Business Models for the Internet of Things: An In-Depth Categorization, Design and Innovation Tools, Challenges, and Solutions

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Abstract— **The swift expansion of the Internet of Things (IoT) has brought about a fundamental transformation in the functioning of enterprises, leading to the emergence of groundbreaking offerings in various industries. As this disruptive technology persists in reshaping sectors, comprehending the essential business models responsible for its prosperity becomes ever more essential. This investigation primarily aims to provide a thorough categorization of IoT business models with eight classes of business models, encompassing paradigms such as Product-oriented, Service-centric, Outcome-based, Pay-per-usage, Data-driven, Subscription, Compliance, and Testbed. Subsequently, challenges inherent to IoT business models are analyzed, accompanied by corresponding solutions. The study further provides an extensive overview and comparison of primary business model innovation (BMI) tools tailored to the IoT landscape, comparing those tools and investigating the primary features and usability of each BMI tool.**

Keywords: IoT business models; business model innovation, business model challenges; business model solutions; digital transformation

I. INTRODUCTION

There is no constant definition for business model. However, on the one hand, the early statement on the definition of a business model defines it as the following statement: “A business model outlines the composition, organization, and management of transactions crafted to generate value by leveraging business opportunities” [1]. Moreover, a business model refers to how an organization intends to generate revenue efficiently, taking into account the assumptions on how it will create and capture value to benefit the enterprise. It involves the organization's strategy for balancing costs and benefits while ensuring a profitable operation [1]. According to Lai et al., value creation and value capture are the two primary functions of a business model. In a similar vein, it is defined in their paper that the business model is the core representation of how an enterprise provides value to its customers, persuades them to pay for that value, and then transforms those payments into profits [1]. IoT business models are no exception. IoT is considered critical to the fourth industrial revolution. The usage and popularity of IoT have rocketed, such that the number of connected devices to the Internet has risen significantly [2]. This development will lead to massive opportunities for firms to employ this technology in their business models, services, and products to strengthen their competitive advantage [2]. Because of its ability to collect detailed data on customer product usage, IoT has attracted significant interest from both practitioners and scholars. They are particularly intrigued by its potential to facilitate the creation of innovative product and service offerings as well as the reevaluation and enhancement of current business models using this valuable information [2]. The rise of IoT and its transformative potential across industries necessitate a thorough understanding of the novel business opportunities it brings forth and the innovative business models tailored to operate within the IoT landscape.

A notable research gap exists in the IoT business model domain, where a comprehensive categorization of these models, coupled with a compilation of challenges and corresponding solutions, remains largely absent. While individual studies address specific challenges, a consolidated overview is missing, hindering a holistic understanding. Additionally, the exploration of business model innovation tools tailored to the IoT context is lacking, limiting strategies to adapt and evolve these models. A cohesive research effort is crucial to categorize IoT business models, collate challenges and solutions, and delve into innovative tools, ultimately fostering a deeper comprehension and more effective management of IoT-driven businesses. This study endeavors to address these gaps appropriately.

This paper is structured as follows: In Section II, we describe the research methodology, including the search strategy, databases searched from, and our study selection strategy. The results of this review are presented in Section III. In that section, a summary of the papers that went under review is shown. After that, IoT business model categories are described, followed by the challenges and limitations involved in IoT-based business models and their possible solutions and remedies. Moreover, a detailed description of Business Model Innovation (BMI) tools and frameworks is provided, and BMI tools are compared regarding their inherent features. Finally, sections IV and V discuss our results and conclude the paper, respectively.

II. METHODS

A. Databases and Search Strategy

Our primary sources of study were Google Scholar and Scopus. However, we did not limit our sources to these and searched other databases too. Those include the Web of Science and PubMed. Our approach involved employing a keyword search strategy to extract relevant studies from databases.

B. Study Selection

As shown in Fig. 1, the study selection procedure involved several sequential steps to identify relevant papers for the research. Initially, a keyword search in databases yielded 84 papers. After removing eight duplicate items, 76 papers remained for further evaluation. The abstracts and conclusions of these papers were carefully assessed, leading to the exclusion of irrelevant studies, leaving 37 papers for further consideration. In the subsequent stage, a thorough examination of the titles of the sections, figures, and tables resulted in the retention of 33 papers. Finally, the full text of the remaining 33 papers was comprehensively reviewed, leading to the final selection of 26 papers that best aligned with the research objectives. It is worth mentioning that our study solely focused on English-written papers published from 2010 to 2023.

Figure 1. Study Selection Procedure

III. RESULTS

This section presents various findings from our research. Firstly, we have categorized IoT business models into eight primary categories: Product-oriented, Service-centric, Outcome-based, Pay-per-usage, Data-driven, Subscription, Compliance, and Testbed. Each category comprises several sub-models, which will be explored further in this section as depicted in Fig. 3. Furthermore, the challenges associated with IoT-based business models and their related solutions represent the subsequent results of our study, and we will discuss how each challenge must be addressed in the context of IoT. Lastly, we provide a complete description of IoT BMI tools, compare their advantages and disadvantages, and describe each tool's primary features.

A. Publication Study Themes

The number of publications on each study theme is shown in Fig. 2. As illustrated, the most investigated theme is the Service-centric model, accounting for seven papers. Conversely, two of the least researched themes are Compliance and Subscription models. Moreover, the figures for Product-oriented and Data-driven models stand at a similar level of five. In the next section, each theme is described in thorough detail.

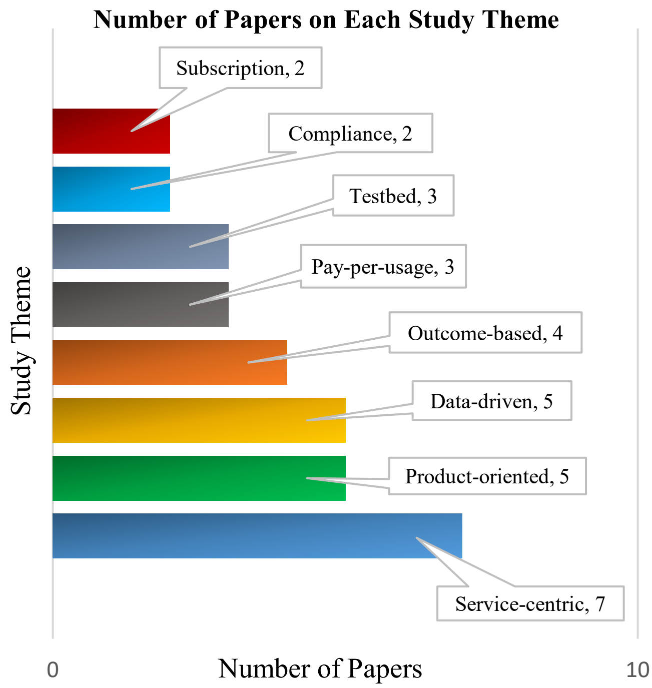

Figure 2. Number of Publications per Research Theme

B. Business Models in IoT

1) Product-Oriented Models: a firm's most valuable asset with this particular business model is its products or physical assets, and their business would lose its significance without them. These models encompass various specific business models, such as the product-sales model, which involves selling IoT devices or hardware to consumers or businesses. Within this category, a wide array of devices, ranging from consumer wearables that monitor exercise [1] to sensors used in industrial settings, fall under this classification. Other firms with a Value-added Reselling business model could collaborate with IoT device manufacturers and solution providers to resell their products along with additional value-added services or customization. Another model within this category is the Asset-sharing model, which operates by allowing customers to access its assets for a limited period of time [2]. On the other hand, the asset-tracking model offers tracking capabilities to other firms or individuals for their products or personal belongings. Tracking becomes valuable when routes are analyzed to capture insight for optimizing business processes [1]. Additional models include the Robotics as a Service model, which aims to develop robots for use in hazardous or inaccessible environments, such as toxic fields or warzones [1]. Furthermore, its interconnection with IoT enables businesses to automate operations and manage and improve robot fleets. Automation as a Service, modifies processes through automated looping and feedback procedures. Additionally, there is the Razor and Blade model. In the context of the Internet of Things (IoT), the Razor and Blade business model follows the same principles as its conventional version. Within IoT, razor refers to the low-cost IoT devices or hardware sold to customers. However, the true value and profitability of the Razor and Blade business model in IoT stem from the blades, which represent the ongoing services, subscriptions, or consumable components necessary to operate and enhance the functionality of the IoT devices.

2) Service-Centric Models: these models are characterized by generating revenue primarily through the services they offer rather than the products they sell. Within this category, there are various models, including Cloud-based services such as Platform as a Service, which simplifies application development and integration into existing solutions by offering developers a ready-to-use platform for building and managing applications without dealing with infrastructure complexities. Software as a Service allows software access via the internet, avoiding local installations [3], and Infrastructure as a Service offers essential processing power and storage through online cloud-based hardware and applications [3]. Additionally, there is Virtual and Augmented Reality as a Service, which integrates IoT devices and data with AR and VR technologies to provide immersive experiences, remote assistance, and visualization of IoT data. In Smart City as a Service, IoT technologies are integrated into urban infrastructure to improve city services and enhance the quality of life for residents. It is further divided into Smart Home as a Service, Smart Grid as a Service, and Transportation and Logistics Optimization models. Smart Home as a Service provides integrated and remotely managed solutions to homeowners for automating and controlling various home devices and systems, enhancing convenience, energy efficiency (e.g., utilizing central cooling facilities to minimize energy consumption [1]), and security. However, Smart Grid as a Service refers to the delivery and management of intelligent energy distribution and consumption solutions via IoT devices. The transportation and Logistics optimization model uses advanced analytics and technologies such as blockchain to optimize the movement and quality of goods [4] and people within urban areas to mitigate congestion and improve overall transportation and logistics operations, such as using road sensors to analyze traffic data for optimal traffic flow management [5]. According to Paiola et al., another approach to improving production efficiency is the Connectivity model, which offers solutions that connect numerous customer-used products to collect and analyze data, empowering businesses to optimize their current business model through improved positioning and pricing, product enhancement, customer segmentation, etc. [6]. There are certain models tailored to specific industries that incorporate IoT as a central component within that industry. For instance, we can cite examples like Healthcare as a Service, which allows healthcare providers to offer telemedicine services for remote consultations, enhancing healthcare accessibility, Logistics as a Service, which provides businesses with outsourced warehousing, inventory management, and transportation services, streamlining operations and improving efficiency [1], and Green Solutions as a Service, such as waste management and implementations of IoT in renewable energy production. Finally, IoT enables Edge as a Service providers to offer computing resources and data processing capabilities at the edge of the network, enabling efficient real-time data analysis and reducing latency.

3) Outcome-Based Models: Outcome-based business models (OBBM) pertain to a business strategy where the provider focuses on delivering specific solutions or outcomes to the customer rather than merely selling a product or service [2]. Under this model, the customer's payment is based on the achieved outcomes or value provided.

One of the models falling under OBBM is Predictive Maintenance as a Service in which IoT devices are deployed to monitor the condition of machinery or equipment, and the provider guarantees the delivery of predictive maintenance services to reduce downtime and enhance operational efficiency. Process optimization model [3] aims to enhance a firm's operations by focusing on making processes more efficient through the integration of IoT-enabled processes to replace traditional methods. Various specific use cases can be identified in the Process optimization model, such as Agriculture yield optimization, where IoT technologies are utilized to monitor and analyze agricultural parameters like soil moisture, temperature, and crop health. The provider commits to increasing crop yield, and the payment is tied to the improved harvest. This approach also benefits agribusiness by incentivizing suppliers to be more selective and provide only high-quality products that lead to the desired outcomes [7]. Other models within OBBM include Security as a Service, where security and privacy in certain operations are guaranteed, and Energy Efficiency as a Service [1], offers IoT solutions to optimize energy consumption in buildings, factories, or facilities.

4) Pay-per-Usage Models: Pay-per-usage models within the IoT context refer to business models where customers are billed according to their actual utilization of IoT services or devices [2]. These models are appealing to customers as they offer greater flexibility and cost-effectiveness. Customers only pay for the resources they consume and can easily adjust their usage based on demand [8]. Within the Pay-per-usage model in IoT, several sub-business models can be implemented. The usage can encompass a variety of items, ranging from IoT devices, bandwidth, and certain APIs [3], to IoT-based services, actual data, and licensing. Additionally, some business models vary based on the user's location, with fees changing according to where usage occurs. Another model is time-based, charging based on the amount of time a certain IoT device or service is utilized. The functionality model represents a business approach in which IoT providers offer a foundational level of functionality to customers, and additional features or capabilities can be accessed or unlocked on demand. Customers pay for the expanded functionality based on their actual usage. The Event-based model charges customers based on specific events triggered by IoT devices. For instance, a customer might be billed when a sensor detects a certain threshold being crossed. Meanwhile, the Quality-of-Service model (QoS) incurs costs based on the level of service quality delivered, such as responsiveness, uptime, and reliability. Lastly, the User count model charges customers based on the number of users or devices registered under their account.

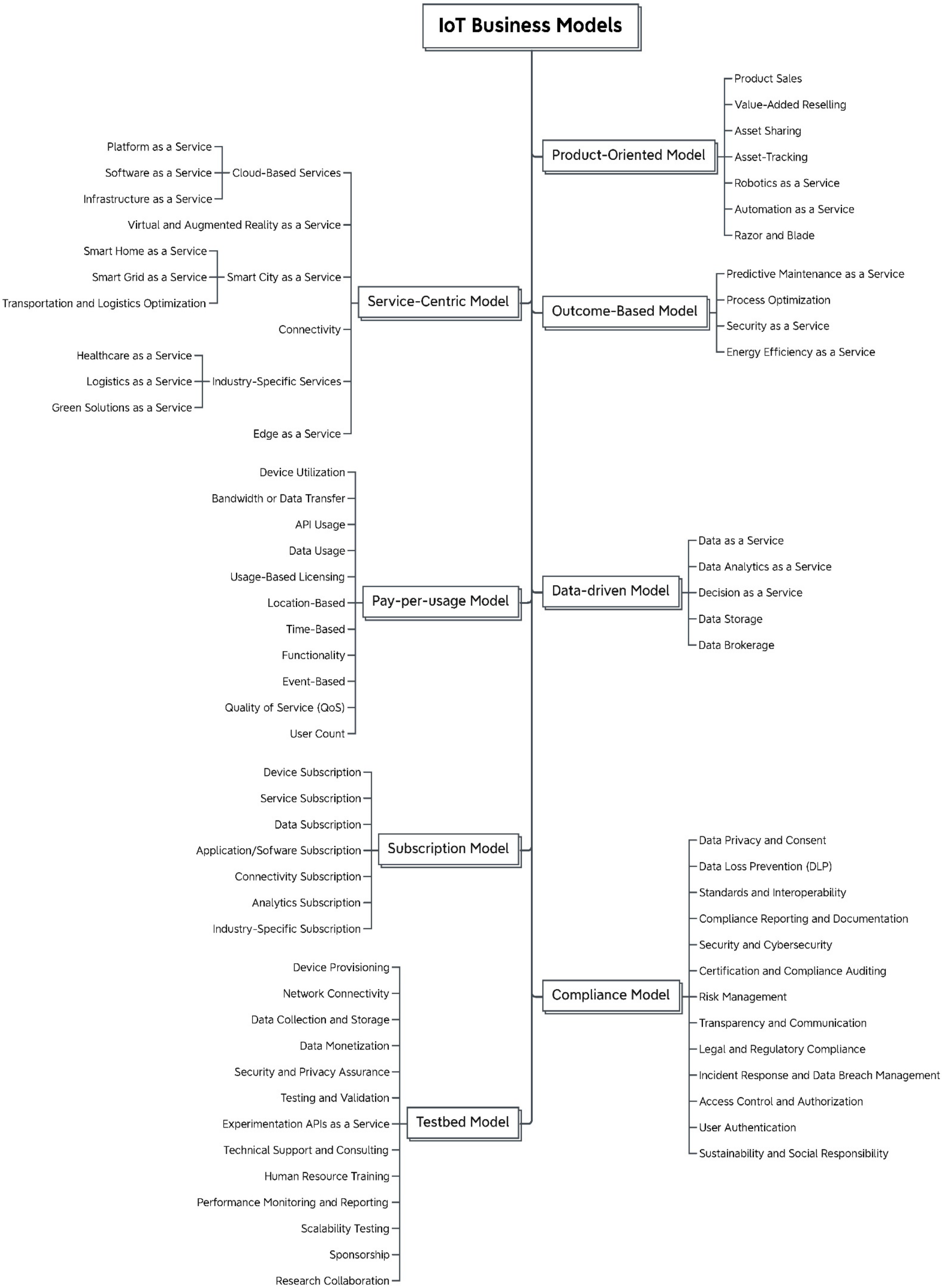

Figure 3. IoT Business Model Categories

5) Data-Driven Models: Data-driven models heavily rely on data as they collect, analyze, and monetize the information generated by IoT devices to offer valuable insights or sell it to third parties. This category of business models includes several sub-models, each of which monetizes data in different ways. One approach is direct monetization, as exemplified by Data as a Service [3], where revenue is generated by selling or licensing the collected IoT data to other businesses, researchers, or marketers for analysis and targeted advertising. Another method involves data processing, as seen in the Data Analytics as a Service model and the Decision as a Service model. Data Analytics as a Service involves processing and analyzing IoT-generated data to extract insights, while Decision as a Service takes the analysis a step further by providing actionable recommendations and automated decision-making based on the data analysis results. Lai et al. provided an example in their research, illustrating how data collected from sensors installed in each production line of a firm can be analyzed to improve awareness of the current situation. These insights range from identifying simple patterns to creating high-quality and complex visualizations [1]. Apart from processing capabilities, IoT providers with a Data storage model offer large capacities for storing data on their storage infrastructures [3]. Lastly, companies adopting the Data brokerage business model function as intermediaries between data providers (e.g., IoT device owners) and data consumers (e.g., businesses and researchers). They facilitate the exchange of data, creating value for both parties.

6) Subscription Models: IoT subscription-based business model centers around providing products, services, or data access regularly for a predetermined duration, typically on a monthly or annual basis. There are several similarities between these models and Pay-per-usage models. The main difference is that in the Subscription model, time is the determining factor, while in Pay-per-usage models, the consumed resource matters. Clients enroll in the IoT service or solution, making regular payments to receive ongoing benefits from the utilization of certain IoT devices, services, or data. Access to services allows clients to pay for the functionalities provided by IoT devices instead of owning them. Accessibility to this type of product or service is unlimited [2]. In the Application subscription model, customers choose subscriptions to access and utilize IoT applications or software solutions. The company develops and maintains applications that utilize IoT data, enabling customers to accomplish specific tasks or gain valuable insights by paying a recurring subscription fee. On the other hand, in the Connectivity model [9], customers subscribe to access IoT connectivity services. The company offers the necessary communication infrastructure to connect IoT devices to the Internet or other networks and charges a recurring fee for providing and maintaining the connectivity. The Analytics subscription model places primary emphasis on delivering data analytics services to customers utilizing their IoT data. The company provides sophisticated analytics tools and algorithms to process and analyze the data generated by IoT devices, and customers are charged a recurring fee to obtain valuable insights from their data. Ultimately, there are specialized subscription models designed to cater to specific industries or sectors. Companies customize their IoT services and offerings to address the unique requirements of industries such as Healthcare, Agriculture, Logistics, or Energy and charge industry-specific recurring fees for their services.

7) Compliance Models: Compliance model is a business approach in which IoT devices and solutions are developed and executed in accordance with specific regulations, industry standards, or security requirements. Its primary focus is to ensure that the IoT ecosystem adheres to the required compliance standards and guidelines. In the subsequent section, we will explore the business models falling under this category. Data privacy and consent model prioritizes managing and safeguarding user data in compliance with privacy regulations by obtaining explicit user consent. The Data Loss Prevention (DLP) model aims to prevent unauthorized access, transmission, or loss of sensitive data from IoT devices through the implementation of protective measures, as highlighted by Lee et al. in their work [10]. DLP involves data classification, data discovery to find sensitive information, and data monitoring to enforce security policies against unauthorized access or transmission of sensitive data. It helps organizations protect their data and prioritize security measures based on data sensitivity. Another significant model is the Standards and Interoperability model, which focuses on enhancing overall system efficiency and usability by ensuring compatibility and interoperability among different IoT devices and platforms through adherence to industry standards. Interoperability, as defined in the research done by Lee et al. [10], is the capability of various functional units to communicate, execute programs, or transfer data among each other with little or no user knowledge about their unique characteristics. Other models in this category include the Compliance reporting and documentation model, Security and cybersecurity model, Certification and compliance auditing model, and Risk management model. The Compliance reporting and documentation model involves maintaining comprehensive documentation of IoT compliance efforts and reporting to relevant authorities as required by regulations. Security and cybersecurity model implements robust cybersecurity measures to safeguard against unauthorized access, attacks, and breaches. However, the Certification and compliance auditing model demonstrates adherence to industry standards and regulations in IoT data management and security through certifications and compliance audits, while the Risk management model identifies potential risks associated with IoT devices and data handling and implements strategies to mitigate and manage those risks effectively. On the other hand, transparency and communication entail open disclosure of data practices, ensuring user awareness of data collection, processing, and utilization. Legal and regulatory compliance guarantees adherence to data privacy, security, and usage laws, safeguarding both user rights and legal obligations. Incident response and data breach management protocols enhance data protection and trust. Access control and authorization mechanisms limit interactions with authorized users, reducing security risks. The user authentication model employs different methods, like multi-factor authentication, that ensure legitimate access. Sustainability and social responsibility prioritize environmentally friendly practices and uphold ethical standards in IoT operations. Overall, these models ensure a comprehensive and compliant approach to IoT implementation.

8) Testbed Models: various key services are presented to participants as value propositions in IoT testbed models, but the primary one is the platform to facilitate their testing, experimentation, and development of IoT solutions [11]. These models are designed to offer a controlled and realistic environment for users to validate their devices, applications, and services. Device provisioning model provides IoT devices for diverse applications. The Network connectivity model ensures reliable communication, while the Data collection and storage model efficiently manages data for the user. On the other hand, the Data monetization model explores value generation from data insights, and Security and privacy assurance model implements robust protection methods to assure security for the client. In this regard, Subahi et al. implemented a testbed to recognize security vulnerabilities in IoT devices and infrastructures [12]. The testing and validation model assesses device performance through several tests under various conditions. Experimentation APIs enable programmatical interaction with the testbed, facilitating automated experimentation. Technical support and consulting offer consultation and support to mitigate technical issues and optimize deployment. Human resource training is another Testbed model that provides essential trainings to the client's users and improves their skills. Performance monitoring and reporting provide detailed insights into the current performance of the operations. The scalability testing model assesses application scalability and does different tests to ensure the solutions work properly under increased device load and network traffic. The Sponsorship model seeks external financial support interested in supporting current IoT businesses, and it is usually done in exchange for visibility, access to research findings, or early access to innovation solutions. However, the Research collaboration model encourages collaborative research projects and knowledge sharing with external partners such as universities or other corporations to expand the testbed's reach.

C. Challenges of IoT-Based Business Models

The challenges of IoT business models encompass various aspects. Firstly, building these models poses difficulties at the ecosystem and industry interface levels, necessitating an ecosystem perspective for value design [1]. Secondly, the diversity of interconnected devices in the IoT makes it challenging to design models that effectively leverage these devices within unstructured ecosystems [13]. Thirdly, extensive cross-industry collaboration is required to create IoT-enabled services, which challenges existing industry boundaries and operating models [9]. Additionally, large companies may face inertia in fostering innovation within the IoT industry [3]. The lack of funding and financial capabilities hinders the development and commercial exploitation of IoT applications [9].

Moreover, the scarcity of academic knowledge on IoT business models complicates the construction of effective models [14]. Accurately predicting usage and demand is challenging, leading to uncertainty for customers and pricing difficulties for service providers [8]. The integration of physical and digital components in hybrid business models raises coordination and data security challenges [15]. Data management and privacy are crucial concerns due to the interconnected nature of devices [10]. Lastly, writing secure smart contracts is difficult due to various business logics and platform vulnerabilities [16]. These challenges and solutions are summarized in Table I.

D. Addressing Challenges of IoT-Based Business Models

Developing business models for emerging ecosystems requires an ecosystem perspective and a value design approach [1]. To address the diversity and fragmentation in IoT ecosystems, standardization of interfaces and the adoption of modularized objects become crucial [13]. Furthermore, adopting an ecosystem approach and utilizing IoT-specific business model frameworks can bring structure and coherence to unstructured IoT ecosystems [9]. To address financial limitations, an ideal way would be a bank loan to cover all prospective capital expenditure (CAPEX) costs that are paid over time from savings or financial returns [9]. These costs refer to funds invested in long-term fixed assets expected to generate future benefits. These investments, like machinery or technology upgrades, are distinct from day-to-day operating expenses and are carefully evaluated for their financial viability and strategic alignment. Lack of investment, however, could be mitigated by increasing support for research that receives funding from governmental bodies or academic institutions. Overcoming innovation inertia in large companies can be achieved by involving IoT user-developer communities in fostering bottom-up innovation [3]. Additionally, employing platform-based business models and anonymization techniques can effectively integrate physical and digital components while ensuring data privacy [15]. Transparent communication, usage prediction enhancement provided by usage data analytics, and flexible revenue models are essential factors for addressing challenges related to predicting demand and adapting to market conditions [8]. Moreover, formalization techniques, such as theorem proving, offer a viable solution to address security vulnerabilities in smart contracts [16].

Lastly, ensuring secure and responsible data usage in IoT ecosystems necessitates the implementation of data governance frameworks [17] and adherence to interoperability standards [10]. By considering these challenges and solutions, the development of effective IoT business models can be greatly facilitated, emphasizing the significance of ecosystem thinking, collaboration, standardization, and secure data handling.

TABLE I. CHALLENGES AND CORRESPONDING SOLUTIONS OF IOT BUSINESS MODELS

	Challenge	Solution
1	The need for an ecosystem business model	Ecosystem perspective and value design approach
2	Diversity of objects and unstructured ecosystems	Object modularization and standardization
3	Extensive cross-industry collaboration	Adopting ecosystem business model frameworks
4	Inertia in large companies	User-developer communities (crowdsourcing)
5	Lack of funding and financial capabilities	Bank loan to cover all up-front CAPEX costs, which is paid back over time
6	Lack of knowledge of IoT business models	Employing frameworks or design tools for IoT business model innovation
7	Difficulty in predicting usage and demand	Prediction via usage data analytics and dynamic price adjustments
8	Integration of physical and digital components	Employing a Platform-based approach to connect physical and digital components
9	Data management and privacy	Data governance frameworks and interoperability standards
10	Security vulnerabilities in smart contracts	Formalization methods and automated tools to address vulnerabilities

E. *Business Model Innovation (BMI) Tools and Frameworks*

In this section, nine of the most famous BMI tools and frameworks are introduced in detail, each with its advantages and disadvantages. At the end of the section in Table II, these tools are compared and their primary features are investigated.

1) Business Model Canvas: Osterwalder's business model canvas [18], a highly regarded and celebrated tool for business model innovation, comprises nine building blocks in a rectangular layout, guiding users through a step-by-step process. The model starts with understanding the specific needs of customer segments and progresses through developing a value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and a cost structure [19]. Osterwalder emphasizes the centrality of customer segments and advocates building the business around their needs. The canvas focuses on both value (right side) and efficiency (left side) through key resources, activities, and partnerships. While this model is user-friendly and mature, it lacks in technological aspects of business modeling [19].

2) The DNA Model [20]*:* the DNA model, a modification of Osterwalder's Canvas, represents an initial attempt at IoT business modeling. Fig. 4 illustrates that it organizes the nine building blocks into three categories: design, needs, and aspirations [19]. Sun proposes a sequential approach, beginning with defining the supply infrastructure (design), followed by the external infrastructure (needs), and concluding with the end result (aspirations). However, the model falls short in addressing the interaction between IoT layers and the profitability of IoT technologies. Nevertheless, it presents a conceptual ecosystem perspective by consolidating key partnerships, resources, and activities within the design block [19].

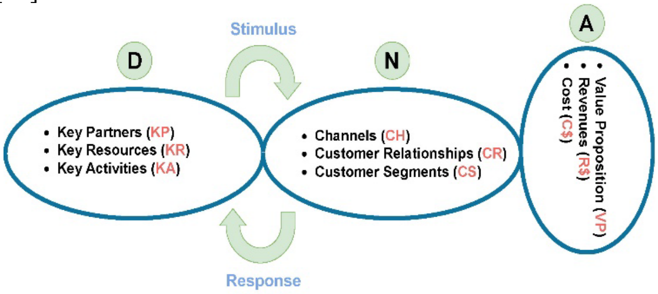

Figure 4. DNA Model [20]

3) The Business Model Cube: the business model cube [21] suggests that a business model comprises six interconnected building block dimensions, with relations between them. These dimensions encompass the value proposition, user and customer, value chain, competence, network, and value formula. Lindgren highlights the significance of technology in business modeling and introduces flexibility through interdimensional relationships [19]. Although not revolutionary compared to Osterwalder's model, it advances the integration of technology into business models. However, the visual representation of these relationships requires further refinement [19]. The intersection between the business model cube and IoT lies in how businesses can leverage IoT to enhance their value proposition, optimize their value architecture, and foster new collaborations within their value network. Incorporating IoT technologies unlocks new opportunities, improves efficiency, and delivers enhanced value to customers.

4) St. Gallen Business Model Navigator (Magic Triangle): Magic triangle [22] proposes that a business model's core definition includes four main building blocks: "Who?", "What?", "How?", and "Value?". These blocks, as shown in Fig. 5, represent the customer segment, perceived value, value delivery, and revenue streams. The model emphasizes customer-centric thinking and financial sustainability [19]. Gassmann's well-established and user-friendly model offers online courses, software tools, and business model patterns for creative ideation. Business modeling is seen as a competitive advantage, and those who neglect it tend to be less successful. The tool encourages businesses to think creatively and develop new revenue streams based on these core dimensions [19].

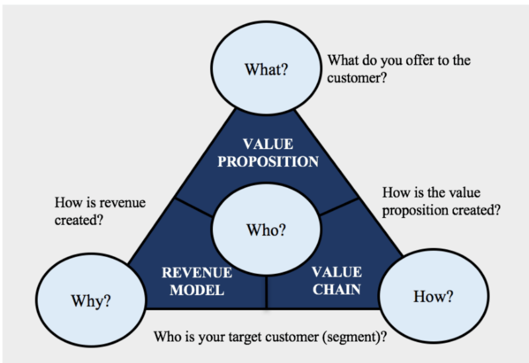

Figure 5. St. Gallen Magic Triangle [22].

5) Value Design Model [13]*:* this model proposes an ecosystem perspective for IoT business modeling, advocating a collaborative network-centric approach. It suggests viewing IoT business models as part of a larger collaborative ecosystem to capture diverse value streams. The model comprises four main blocks: value drivers, value nodes, value exchanges, and value extracts, which interact to create and capture value within the IoT ecosystem (Fig. 6) [19]. Value design encourages a shift from vendor-centric to network-centric thinking, helping companies explore new revenue streams. While still conceptual, it lays the groundwork for future research and development in IoT business modeling, addressing important aspects of cost, revenue streams, and value extraction within the ecosystem [19].

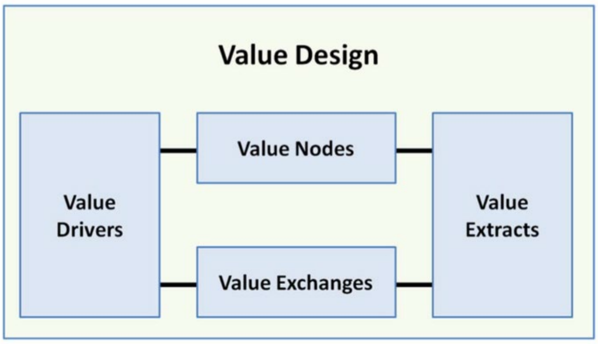

Figure 6. Value Design Model [13]

6) Turber BM Type for IoT [23]*:* this BMI framework is a visual representation designed to address the complexity of IoT business activities involving multiple collaborations. It adopts a Service-Dominant (SD) logic, viewing participants' success in the ecosystem as beneficial to all [19]. Combining Gassmann's magic triangle with an IoT ecosystem perspective creates a 3D model with dimensions for participants, responsibilities, value drivers, and value creation. Although promising, the model is still in early to mid-stage development and lacks maturity and usability. A 2D version has been proposed to enhance usability [19].

7) 3DCM Model: Chan's 3DCM model [24] aims to enhance Turber's work by converting it into a 2D format, improving usability [19]. Chan emphasizes the importance of strategic aspects in IoT business model tools to aid businesses in taking a first-mover position, resulting in the inclusion of strategy and tactics dimensions. The model comprises eight dimensions, including collaborators, input, network, service, content, benefits, strategy, and tactics [19]. While it draws from existing IoT literature, the new additions do not fully address certain issues like revenue streams and cost structures between collaborators, causing the model to lack usability and maturity [19].

8) CX-BMI Model: this model aims to align customer values and the firm's strategic needs by integrating customer experience (CX) and business model innovation (BMI). It presents a three-step process that helps managers understand customer perceptions, strategic orientation, and opportunities to enhance the customer experience. As clearly illustrated in Fig. 7, the model identifies five dimensions of CX: cognitive, physical, sensory, emotional, and social, which become key drivers of CX. Customers rank these drivers based on their experience with the firm, and each driver is labeled "Green", "Yellow", or "Red" based on its current contribution and upside potential. The approach for managing CX dimensions within the business model includes "Defend", "Improve", "Build", and "Ignore" activities to focus on enhancing customer perceptions and overall CX [25].

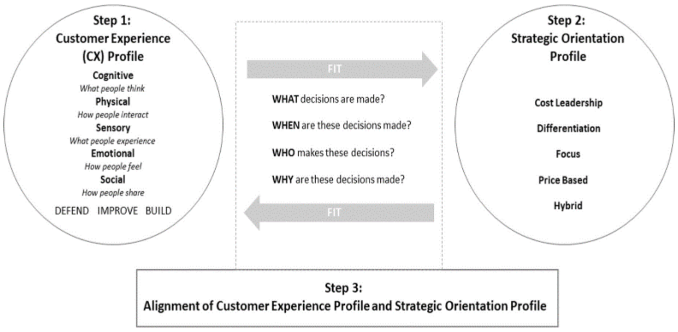

Figure 7. CX-BMI Model [25]

9) IoT Business Model Builder: This model is an iterative process consisting of three phases: ideation, preparation, and evaluation (Fig. 8) with a total of nine procedures, which are as follows [26].

a) Create opportunity ideas: participants brainstorm and cluster opportunity ideas, resulting in a long list of opportunities.

b) Sketch opportunities: opportunity ideas are discussed, and value drivers to increase customer benefit are ideated, creating a long list of sketched opportunities.

c) Select opportunities: participants agree on selection criteria and choose opportunities, leading to a final shortlist.

d) Detail the offering from a user perspective: participants detail the offering along the customer journey and identify required capabilities.

e) Analyze the stakeholder network for each opportunity: four questions are answered for each opportunity, and a stakeholder network diagram is prepared.

f) Select a focus node/stakeholder from the stakeholder network: a clear understanding of the business model to be analyzed for each node/stakeholder is gained.

g) Complete business model and business case for the focus node/stakeholder: the business model is refined and completed, and alternative models are considered based on the stakeholder network.

h) Aggregate results: stakeholder network diagram and business case are finalized, assumptions are validated, and management decisions are prepared.

i) BM scenario planning: sensitivity analysis and scenario creation are done, calculating business cases for each scenario and scheming the ideal business model for each.

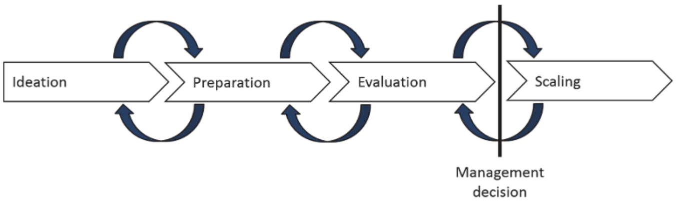

Figure 8. Different Phases of IoT Business Model Builder [26]

IV. DISCUSSION

Although XaaS (anything as a service) business models often prioritize service-centric approaches, it's crucial to recognize that not all XaaS models are exclusively centered around services. While numerous XaaS offerings do indeed furnish a range of services via cloud platforms, such as Software as a Service (SaaS) or Platform as a Service (PaaS), certain XaaS models can also incorporate elements of approaches focused on products or desired outcomes. For example, in specific XaaS arrangements, the emphasis could be on delivering distinct products or attaining specific results while utilizing the convenience and adaptability of cloud-based delivery methods. As a result, the term "XaaS" encompasses a wide array of business models that extend beyond purely service-centric paradigms. Thus, certain business models might be characterized as hybrid models capable of aligning with two or even multiple distinct categories of business models. However, in this study, for the sake of simplicity, each model is assigned to a single category that best corresponds to its overarching business focus. As an illustration, the Connectivity model is predominantly categorized under the Service-centric business model. Nonetheless, it also expedites the procedures associated with data conveyance and analysis through the connections it establishes among all IoT devices within the ecosystem. Consequently, Connectivity could potentially be situated within the domain of Data-driven business models as well. Nevertheless, owing to its primary function of furnishing connectivity, it is recognized more as a Service-centric model than a Data-driven one.

Blockchain technology offers a range of functionalities to enhance IoT business models. These functionalities include decentralized trust, enabling direct communication and transactions between IoT devices while eliminating single points of failure. Secure data exchange ensures tamper-proof data sharing, safeguarding sensitive information's privacy and integrity. Smart contracts automate processes like device authentication [16] and data sharing. Supply chain management benefits from tracking goods' provenance to combat counterfeiting [4]. Micropayments and monetization enable autonomous IoT transactions, creating new revenue streams. Interoperability enhances IoT network efficiency through standardized, decentralized communication. Tokenization and incentives reward IoT devices for contributing and fostering participation and cooperation. Overall, blockchain's applications revolutionize IoT operations, boosting trust, security, efficiency, and collaboration.

TABLE II. BMI TOOLS/FRAMEWORKS COMPARISON

	BMI Tool/Framework	Main Properties	Year Proposed
1	Business Model Canvas	❖ Mature ❖ Easy to use ❖ Most popular BMI tool ❖ Not powerful for technological modeling	2010
2	The DNA Model	❖ Improved version of BM canvas for IoT modeling ❖ Has “Ecosystem” perspective ❖ Lacks connection between IoT layers and profitability from IoT technologies	2012
3	The Business Model Cube	❖ Powerful for technological business modeling ❖ Flexible through interdimensional relationships	2013
4	St. Gallen Magic Triangle	❖ Customer-centric thinking ❖ Focus on financial stability ❖ Good for creative business modeling	2014
5	Value Design Model	❖ Has “Ecosystem” perspective ❖ Network-centric thinking	2014
6	Turber BM Type for IoT	❖ Combination of “Magic Triangle” with IoT “Ecosystem” thinking ❖ 3D format ❖ Lack of maturity and usability	2014
7	3DCM Model	❖ 2D format of Turber BM type ❖ Enhanced usability from Turbermodell ❖ Has issues in revenue streams and cost structures	2015
8	CX-BMI Model	❖ Connects Customer Experience (CX) to BMI ❖ Extreme attention on CX and CX-based modeling	2020
9	IoT Business Model Builder	❖ Highly iterative process for business modeling ❖ Straightforward through nine explicitly explained steps	2015

V. CONCLUSION

Understanding different IoT business models is crucial for organizations as it allows them to explore diverse revenue generation approaches, catering to a wide range of customer needs and markets. Furthermore, comprehending the challenges and solutions related to IoT business models is essential to successfully navigating the complex landscape of IoT implementation. Awareness of these challenges helps businesses proactively devise strategies and implement robust security measures, ensuring the safe and efficient functioning of IoT devices and networks. Additionally, knowledge of business model innovation tools and frameworks empowers organizations to design and refine their IoT business models effectively, fostering innovation, sustainability, and competitiveness in the rapidly evolving IoT market. By staying informed about these aspects, companies can seize opportunities, overcome obstacles, and leverage the full potential of IoT technology for transformative growth.

This research provided a comprehensive and well-structured analysis of IoT business models and successfully categorizes them into eight primary categories, including Product-oriented, Service-centric, Outcome-based, Pay-per-usage, Data-driven, Subscription, Compliance, and Testbed. Our research has paid noticeable attention to the challenges IoT business models face and presents valuable solutions to address those issues. Additionally, we investigated different business model innovation (BMI) tools and frameworks in the context of IoT.

Our results critically evaluate the challenges encountered in the development and implementation of IoT-based business models. By providing well-supported solutions to these challenges, the paper offers valuable insights to businesses looking to harness the potential of IoT technologies and deal with the challenges mentioned earlier.

As mentioned, we explored various business model innovation tools that offer valuable insights into the dynamic landscape of IoT business models. These tools collectively equip organizations with a range of strategic options to navigate the intricacies of IoT business models effectively, fostering innovation and sustainable growth in this transformative realm.

Looking ahead, there is a compelling avenue for future research to address specific dimensions within the realm of IoT business models. Firstly, a deeper exploration of business models centered around enhancing the customer experience is warranted. This entails understanding how IoT can be leveraged to create value through improved user interactions and personalized services. Secondly, the development of more sophisticated business model innovation (BMI) tools should prioritize incorporating customer experience and behavioral elements, allowing businesses to craft strategies that resonate with users' preferences and habits. Lastly, an imperative exists to investigate and refine cutting-edge BMI tools tailored for business models that integrate technology intricately. Such tools should emphasize the seamless integration of technological advancements, creating agile and adaptable frameworks that capture the full potential of IoT's transformative capabilities.

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