction.

For brevity, the following table presents only the most important effective codes and concepts with the highest frequency and conceptual weight across the 55 studies.

After completing the stages of identification, screening, data extraction, conceptual coding, and quality control of qualitative findings, the final meta-synthesis results are presented at this stage, and the relative importance of the extracted components is quantitatively determined. The purpose of this step is to move beyond the mere description of concepts toward structural analysis and scientific prioritization of the model components.

Table 4. Final Meta-Synthesis Findings: Extracted Influential Factors

Macro Category	Concept	Sample Codes	Source
Industry 4.0 technologies	Smart technologies	Artificial intelligence, machine learning, predictive analytics	Felipe et al. (2025); Singh et al. (2022)
Industry 4.0 technologies	Data infrastructure	Big data, data mining, data management	Davenport et al. (2012); Thanasas et al. (2026)
Industry 4.0 technologies	Distributed ledger technology	Blockchain, smart contract	Said et al. (2026); Mhlanga (2023)
Industry 4.0 technologies	Cloud computing	Cloud processing, distributed storage	Armbrust et al. (2010)
Organizational capabilities and readiness	Digital maturity	Level of digital transformation, technological readiness	Bahrami et al. (2024)
Organizational capabilities and readiness	Dynamic capabilities	Agility, absorptive capacity, resource reconfiguration	Asamoah et al. (2026)
Organizational capabilities and readiness	Digital governance	Data policy-making, regulatory compliance	Rupeika-Apoga et al. (2025)
Organizational capabilities and readiness	Data-driven culture	Data-based decision-making, organizational learning	Lin et al. (2026)
Banking service transformation	Digital service innovation	Digital service design, personalization	Masitoh and Sylvia (2025)
Banking service transformation	System integration	Channel synergy, open banking	Xie and Hu (2024)
Banking service transformation	Process automation	Robotic process automation, process intelligence	Adewumi et al. (2024)
Customer experience and value	Digital customer experience	User experience, digital interaction	Milanlou et al. (2024)
Customer experience and value	Digital trust	Security, privacy, assurance	Melnyk (2024)
Customer experience and value	Digital service quality	Efficiency, accessibility, responsiveness	Arcand et al. (2017)
Performance and sustainability outcomes	Financial performance	Profitability, return on assets, productivity	Czechowska and Paduszyńska (2024)
Performance and sustainability outcomes	Competitive advantage	Digital differentiation, market share	Bustinza et al. (2015)
Performance and sustainability outcomes	Sustainability 4.0	Sustainable value creation, financial inclusion	Filgueiras et al. (2024)

The presented table indicates the final structure of the meta-synthesis findings in the form of a hierarchical system consisting of five macro categories, a set of intermediate concepts, and corresponding operational codes. This structure shows that the phenomenon of "digital banking services within the framework of Industry 4.0" has a multilayered, systemic, and causal nature that emerges from the simultaneous interaction of technology, organizational capabilities, service transformation, and customer experience, ultimately leading to performance and sustainability outcomes.

At the first level, "Industry 4.0 technologies" were identified as the transformational foundation of digital banking. Concepts such as smart technologies, including artificial intelligence, machine learning, and predictive analytics; data infrastructures, including big data and data mining; distributed ledger technology, including blockchain; and cloud computing represent the transition of banks from traditional transactional systems to intelligent, distributed, and data-driven architectures.

The analysis of this category shows that technologies are presented in the literature not as an end in themselves but as "value drivers." For example, smart technologies enable behavioral analysis of customers and service personalization; blockchain strengthens the infrastructure of trust and transparency; and cloud computing increases operational flexibility and scalability. Therefore, this category plays an antecedent role in the causal structure of the model.

The findings show that technology alone does not lead to transformation; rather, "organizational capabilities and readiness" play a key mediating role in converting technological capacity into service and performance outputs. Concepts such as digital maturity, dynamic capabilities, digital governance, and data-driven culture indicate the internal capability level of banks to absorb, integrate, and exploit emerging technologies.

At the third level, banking service transformation appears as the tangible manifestation of Industry 4.0 in banking. Concepts such as digital service innovation, system integration, and process automation show that digital transformation is not limited to adding online channels; rather, it requires redesigning the service model and operational architecture.

Digital service innovation reflects the development of personalized and interactive services; system integration indicates synergy between physical and digital channels, including omnichannel services and open banking; and process automation reflects increased efficiency and reduced human error.

This category represents the "capability-to-service conversion" stage in the model structure.

The analysis of the findings shows that the central focus of the literature is "digital customer experience." Concepts such as user experience, digital interaction, trust, and digital service quality indicate that the ultimate criterion for the success of digital transformation is the value perceived by the customer.

Digital trust, which is based on security and privacy, is an essential condition for technology adoption. Digital service quality is also measured through indicators such as accessibility, responsiveness, and efficiency. Therefore, this category represents the intersection of technology and the market and plays a decisive role in the sustainability of digital transformation.

Finally, the category of "performance and sustainability outcomes" shows that digital transformation in banking leads not only to improved customer experience but also to strategic outcomes such as financial performance, competitive advantage, and Sustainability 4.0.

Financial performance is measured through indicators such as profitability and productivity; competitive advantage is assessed through digital differentiation and increased market share; and Sustainability 4.0 reflects long-term value creation, financial inclusion, and alignment with sustainable development goals.

This level shows that Industry 4.0 in banking is not merely a technological transformation but a paradigmatic shift in the logic of value creation and sustainable development.

Shannon Entropy in Step Seven

After extracting, coding, and categorizing the concepts derived from the 55 selected studies, the final step in the meta-synthesis was to determine the relative importance of the extracted components. In qualitative studies, merely extracting categories is not sufficient; it is also necessary to determine which components play a more central and distinctive role in constructing the conceptual model.

In this study, Shannon entropy was used to assign objective and non-subjective weights to the components. Shannon entropy is one of the multi-criteria decision-making methods based on information theory and measures the uncertainty or dispersion of information in an indicator.

Table 5. Results of Weighting Model Components Using Shannon Entropy

No.	Component	Entropy Value (Ej)	Divergence Degree (Dj)	Final Weight (Wj)	Rank
1	Digital governance	0.881	0.119	0.082	1
2	Cloud computing	0.889	0.111	0.077	2
3	Process automation	0.893	0.107	0.074	3
4	System integration	0.896	0.104	0.072	4
5	Data-driven culture	0.901	0.099	0.069	5
6	Smart technologies	0.906	0.094	0.065	6
7	Data infrastructure	0.912	0.088	0.061	7
8	Distributed ledger technology	0.918	0.082	0.057	8
9	Digital service innovation	0.924	0.076	0.053	9
10	Digital customer experience	0.931	0.069	0.048	10
11	Digital service quality	0.936	0.064	0.045	11
12	Digital trust	0.942	0.058	0.041	12
13	Digital maturity	0.947	0.053	0.038	13
14	Dynamic capabilities	0.951	0.049	0.035	14
15	Financial performance	0.956	0.044	0.032	15
16	Competitive advantage	0.961	0.039	0.028	16
17	Sustainability 4.0	0.965	0.035	0.023	17

The results obtained from weighting the extracted components using Shannon entropy show that the distribution of concept importance in the Industry 4.0 literature on digital banking has a hierarchical and structural nature. These results are not merely numerical rankings; rather, they indicate the theoretical position of each component in the digital value creation chain.

The highest weight was assigned to "digital governance." This finding is theoretically significant because, in digital banking, technology cannot be implemented sustainably

without regulatory frameworks, risk management, regulatory compliance, and data policy-making. The considerable dispersion of research attention to this component indicates that digital governance is one of the most challenging and, at the same time, most differentiating dimensions of Industry 4.0 transformation in banking.

Cloud computing and process automation ranked next. This indicates that scalability infrastructures and the intelligentization of operations are operational drivers of transformation. Differences in the level of emphasis placed by studies on these technologies increased their degree of divergence and, consequently, their final weights.

In the middle of the table are components such as data-driven culture, digital maturity, and dynamic capabilities. Although these components are highly fundamental from a theoretical perspective, because they have been mentioned in almost all studies, their distribution was more uniform, and therefore they received lower entropy weights.

Digital service innovation, system integration, and process automation play an intermediary role between technology and customer experience. Their placement in the middle ranks of the table shows that digital transformation in banking is not possible without redesigning the service architecture.

This level functions in the causal model as the "mechanism for converting resources into value."

Digital customer experience, digital service quality, and digital trust ranked lower. The reason is that almost all studies related to digital banking have referred to the importance of experience and trust; therefore, their distribution was more uniform and their degree of divergence was lower.

Financial performance, competitive advantage, and Sustainability 4.0 received the lowest weights. This is structurally logical because these components represent the final outcomes of the transformation process and are usually presented as model consequences rather than as drivers. This prepares the ground for empirical testing of structural relationships in the structural equation modeling stage.

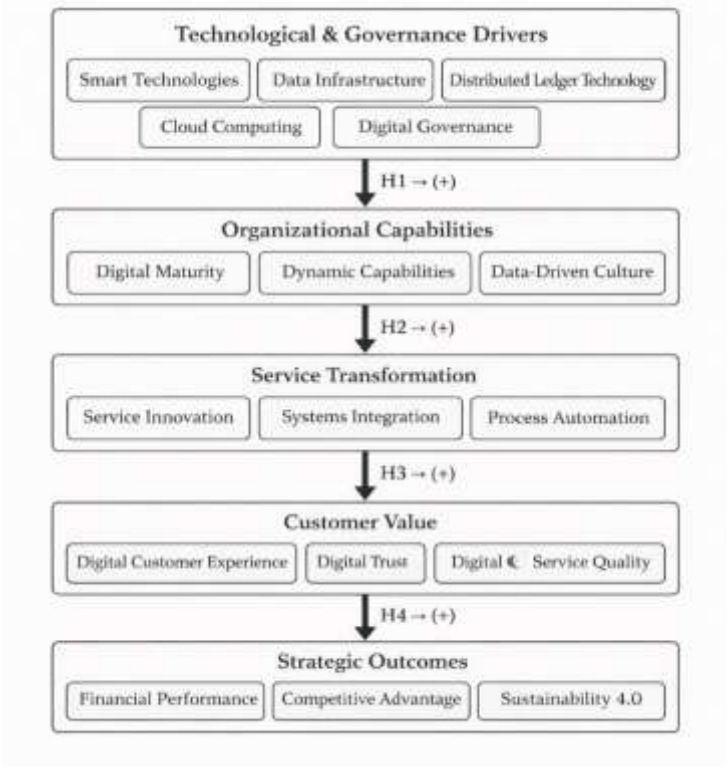

Figure 1. Final Model Obtained From the Meta-Synthesis

4. Discussion and Conclusion

The findings of the present study demonstrated that digital banking transformation within the framework of Industry 4.0 is a multidimensional and systemic phenomenon shaped by the interaction among technological infrastructures, organizational capabilities, service transformation mechanisms, customer-centered value dimensions, and strategic performance outcomes. The meta-synthesis process led to the identification of five macro

categories and seventeen key concepts, indicating that digital banking transformation cannot be explained solely through technological adoption. Rather, transformation emerges from the coordinated alignment of intelligent technologies, governance structures, organizational readiness, process redesign, customer trust, and sustainability-oriented value creation. The results therefore support the view that Industry 4.0 in banking represents a paradigmatic transition from traditional transaction-centered banking toward intelligent, data-driven, and ecosystem-based financial services [2, 8, 17].

One of the most significant findings of the study was the central role of Industry 4.0 technologies as the foundational drivers of digital banking transformation. The extracted concepts, including artificial intelligence, big data, cloud computing, blockchain, predictive analytics, and intelligent automation, demonstrated that advanced digital technologies form the infrastructural core of modern banking ecosystems. This finding is consistent with previous studies emphasizing the transformative role of Industry 4.0 technologies in banking and financial services [2-4]. The results further showed that technologies such as artificial intelligence and machine learning are no longer peripheral innovations but central mechanisms for customer personalization, intelligent risk assessment, fraud detection, and operational optimization. This finding aligns with studies indicating that AI-driven analytics and intelligent systems significantly improve banking responsiveness and decision-making quality [28, 32, 33]. Moreover, the importance assigned to big data infrastructure confirms the argument that data has become the most strategic resource in the digital economy because banks increasingly rely on real-time analytics and predictive models to maintain competitiveness and customer relevance [1, 23, 26].

The findings also highlighted the critical importance of blockchain and distributed ledger technologies in creating transparency, trust, and security within digital banking ecosystems. This result supports prior studies demonstrating that blockchain technologies enhance financial transparency, support fraud detection, facilitate decentralized verification, and improve trust within financial networks [37, 38]. The significance of blockchain in the present findings may also reflect the growing need for secure and trustworthy infrastructures in digital banking environments where customers increasingly interact through remote and automated channels. Similarly, cloud computing emerged as one of the most influential components of digital banking transformation. This finding is theoretically meaningful because cloud infrastructure provides scalability, interoperability, and operational flexibility, all of which are essential for modern banking platforms operating in highly dynamic environments [41, 42]. The high relative weight of cloud computing obtained through Shannon entropy analysis further indicates that operational scalability and distributed processing capabilities are among the primary drivers of digital transformation in banking.

Another important finding of the study was the mediating role of organizational capabilities and readiness in transforming technological resources into strategic and service-oriented outcomes. The findings showed that digital maturity, dynamic capabilities, digital governance, and data-driven culture function as enabling mechanisms that determine whether banks can effectively absorb and exploit Industry 4.0 technologies. This result strongly supports the resource-based and dynamic capabilities perspectives, which emphasize that sustainable competitive advantage depends not merely on technology ownership but on the organizational ability to integrate, reconfigure, and strategically utilize resources [35, 46, 47]. The findings also align with studies demonstrating that digital transformation success depends heavily on organizational agility, absorptive capacity, innovation capability, and managerial responsiveness [47, 48]. In this regard, the study confirms that technological transformation without organizational readiness produces fragmented and unsustainable outcomes.

The particularly high ranking of digital governance in the entropy analysis constitutes one of the most theoretically important findings of the study. Digital governance received the highest relative weight among all extracted components, indicating that governance structures, regulatory compliance, cybersecurity, and data policy frameworks represent the most differentiating dimensions of Industry 4.0 transformation in banking. This result is highly consistent with prior studies emphasizing that digital finance ecosystems require strong regulatory mechanisms to balance innovation with accountability and stability [40, 49]. In highly regulated sectors such as banking, digital transformation introduces new ethical, legal, and operational risks related to data privacy, cybersecurity, algorithmic transparency, and automated decision-making. Consequently, governance becomes not merely a support mechanism but a strategic foundation for sustainable transformation. The findings also support broader institutional perspectives arguing that digitalization outcomes are influenced by governance quality, institutional capacity, and regulatory adaptation [50, 51].

The results further indicated that digital service transformation constitutes the operational manifestation of Industry 4.0 within the banking sector. Concepts such as digital service innovation, system integration, omnichannel banking, and process automation showed that transformation extends beyond the simple digitization of services. Instead, banks are redesigning service architectures and customer interaction models through integrated digital ecosystems. This finding supports the digital servitization perspective, which argues that organizations increasingly create value through digitally enabled service ecosystems rather than isolated products or transactions [5, 45]. The findings also correspond with studies emphasizing the importance of open banking, integrated channels, and automated service systems in contemporary banking transformation [16, 18]. The strong position of process automation in the findings indicates that operational intelligence and efficiency remain central strategic priorities for banks seeking to compete in digital environments characterized by speed, scalability, and real-time responsiveness.

Another major finding of the study was the centrality of digital customer experience and digital trust in the conceptual structure of banking transformation. The findings showed that customer value in digital banking is increasingly defined through user experience quality, personalization, responsiveness, accessibility, trust, and digital interaction quality. This finding strongly aligns with studies indicating that customer perceptions of convenience, reliability, and usability significantly influence digital banking adoption and continued usage intentions [20, 21]. The findings also support the argument that trust has shifted from traditional face-to-face relational trust toward technologically mediated trust structures based on security, privacy protection, transparency, and system reliability [21]. Furthermore, the importance of digital experience management confirms grounded theory findings suggesting that customer-centered digital service design is a decisive factor in banking competitiveness [53]. Therefore, the study demonstrates that technological sophistication alone is insufficient unless it translates into meaningful customer experiences and perceived value.

The findings additionally revealed that digital transformation in banking contributes to broader strategic and societal outcomes, including financial performance, competitive advantage, financial inclusion, and Sustainability 4.0. This result is consistent with studies demonstrating that digitization improves operational efficiency, profitability, productivity, and market responsiveness within the banking sector [42, 43, 57]. The findings also support research showing that digital banking and FinTech ecosystems can enhance financial inclusion by reducing geographical and infrastructural barriers to financial services [7, 19]. However, the relatively lower entropy weights assigned to performance and sustainability components indicate that these dimensions are generally treated in the literature as outcomes of transformation rather than as primary drivers. This structural positioning is theoretically coherent because financial performance and sustainability emerge after technological, organizational, and service transformations have already occurred.

The present findings also suggest that the evolution of banking transformation is increasingly moving toward integrated ecosystem models characterized by platformization, intelligent automation, and data-driven value networks. Emerging technologies such as quantum computing, metaverse banking, distributed AI systems, and advanced predictive analytics indicate that the future of banking may extend beyond current digital banking models toward more autonomous and interconnected financial ecosystems [31, 64-66]. The identification of these emerging concepts within the literature demonstrates that Industry 4.0 transformation is not a completed process but an evolving trajectory that continuously reshapes banking structures, customer expectations, and competitive dynamics.

The study also contributes theoretically by integrating fragmented streams of literature into a unified conceptual framework. Previous research has often examined digital banking from isolated perspectives, including technology adoption, digital maturity, customer behavior, governance, accounting transformation, or financial performance [12, 15, 44]. In contrast, the present study synthesizes these dimensions within a systemic and hierarchical structure that clarifies the causal relationships among technological infrastructure, organizational capability, service transformation, customer value, and strategic outcomes. This integrative perspective provides a stronger conceptual basis for future empirical modeling and structural equation analysis in digital banking research.

From a methodological perspective, the study demonstrates the usefulness of meta-synthesis for constructing conceptual models in emerging interdisciplinary domains. The integration of qualitative coding, comparative analysis, Shannon entropy weighting, and causal interpretation enabled the identification of both conceptual relationships and relative component importance. The use of entropy analysis was particularly

valuable because it moved the study beyond descriptive synthesis toward analytical prioritization of the extracted concepts. This methodological integration enhances the robustness and explanatory power of the proposed conceptual framework.

Overall, the findings indicate that digital banking transformation within the framework of Industry 4.0 is fundamentally a systemic transformation process involving technological intelligence, organizational adaptability, governance maturity, customer-centered service redesign, and sustainability-oriented value creation. The results therefore suggest that successful digital transformation in banking depends not on isolated technological investments but on the strategic integration of technological, organizational, and relational capabilities within a coherent digital ecosystem architecture.

One limitation of the present study is that the meta-synthesis relied exclusively on published scientific literature, which may have excluded valuable practical experiences, internal banking reports, and industry-specific implementation knowledge. In addition, although the study included both domestic and international sources, the conceptual emphasis of the literature may still reflect publication biases and regional differences in digital transformation maturity. Another limitation relates to the rapid evolution of Industry 4.0 technologies, meaning that some emerging innovations may evolve faster than the academic literature itself. Furthermore, because the study was qualitative and conceptual in nature, the proposed framework has not yet been empirically validated through large-scale quantitative testing.

Future research should empirically test the proposed conceptual model using structural equation modeling, multi-level analysis, or machine learning approaches in different banking environments. Comparative studies between developed and developing economies may also provide deeper insight into the contextual factors influencing Industry 4.0 banking transformation. Researchers should additionally investigate the role of emerging technologies such as quantum computing, generative artificial intelligence, decentralized finance, and metaverse banking in shaping future digital banking ecosystems. Longitudinal studies examining the dynamic evolution of customer trust, digital governance, and organizational capability over time would further enrich the literature. Moreover, future studies could explore the interaction between sustainability goals, financial inclusion, and intelligent banking systems within the broader context of Industry 5.0.

Bank managers and policymakers should approach digital transformation as a systemic strategic initiative rather than a collection of isolated technological projects. Investment priorities should focus simultaneously on intelligent technologies, governance mechanisms, cybersecurity infrastructure, organizational learning, and customer experience management. Banks should strengthen data-driven cultures and dynamic capabilities to improve adaptability and long-term competitiveness. Policymakers should also develop balanced regulatory frameworks that encourage innovation while ensuring privacy protection, transparency, and financial stability. In addition, banking institutions should prioritize customer trust, digital accessibility, and sustainable value creation in order to ensure that Industry 4.0 transformation contributes not only to operational efficiency but also to social and economic development.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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All procedures performed in this study were under the ethical standards.

References

[1] T. H. Davenport, P. Barth, and R. Bean, "How "Big Data" is Different," *MIT Sloan Management Review,* vol. 54, no. 1, pp. 22-24, 2012.

[2] T. Felipe, R. T. Oliveira, A. Toth-Peter, S. Mathews, and U. Dulleck, "Digital transformation in commercial banks: Unraveling the flow of Industry 4.0," *Digital Business,* vol. 5, no. 2, p. 100129, 2025, doi: 10.1016/j.digbus.2025.100129.

[3] Y. P. Kornarius, A. Vanderstukken, A. Gunawan, and J. Stoffers, "Industry 4.0 technologies in the service sector: A systematic literature review," *Journal of Technology*

Management and Innovation, vol. 20, no. 4, pp. 114-129, 2025, doi: 10.4067/s0718-27242025000400114.

[4] G. Thanasas, G. Kampiotis, and C. Halkiopoulos, "Transforming digital accounting: Big data, IoT, and Industry 4.0 technologies-A comprehensive survey," *Journal of Risk and Financial Management,* vol. 19, no. 1, p. 92, 2026, doi: 10.3390/jrfm19010092.

[5] B. Tronvoll, A. Sklyar, D. Sörhammar, and C. Kowalkowski, "Transformational shifts through digital servitization," *Industrial Marketing Management,* vol. 89, pp. 293-305, 2020, doi: 10.1016/j.indmarman.2020.02.005.

[6] I. F. L. V. Filgueiras *et al.*, "Analyzing the benefits of Industry 4.0 technologies that impact Sustainability 4.0 in banking services," *Sustainability,* vol. 16, no. 14, p. 6179, 2024, doi: 10.3390/su16146179.

[7] F. Y. Mpofu, "Industry 4.0 in finance, digital financial services and digital financial inclusion in developing countries: Opportunities, challenges, and possible policy responses," *International Journal of Economics and Financial Issues,* vol. 14, no. 2, pp. 120-135, 2024, doi: 10.32479/ijefi.15081.

[8] S. Masitoh and N. H. Sylvia, "From digitisation to full digital banking: A systematic literature review on the multilevel integration of Industry 4.0 technologies and conceptual frameworks in banking transformation," *International Journal of Business Law, Business Ethic, Business Communication & Green Economics,* vol. 2, no. 3, pp. 34-57, 2025, doi: 10.70142/ijbge.v2i3.416.

[9] O. Bandara, K. Vidanagamachchi, and R. Wickramarachchi, "A model for assessing maturity of Industry 4.0 in the banking sector," 2019, pp. 1141-1150.

[10] E. Boffa and A. Maffei, "Development and application of an integrated business model framework to describe the digital transformation of manufacturing: A bibliometric analysis," *Production & Manufacturing Research,* vol. 11, no. 1, p. 2164952, 2023, doi: 10.1080/21693277.2023.2164952.

[11] N. I. Saleh and M. T. Ijab, "IR4.0 readiness model for SMEs: A cross-sector analysis in Malaysia," *Results in Engineering,* vol. 28, p. 107479, 2025, doi: 10.1016/j.rineng.2025.107479.

[12] M. Bahrami, G. Hashemzadeh, A. Shahmansouri, and K. Fathi Hafshejani, "Analysis of components affecting Industry 4.0 maturity assessment in Iranian banking," *Sepehr-e-Eqtesad Quarterly,* 2024.

[13] V. Shahabi, A. Azar, F. Faezi Razi, and M. Fallah Shams, "Modeling the impact of the Fourth Industrial Revolution on the banking services supply chain using system dynamics and fuzzy DEMATEL," *International Business Management,* vol. 4, no. 1, pp. 76-89, 2021.

[14] B. Zeinati, M. Taleghani, and A. Sharj-Sharifi, "Designing Industry 4.0 maturity dimensions in the banking services supply chain and digital banking development using a grounded theory approach," 2025.

[15] A. Safajoo, A. Rezaeian, J. Haghighat Monfared, and A. Abdollahi, "Presenting a model for measuring maturity levels of digital transformation in the banking industry," *Management, Education and Development in the Digital Age,* vol. 2, no. 3, 2025, doi: 10.61838/medda.230.

[16] A. Papathomas and G. Konteos, "Financial institutions digital transformation: The stages of the journey and business metrics to follow," *Journal of Financial Services Marketing,* vol. 29, pp. 590-606, 2024, doi: 10.1057/s41264-023-00223-x.

[17] T. J. Purwanto, T. Atmoko, and S. T. Rahardjo, "Driving digital banking transformation in Indonesia amid Industry 4.0," *Arthatama: Journal of Business Management and Accounting,* vol. 9, no. 2, pp. 246-257, 2025. [Online]. Available: https://journal.lifescifi.com/index.php/art/article/view/699.

[18] C. Xie and S. Hu, "Open banking: An early review," *Journal of Internet and Digital Economics,* vol. 4, no. 2, pp. 73-82, 2024, doi: 10.1108/JIDE-03-2024-0009.

[19] C. Martínez de Ibarreta, A. Ruíz-Rúa, C. Gijón, and F. Fernández-Bonilla, "Banking digitalization in Spain: How branch closures and digital barriers reshape financial inclusion," *Digital Business,* vol. 5, no. 1, p. 100119, 2025, doi: 10.1016/j.digbus.2025.100119.

[20] E. T. Maziriri, T. F. Rukuni, B. Nyagadza, and T. Bepe, "The customer's quest to manage funds digitally: Exploring the factors that influence the intention to use and the ongoing use of mobile banking apps," *Computers in Human Behavior Reports,* vol. 21, p. 100907, 2026, doi: 10.1016/j.chbr.2025.100907.

[21] V. Melnyk, "Transforming the nature of trust between banks and young clients: From traditional to digital banking," *Qualitative Research in Financial Markets,* vol. 16, no. 4, pp. 618-635, 2024, doi: 10.1108/QRFM-08-2022-0129.

[22] L. Wu, Q. Wang, H. Jin, and D. Li, "How do digital entrants affect the digital transformation of incumbents? Differential effects of corporate governance factors," *Information & Management,* vol. 63, no. 1, p. 104269, 2026, doi: 10.1016/j.im.2025.104269.

[23] Z. B. Yusof, "The role of high-quality data in risk assessment: Strategies for ensuring accuracy, completeness, and timeliness in financial predictive analytics," *International Journal of Advanced Computational Methodologies and Emerging Technologies,* vol. 15, no. 2, pp. 8-16, 2025.

[24] G. L. Thanasas, G. Kampiotis, and A. Karkantzou, "Enhancing transparency and efficiency in auditing and regulatory compliance with disruptive technologies," *Theoretical Economics Letters,* vol. 15, no. 1, pp. 214-233, 2025, doi: 10.4236/tel.2025.151013.

[25] L. Theodorakopoulos, A. Theodoropoulou, A. Tsimakis, and C. Halkiopoulos, "Big data-driven distributed machine learning for scalable credit card fraud detection using PySpark, XGBoost, and CatBoost," *Electronics,* vol. 14, no. 9, p. 1754, 2025, doi: 10.3390/electronics14091754.

[26] L. Theodorakopoulos, A. Theodoropoulou, G. Kampiotis, and I. Kalliampakou, "NeuralACT: Accounting analytics using neural network for real-time decision making from big data," *IEEE Access,* vol. 13, pp. 8621-8637, 2025, doi: 10.1109/ACCESS.2025.3526706.

[27] A. Panchapakesan *et al.*, "Enhancing audit effectiveness through strategic data analytics," IGI Global Scientific Publishing, 2025, pp. 231-252.

[28] S. Iseal, O. Joseph, and S. Joseph, "AI in financial services: Using big data for risk assessment and fraud detection," 2025. [Online]. Available: https://www.researchgate.net/profile/Sheed-Iseal/publication/388036425_AI_in_Financial_Services_Using_Big_Data_for_Risk_Assessment_and_Fraud_Detection/links/67882c2b1afb4e11f5e7fdf9/AI-in-Financial-Services-Using-Big-Data-for-Risk-Assessment-and-Fraud-Detection.pdf.

[29] P. M. Preciado Martínez, R. F. Reier Forradellas, L. M. Garay Gallastegui, and S. L. Náñez Alonso, "Comparative analysis of machine learning models for the detection of fraudulent banking transactions," *Cogent Business & Management,* vol. 12, no. 1, p. 2474209, 2025, doi: 10.1080/23311975.2025.2474209.

[30] H. P. Kothandapani, "AI-driven regulatory compliance: Transforming financial oversight through large language

models and automation," *Emerging Science Research,* vol. 12, pp. 12-24, 2025.
[31] J. Zhou, "Quantum finance: Exploring the implications of quantum computing on financial models," *Computational Economics,* pp. 1-30, 2025.
[32] R. Joghtaei, M. Nasiri, and E. Masoumi, "Designing a model for generative artificial intelligence adoption in the Iranian banking industry," *Technology in Entrepreneurship and Strategic Management,* 2025.
[33] S. Assidi, M. Omran, T. Rana, and H. Borgi, "The role of AI adoption in transforming the accounting profession: A diffusion of innovations theory approach," *Journal of Accounting & Organizational Change,* vol. 21, no. 5, pp. 915-936, 2025, doi: 10.1108/JAOC-04-2024-0124.
[34] A. M. Abdo-Salloum and H. Y. Al-Mousawi, "Accounting students' technology readiness, perceptions, and digital competence toward artificial intelligence adoption in accounting curricula," *Journal of Accounting Education,* vol. 70, p. 100951, 2025, doi: 10.1016/j.jaccedu.2025.100951.
[35] M. Lin, Y. Liu, and J. Ren, "Digitalization, absorptive capacity, and innovation performance: Evidence from China's hidden champion enterprises," *Finance Research Letters,* vol. 89, p. 109319, 2026, doi: 10.1016/j.frl.2025.109319.
[36] F. Magli, *Innovations in corporate reporting: The effects of digital innovation, sustainability, and AI*. Springer Nature, 2025.
[37] Y. Said, A. M. Khaddar, L. Hassine, A. Eddaoui, and T. Chafiq, "The impact of blockchain on the banking sector: A systematic review of applications, challenges, and future directions," *Asia and the Global Economy,* vol. 6, no. 1, p. 100133, 2026, doi: 10.1016/j.aglobe.2025.100133.
[38] E. Kokogho, O. C. Onwuzulike, B. M. Omowole, C. P. M. Ewim, and M. O. Adeyanju, "Blockchain technology and real-time auditing: Transforming financial transparency and fraud detection in the Fintech industry," *Gulf Journal of Advance Business Research,* vol. 3, no. 2, pp. 348-379, 2025, doi: 10.51594/gjabr.v3i2.88.
[39] N. Kostopoulos, Y. C. Stamatiou, C. Halkiopoulos, and H. Antonopoulou, "Blockchain applications in the military domain: A systematic review," *Technologies,* vol. 13, no. 1, p. 23, 2025, doi: 10.3390/technologies13010023.
[40] R. Rupeika-Apoga, J. Priede, G. Berzins, and E. Kehris, "Regulation and innovation in digital finance: The transformation of Latvia's banking sector," *Digital Business,* vol. 5, no. 2, p. 100147, 2025, doi: 10.1016/j.digbus.2025.100147.
[41] A. Adewumi, S. E. Ewim, N. J. Sam-Bulya, and O. B. Ajani, "Advancing business performance through data-driven process automation: A case study of digital transformation in the banking sector," *International Journal of Multidisciplinary Research Updates,* vol. 8, no. 02, 2024, doi: 10.53430/ijmru.2024.8.2.0049.
[42] L. A. Bueno, T. F. A. C. Sigahi, I. S. Rampasso, W. Leal Filho, and R. Anholon, "Impacts of digitization on operational efficiency in the banking sector: Thematic analysis and research agenda proposal," *International Journal of Information Management Data Insights,* vol. 4, no. 1, p. 100230, 2024, doi: 10.1016/j.jjimei.2024.100230.
[43] H. M. Al-Hattami, "The impact of digital accounting systems on financial performance in the banking sector," *International Journal of Intelligent Information Technologies,* vol. 21, no. 1, 2025, doi: 10.4018/IJIIT.377599.
[44] M. Al-Okaily, A. A. Alsmadi, N. Alrawashdeh, A. Al-Okaily, Y. Oroud, and A. S. Al-Gasaymeh, "The role of digital accounting transformation in the banking industry sector: An integrated model," *Journal of Financial Reporting and Accounting,* vol. 22, no. 2, pp. 308-326, 2024, doi: 10.1108/JFRA-04-2023-0214.
[45] T. Adsiz and Y. Ozturkoglu, "A conceptual framework for a new service model: Digital servitization with an Industry 4.0 perspective," *Journal of Global Operations and Strategic Sourcing,* vol. 18, no. 2, pp. 267-284, 2025, doi: 10.1108/JGOSS-08-2022-0091.
[46] A. Abdurrahman, "Examining the impact of digital transformation on digital product innovation performance in banking industry through the integration of resource-based view and dynamic capabilities," *Journal of Strategy & Innovation,* vol. 36, no. 1, 2025, doi: 10.1016/j.jsinno.2025.200540.
[47] C. A. Asamoah, K. N. Takyi, A. Klapalová, I. Agirre-Aramburu, and J. Matošková, "Dynamic managerial capabilities, digital innovation and perceived financial performance in the banking sector," *Scientific African,* vol. 31, p. e03157, 2026, doi: 10.1016/j.sciaf.2025.e03157.
[48] B. Faro, B. Abedin, D. Cetindamar, and F. Daneshgar, "Dynamic capabilities for nimbleness and resilience in a continuous digital transformation: Action design research in an Australian financial services organisation," *Journal of Enterprise Information Management,* vol. 37, no. 4, pp. 1206-1226, 2024, doi: 10.1108/JEIM-10-2023-0567.
[49] A. Farhadi Kotenaei, S. Vardi, A. Mehrara, and H. Azadi Rikandeh, "Presenting a digital governance model in the Iranian banking industry: Case study of Tose'e Ta'avon Bank," *Knowledge of Entrepreneurship,* no. 15, pp. 53-68, 2025.
[50] M. Aydin, A. Bagci, N. Demirtas, Y. Sogut, M. E. Altundemir, and T. Gürdal, "The relationship of digitalization, industrialization, financial freedom and institutional quality with economic complexity: A panel data analysis on E-7 countries," *Central Bank Review,* vol. 26, no. 1, p. 100241, 2026, doi: 10.1016/j.cbrev.2026.100241.
[51] H. Iftikhar, L. Guang, and A. Ullah, "A multi-dimensional FinTech composite integrating infrastructure, access, usage, knowledge transfer, and governance-by-technology: The role of digital silk road policy in BRI economies," *Technology in Society,* vol. 85, p. 103162, 2026, doi: 10.1016/j.techsoc.2025.103162.
[52] G. Asimakopoulos, H. Antonopoulou, K. Giotopoulos, and C. Halkiopoulos, "Impact of information and communication technologies on democratic processes and citizen participation," *Societies,* vol. 15, no. 2, p. 40, 2025, doi: 10.3390/soc15020040.
[53] K. M. Milanloo, M. Naeimi Nezamabad, and M. Mohammadian, "Designing a digital customer experience management model in the banking industry using grounded theory," *Interdisciplinary Studies in Marketing Management,* vol. 11, pp. 45-67, 2024.
[54] R. Fuentes and B. Fattouh, "When digitalization pervades, business models converge: A conceptual model for the electricity industry," *Business Horizons,* vol. 69, no. 1, pp. 101-111, 2026, doi: 10.1016/j.bushor.2025.01.003.
[55] Q. Zhang, F. Shahzad, C. Jana, N. Ivkovic, and G. W. Weber, "Navigating digitalization and global value chains: Empirical insights from the Chinese manufacturing industry," *Journal of Industrial Information Integration,* vol. 51, p. 101083, 2026, doi: 10.1016/j.jii.2026.101083.
[56] A. V. Thakor, "Fintech and banking: What do we know?," *Journal of Financial Intermediation,* vol. 41, p. 100833, 2020, doi: 10.1016/j.jfi.2019.100833.
[57] I. D. Czechowska and M. Paduszyńska, "Digital banking performance on the example of PayTech solutions: Polish perspective," *Procedia Computer Science,* vol. 246, pp. 1770-1779, 2024, doi: 10.1016/j.procs.2024.09.679.

[58] B. Moomivand, R. Gholami Jamkarani, M. Maleki, and H. Jahangirnia, "Providing a framework to identify drivers affecting the future of the banking industry with emphasis on the role of financial technology," *Financial Economics,* vol. 16, no. 4, pp. 175-194, 2022, doi: 10.30495/fed.2023.1930131.2400.
[59] Z. Noorki and S. Kowsari, "Designing a virtual banking business model in Iran using scenario planning for the 2036 horizon," *Value Creation in Business Management,* vol. 5, no. 1, pp. 373-399, 2025.
[60] V. Veysi, F. Namamian, S. Hasani, and O. Kahrizi, "Designing and developing a digital banking market penetration model in Bank Sepah using interpretive structural modeling," *Intelligent Strategic Management,* vol. 5, no. 1, 2026.
[61] A. Mahmoudi, A. Khamseh, and M. Hosseini-Shakib, "A systemic model of the social banking innovation process with a digital transformation approach," *Investment Knowledge,* vol. 16, no. 2, pp. 33-59, 2027.
[62] S. Strazzullo, S. Moro, and L. Cricelli, "Unveiling the relationship between sustainable development and Industry 4.0: A text mining literature analysis," *Sustainable Development,* vol. 31, pp. 2851-2862, 2023, doi: 10.1002/sd.2552.
[63] J. Oliveira, D. Schreiber, and V. D. Jahno, "Sustainability in civil construction through Industry 4.0 and BIM technologies," *Automation in Construction,* vol. 182, p. 106729, 2026, doi: 10.1016/j.autcon.2025.106729.
[64] A. Khang, K. C. Rath, K. Madapana, J. Rao, L. P. Panda, and S. Das, "Quantum computing and portfolio optimization in finance services," Productivity Press, 2025, p. 27.
[65] S. Mohd, M. Dasgupta, F. Akter, M. P. Arunachalam, and S. Sharma, "Quantum computing applications in financial modeling and portfolio optimization," 2025: IEEE, pp. 868-872, doi: 10.1109/CE2CT64011.2025.10939675.
[66] Q. H. Pham and V. K. Phuc, "A model of pre-adoptive appraisal toward metaverse banking: Moving from Industry 4.0 to Industry 5.0," vol. 4: Elsevier, 2025, pp. 374-387.