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RESEARCH PAPER

Designing the future of bond markets: Reducing transaction costs through tokenization

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Abstract

Corporate bonds are an attractive option for corporate financing. However, current bond markets face many challenges and inefficiencies, resulting in high transaction costs (TAC). In recent years, technological advancements like blockchain technology have enabled the possibility of reducing TAC in bond markets. Even though practice experiments with such solutions, academic literature lacks generic design knowledge under the TAC lens to design blockchain-based bonds. Thus, our research follows the design science research (DSR) paradigm to design and develop a bond prototype using the Ethereum blockchain protocol. Our results highlight the capability of blockchain-based bond markets to reduce TAC in the three dimensions of asset specificity, uncertainty, and transaction frequency. Further, our research provides design principles to contribute to both practice and the academic discourse on developing blockchain-based bond markets with reduced TAC.

Keywords Bonds · Design science research · Transaction cost theory · Blockchain

JEL Classification M15 · G14 · D23

Introduction

According to the European Capital Markets Institute, the bond market stands as the largest securities market worldwide. As of 2022, the global bond market reached a total of USD 133 trillion (Bartram et al., 2023). In particular, the corporate bond market in the USA alone accounted for USD 10 trillion in 2020 (International Capital Market Association, 2020), playing a vital role in providing funding to companies on the one hand and, on the other hand, providing diversified markets for investors. As a result of the rising importance of this market, many players and processes have become established in the corporate bond market, for which smooth interaction, high coordination, and information maintenance efforts are required. These complex structures involve different institutional intermediaries, like clearing and settlement houses, which provide trusted services to market participants (Allen & Santomero, 2001). Such intermediaries are involved in interrelated processes like raising bonds, trading promissory bills, or ensuring legitimate settlement, leading to significant latencies in settlement times and additional costs (Kleinbauer & Stone, 2021). Utilizing the bond market involves transaction costs (TAC), which become apparent through growing complexity. This complexity gives rise to inefficiencies, such as additional expenses for coordinating stakeholders and managing incompatibilities. These inefficiencies can result in elevated bid-ask spreads, increased market impact costs, and difficulties in executing large trades efficiently (Edwards et al., 2007; Williamson, 1981). Generally, high TAC can bring about notable drawbacks, including deterring market participation, limiting liquidity, and potentially distorting price discovery mechanisms, leading to less efficient markets (Benston & Smith, 1976). High TAC may also discourage smaller investors or firms from entering

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the market in particular due to the disproportionate impact of these costs on smaller transactions (Williamson, 1981). Such an environment can increase systemic risk, as obscured costs and inefficiencies contribute to market vulnerabilities (Coase, 1937).

In general, there are two ways to minimize TAC. On the one hand, the number of required transactions, i.e., transfers across technically separate entities, can be reduced through vertical integration whereby previously external activities, like credit rating activities, are (vertically) integrated into a company (Ciborra, 1983; Feulner et al., 2022; Williamson, 1981). Research on achieving transaction efficiency has increasingly focused on the use of digital technologies (Ciborra, 1983; Gurbaxani & Whang, 1991; Williamson, 1981). Until today, scholars have demonstrated how the use of digital technologies contributed to reducing TAC in various settings and use cases beyond bond markets (Aubert et al., 1996; Grover et al., 1996; Gurbaxani & Whang, 1991; Lacity & Willcocks, 1995; Li & Fang, 2022).

Among the most prominently discussed digital technologies for reducing TAC are blockchain technologies. As blockchain solutions are commonly attributed to afford the possibility to conduct trustless transactions (Beck et al., 2016; Feulner et al., 2022), the technology holds the promise of replacing trusted intermediaries. The unique characteristics of blockchains enable both up-to-date and tamper-resistant ledgers, which can increase the trust of market participants, which is particularly important in the financial sector and leads to reduced room for opportunistic behavior, thus less TAC (Rossi et al., 2019). Further, blockchain can enhance transaction efficiency compared to the status quo, where all actors must maintain their data and keep each other updated through additional channels (Andersen & Bogusz, 2019).

Consequently, multinational financial institutions started projects to explore the potential of blockchain-based bonds (HSBC, 2024). Following recent regulatory changes in Germany, enabling the regulatory-compliant issuance, management, and trading of bearer bonds using blockchain technology (Federal Financial Supervisory Authority, 2021), several companies launched their token-based solutions for issuing bonds (Siemens, 2023). This demonstrates the potential of corporate bonds, in the financial sector, whereas industry experts expect up to USD 10 trillion in tokenized assets worldwide (Sandor, 2023). Thus, blockchains represent viable and feasible solutions for reducing TAC in financial markets (Axelsen et al., 2023; Guggenberger et al., 2023), forming a stream of literature around the design of efficient financial markets based on blockchain technology (Grossmann, 2024; Guggenberger et al., 2023; Kranz et al., 2019).

Notably, while there is a substantial corpus of literature dedicated to this domain, there remains a noticeable scarceness of focused research on bond markets, despite their prevalent utilization in contemporary financial practice. Extant literature in the domain of bond markets tend to either offer broad, theoretical perspectives (Chen and Wang, 2020; Grossmann, 2024; Kleinbauer & Stone, 2021) or concentrate on highly specialized applications, e.g., carbon emission markets (Axelsen et al., 2023), leaving a gap of research on the design of TAC efficient corporate bond markets (Guggenberger et al., 2023; Kölbel et al., 2022). This is problematic as the theory on TAC provides a well-established understanding of market mechanisms, offering theoretical guidance into the design of efficient blockchain-based markets. In summary, due to the fact that (1) TAC are significantly incurred within bond markets, (2) blockchain-based solutions can be employed to reduce these costs, and (3) the existing body of literature lacks knowledge on how to design such solutions, this study aims to close this gap by raising and answering the following research question:

> How can a blockchain-based bond system be designed to reduce transaction costs in bond markets?

Our work provides both essential theoretical and practical contributions to the literature on bond markets and the stream of literature on the design of efficient blockchain-based financial markets. We do so by applying a design science research (DSR) process, following the established guidelines of Peffers et al. (2007) and March and Smith (1995). Subsequently, we provide design principles (DPs), developed using the theory of TAC, for the issuance and trading of blockchain-based bonds and illustrate the potential implications of a blockchain-based bond market design. Our results highlight the potential of blockchain-based bonds to reduce TAC in the bond market. Within the evaluation of our prototype, we demonstrate the potential to reduce asset specificity, information asymmetries, and uncertainties while improving transaction frequency.

In the subsequent sections, we will elaborate on this paper's theoretical background in the "Theoretical foundations" section and introduce design science research as the methodological framework applied in the "Method" section. After developing meta requirements and design objectives in the "Problematization and derivation of design objectives" section, we present the resulting artifact in the "Design and development" section. The artifact's evaluation is outlined in the "Evaluation" section before presenting our DPs in the "Design principles" section. Finally, we discuss our results and conclude this work in the "Discussion" section.

Theoretical foundations

Corporate bond markets

Corporate debt financing includes either bank-based or market-based financing, which provides the capital for operative activities as well as strategic growth. Thereby, bank-based financing can be complex due to the introduction of regulatory requirements, e.g., Basel III, or higher risk premiums and more securitization (Beck & Demirguc-Kunt, 2006). Thus, the importance of market-based debt financing increases and is the focus of our further analysis. Corporate bonds, hereinafter referred to as bonds, are market-based debts. Bonds offer different configurations concerning their interest rates (coupon), amortization, repayment methods (redemption), and terms (maturity) (Edwards et al., 2007). Thereby, the current bond market is based on centralized systems to establish trust between investors and issuers during the lifecycle of a bond.

The traditional bond lifecycle involves pre-, issuance, and post-issuance processes, including post-trade and other bond actions, leading to complexity due to stringent regulatory requirements and the involvement of numerous parties. In the pre-issuance phase, the modalities of the bond, such as interest rate and maturity, and establishing and specifying agreements, such as legal rights in case of default, are defined (Lambert et al., 2022). Since bonds are considered debt securities, additional laws and regulations for the public offering of a bond must be applied according to the respective jurisdiction. The pre-issuance phase includes the rating of the creditworthiness of the issuing company as well as the bond itself by an independent agency. This is followed by the draft of the bond prospectus, which comprises relevant information for investors. Next, the issuing company delegates one or more investment banks with the identification of potential investors in the bond before issuing the bond to the primary market.

Generally, successful issuances are followed by clearing and settlement processes, which are typically time- and cost-intensive (Milne, 2007). Regarding the clearing and settlement process, there are two different types of bond trades: (1) trades at an exchange and (2) over-the-counter (OTC) trades. In the first case, the exchange operator acts as a middleman, receiving temporary custody of the bond and the cash payment before forwarding them to the respective party. Thus, the settlement time, i.e., the time between the trade initiation and the bond delivery to the buyer and the cash to the seller, depends on the standards set by the exchange operator. In the second case, for OTC trades, the settlement directly occurs between the two trading parties. More specifically, the settlement is executed by the custody and settlement systems of securities, determining the settlement times. These platforms are typically domestic, e.g., the Cascade system of Clearstream Banking in Germany, or supra-national, like the Target-to-Securities (T2S) System for settlement and custody in the EU. However, settlement times between different markets have been widely standardized, e.g., the EU standard for settlement is "T + 2," i.e., settlement is completed 2 days after trade initiation for exchange and OTC trades. In addition, the bond issuance requires central counterparties and additional payment systems for wholesale interbank transfers. In the clearing process, each party faces counterparty risks, i.e., a trade and the individual underlying transactions of the involved parties may not be executed as agreed upon, for example, due to the counterparty's insolvency (Milne, 2007). These risks exacerbate information asymmetries and contribute to the proliferation of trust concerns (Pirrong, 2011). To mitigate counterparty risks, a special financial market infrastructure (FMI) is required using centralized counterparties (Biais et al., 2012). We display a simplified model of a bond lifecycle in Fig. 1.

However, this infrastructure is accompanied by several drawbacks, which we outline in the following. First, the market infrastructure involving multiple centralized intermediaries induces potential illiquidity in the markets, which subsequently leads to price reversals (Bao et al., 2011). Thereby, illiquidity is in part driven by the trade size of the bond, necessitating an improved system which can decrease market entry barriers to facilitate the issuance of smaller bond sizes. Second, recent studies on the efficiency of bond markets indicate elevated expenses and mispricing which decrease bond market efficiency (Bartram et al., 2023). Thus, an improved market design could mitigate these drawbacks by reducing settlement times and ultimately increasing market efficiency (Caytas, 2016).

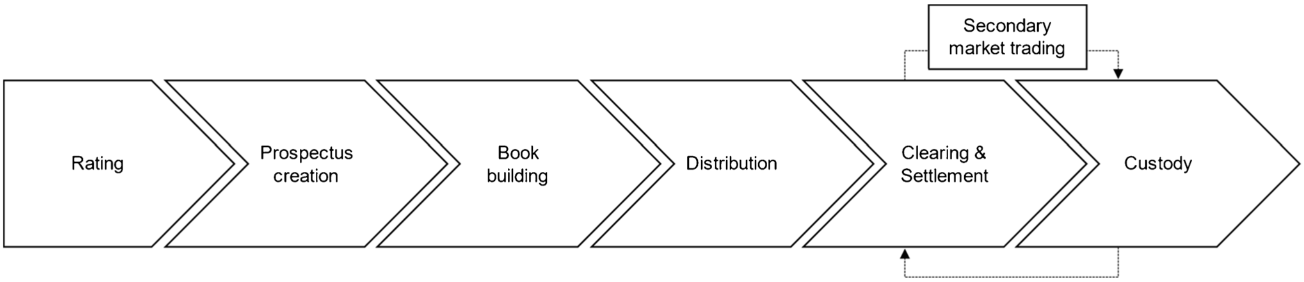

Fig. 1 Bond lifecycle. Own illustration based on Grossmann (2024)

Transaction cost theory in bond markets and IS

One frequently used theory in IS to examine the efficiency of markets is the transaction cost theory (Ahluwalia et al., 2020; Schmidt & Wagner, 2019). As a further development of Coase (1937), Williamson (1981) characterized "effort, time, and cost incurred in searching, creating, negotiating, monitoring, and enforcing a [(financial)] service contract between buyers and suppliers" when participating in markets as transaction costs (TAC) (Ang & Straub, 1998; Mahoney, 1992, p. 537).

The amount of TAC incurred during a transaction lifecycle is determined by existing uncertainties that need to be encountered, the frequency with which a transaction is performed, and the amount of asset specificity given, which depends on a respective (financial) service's or good's transferability (Williamson, 1985). Typical examples of such specificities are expenses like training for working with certain technologies, specific adjustments of physical assets, or geographic dependencies, whose value is limited to stakeholders or use cases and cannot (fully) be realized under different conditions (Liang & Huang, 1998). In addition to asset specificity, multiple kinds of uncertainties can lead to more complex contract formulation, monitoring, and enforcement expenses, thus increasing TAC, too (Coase, 1937; Li & Fang, 2022; Teo & Yu, 2005), whereas Williamson (1981) differentiates between parametrical, i.e., environmental uncertainties, and behavioral uncertainty, i.e., self-optimizing opportunistic behavior by one or both transaction parties.

Until today, several information systems (IS) researchers have shown how the use of digital technologies contributed to reducing TAC in various settings and use cases beyond bond markets (Ciborra, 1983; Gurbaxani & Whang, 1991; Lacity & Willcocks, 1995). In addition to examinations of how IT can positively impact organizations in different ways (Ciborra, 1983; Gurbaxani & Whang, 1991), some of the most prominent fields of application within IS involve outsourcing processes (Alaghehband et al., 2011; Miranda & Kim, 2006; Watjatrakul, 2005), the analysis of digital market and corporate structures (Chen et al., 2017; Li & Fang, 2022), and the development of digital business models (Susarla et al., 2009). In addition to Li and Fang (2022) and Schenk et al. (2019), who examined the impact of open or sharing platforms on TAC compared to conventional market designs, Bauer et al. (2019) found that blockchain-based applications can help to reduce TAC through intermediating between multiple stakeholders. By removing centralized intermediaries from the value chain and replacing them with a trust infrastructure, complexity decreases, thus reducing TAC.

Since traditional bond markets are characterized by high complexity, the coordination of involved parties is imperative. Consequently, substantial TAC are incurred in these markets, requiring the reduction by implementing efficient market designs or coordination mechanisms, such as effective information management (Cordelia, 2006). Given that blockchain has demonstrated its capabilities to lower the TAC in complex market environments (Ahluwalia et al., 2020), our investigation focuses on the extent to which a corresponding system can yield similar improvements in the bond market. Therefore, we will address the central determinants of TAC according to TAC theory, namely *frequency*, *asset specificity*, and *uncertainty* (Williamson, 1985).

Designing blockchain-based systems reducing transaction costs

To date, researchers have investigated the development of blockchain-based systems for the purpose of reducing TAC. With a particular focus on the effects of blockchain-based solutions on uncertainty, Kim and Laskowski (2017) have demonstrated, based on the example of credit risks, that the use of blockchain technology can reduce uncertainties between multiple actors. Through improved transparency, rooms for opportunistic behavior are reduced, and trust is strengthened as a consequence (Schmidt & Wagner, 2019; Zheng et al., 2020). In addition to reducing such behavioral uncertainties, blockchain solutions have been found to reduce parametric uncertainties, too, due to their decentralized and redundant architecture (Golosova & Romanovs, 2018).

In order to maximize transaction frequency and minimize asset specificity, smart contracts are used as decomposable units that perform, e.g., coordinative or functional tasks on blockchain infrastructure (Kim & Laskowski, 2017). The most prominently used blockchain platform to implement blockchain systems, including smart contracts, is Ethereum (Wang et al., 2019). Research that has successfully demonstrated the reduction of TAC using smart contracts including Ahluwalia et al. (2020) for the example of financing startups or Schmidt and Wagner (2019) for the case of supply chain structures.

To represent (financial) assets, digital tokens are frequently used and created, transferred, or stored by smart contracts. For instance, Guggenberger et al. (2023) developed an Ethereum blockchain-based prototype implementing crowdfunding equity tokens. Another recent publication by Axelsen et al. (2023) documents the implementation and examination of a blockchain-based prototype for the trading and settlement of green bonds. Important design knowledge generated throughout these works includes the division of on- and off-chain functionalities for data processing and storage, adherence to standards to ensure the broadest possible applicability, and the use of public blockchains like Ethereum to provide a high degree of transparency.

After introducing the underlying methodology in the next section, we will continue to present the development and evaluation of our blockchain-based prototype for token-based bonds based on the literature discussed.

Method

Due to the significant TAC incurred and the lack of applicable blockchain-based solutions to reduce TAC in bond markets, we follow the design science research (DSR) paradigm. The DSR paradigm offers structured guidelines to build purposeful IT artifacts to address practical problems (March & Smith, 1995). Therefore, to answer our research question, we develop an innovative IT artifact aiming to solve inefficiencies in the bond markets, thereby lowering TAC. Throughout this iterative trajectory, including the requirement analysis, technical implementation, and evaluative cycles, we aim to design a practical solution and develop transferable abstract design knowledge grounded in theory. Figure 2 depicts our research design, delineating the progression from problem identification to concretization, solution development, and abstraction within a structured framework.

In particular, our methodological approach is structured in the following iterative steps according to Peffers et al. (2007): (1) problem identification and motivation, (2) definition of solution objectives, (3) design and development, (4) demonstration, (5) evaluation, and (6) communication. Figure 3 illustrates the research process, which we describe in the following.

Throughout our research, we conducted three design cycles. Following the initial problem identification in step one (Problem Identification), which involved reviewing the literature and expert interviews, the identified issues were formally articulated as meta-requirements (MR). These MRs formed the basis for developing design objectives (DOs) in step two (Objective Definition). In step three (Design and Development), the artifact was developed, functionally tested, and iteratively improved. In doing so, we used the feedback from industry experts to continuously improve the prototype's functionalities in the following design cycle two and design cycle three (Peffers et al., 2007; Sonnenberg and Brocke, 2012). Thereby, we also ensured a holistic perspective on our prototype by including interviews with researchers from different institutions and industries engaged in blockchain technology. As this artifact constitutes an instantiation (Hevner et al., 2004), step four (Demonstration) was divided into the presentation of the functional architecture to clarify processual, legal, and regulatory requirements, followed by the artifact's technical implementation. Step five (Evaluation) focused on the successful implementation of the developed DO. Finally, step six (Communication) marks the final step of the approach and involves communicating the theoretical and practical findings. To provide prescriptive design knowledge derived from the IT artifact and evaluation phase, we formulated DPs by incorporating descriptive

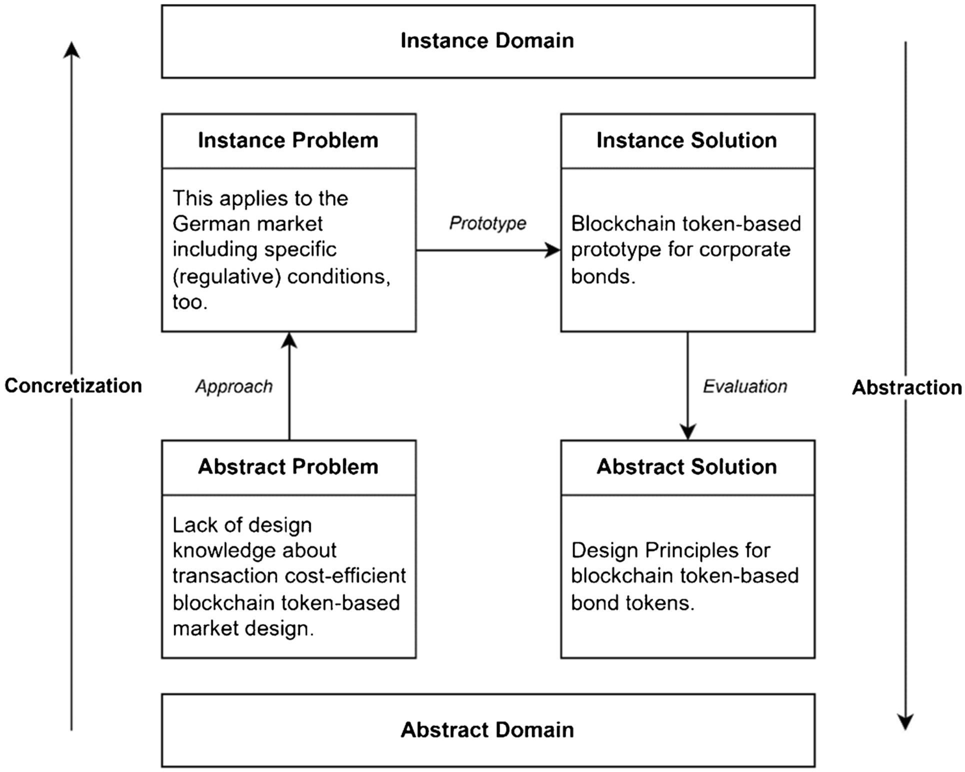

Fig. 2 Structural illustration of our research approach. Own illustration based on Peffers et al. (2007) and Guggenberger et al. (2023)

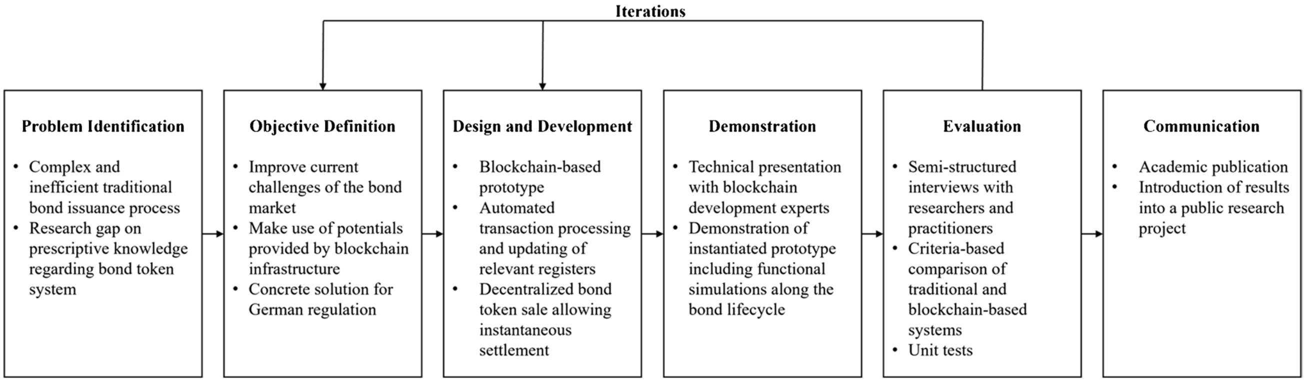

Fig. 3 Steps of the DSR process. Own illustration based on Peffers et al. (2007)

knowledge, specifically employing TAC as a kernel theory (Gregor & Hevner, 2013; Heger, 2020; Walls et al., 1992; Williamson, 1981). The communication of our research findings to the relevant audience, as advocated by Hevner et al. (2004) and Peffers et al. (2007), marked the conclusive phase of our research process, which is achieved through the academic processing and publication of our work including the artifact's source code as well as its documentation. Additionally, our practical and theoretical findings were directly integrated into a publicly funded research project that investigated the tokenization of financial products and markets with an interdisciplinary research team.[1] Our practical contribution in this regard will be presented in detail in the "Discussion" section.

Throughout our research, we consulted with experts and used semi-structured expert interviews to determine the efficacy of the artifact. Expert interviews based on purposive sampling are a well-established evaluation method in DSR studies to assess highly complex artifacts from a multi-dimensional perspective (Guggenberger et al., 2020; Im & Straub, 2015; Tongco, 2007). Purposive sampling is a common practice to select interviewees with expertise in a specific domain (Im & Straub, 2015; Tongco, 2007). We employed this technique to select experts with expertise in blockchain technology applications, the bond industry, legal as well as regulatory domains, and scientific research to ensure that the interviewee's contributions deeply enriched the prototype development and evaluation processes. We contacted potential interviewees by using the individual networks of the authors as well as the professional social network LinkedIn. Across all evaluation cycles, we conducted 14 semi-structured interviews with seven experts from different fields. We display all interview partners in Table 1.

The average duration of the interviews accounted for approximately 43 min and were conducted individually, recorded, and subsequently transcribed. In the following, we started the coding process by labeling important statements for later extraction using the software tool MAXQDA. We thereby adapted the coding strategies that Corbin and Strauss (1990) proposed to analyze the collected data from our qualitative data. The findings of this process are described in the subsequent sections.

Problematization and derivation of design objectives

This section presents the DO development process, commencing with a methodical identification of the underlying problem. As elucidated previously, starting from the abstract inquiry highlighting the extant yet unrealized potential for diminishing TAC within bond markets and acknowledging the lack of design knowledge in this domain, our objective is to formulate a pragmatic resolution encapsulated within a prototypical implementation. Since a rigorous requirements analysis and definition process is needed in developing IT artifacts, we follow a two-staged process (Peffers et al., 2007). First, we identify the MRs before deriving the DOs through a literature review and semi-structured expert interviews. The following two sections present the results of these steps, respectively.

Identification of meta-requirements

Our initial review of the scientific and practice-oriented literature, including whitepapers and project reports, revealed problems such as complex market designs, time-consuming manual processes, and high transaction costs. As a result, we ran a first round of interviews with bond market professionals (E1 and E2) to validate and improve our initial set of MRs. Thus, we follow a problem-centered approach to identify MR, which builds the basis of further design and development processes (Peffers et al., 2007).

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[1] Projectgroup Tokenisierung und Finanzmarkt (ToFi) funded by Zentrum verantwortungsbewusste Digitalisierung (ZEVEDI)

Table 1 Overview of participating interview partners

Expert ID	Professional title	Company	Expertise and area of contribution	Design cycle	Interview ID
1	Certified AML Specialist	Leading Universal Bank	KYC/AML integration	1	1
2	Senior Manager Innovation & Digitization	Universal Bank	Bond issuances, blockchain platforms	1	2
3	Head of Middle Office Derivatives	Leading Universal Bank	Tokenized derivatives	2, 3	3, 4
4	Blockchain Researcher	National Research Institute	Design of decentralized finance ecosystems, security token offerings	2	5
5	Regulatory Lawyer	International Law Firm	Regulatory aspects of security token offerings	2	6
6	Chief Operating Officer	Technology Provider	Security token offerings	2	7
7	Ethereum Developer	Freelancer	Technical aspects of initial coin offerings, design of smart contracts	3	8
8	Researcher	Research Institute	Design of decentralized finance applications	3	9
9	Senior Consultant and Visiting Professor	IT-Management Consultancy, Research Institute	Design of decentralized finance applications, regulatory aspects	3	10
10	Manager	Management Consultancy	Management of security token offerings	3	11
11	Analyst	Investment Bank	Implications of corporate financing and bond markets	3	12
12	Postdoctoral Researcher	University	Transaction costs of bond markets	3	13
13	Delivery Lead	Blockchain-Consultancy	Transaction costs in blockchain-based applications	3	14

As explained earlier, the traditional bond market is characterized by high TAC. This is expressed, for example, by significant delays along the settlement process and considerable efforts required to coordinate the players and processes. Consequently, we focus on the central problem of reducing TAC through blockchain-based bonds. Transaction costs can result from three TAC-specific dimensions (1) transaction frequency (issues hindering optimum throughput and standardization), (2) asset specificity (factors leading to incompatibility between bond markets), and (3) uncertainties (the obligation to avoid room for opportunistic behavior by any stakeholder), which is why we structured our MRs along these dimensions. Table 2 presents the MRs identified throughout the process.

Summarizing the identified MR, the financial process landscape, including the traditional bond issuance, is characterized by many interactions between untrusted market participants acting as intermediaries, leading to significant TAC. Unfortunately, the process design and underlying FMI aimed at ensuring trust and regulatory compliance within transaction processing results in vast cost and time inefficiencies while certain process risks remain (Vakta et al., 2016). Bond markets could benefit significantly from reduced economic barriers to attract more investors, increasing liquidity and tradability. Lastly, tying securities to physical paper-based assets should be revised, as this requires additional market participants, increasing the complexity even more (Milne, 2007).

Derivation of design objectives

Based on the preceding presentation of identified MRs, the following section describes how our DOs for developing a blockchain-based bond prototype were derived. MRs and DOs are of particular interest in the first iteration of expert interviews, which were examined for correctness, importance, and completeness. Based on these findings, we developed a suitable (blockchain-based) technical implementation of the proposed IT artifact, demonstrated in the "Design and development" section.

For our design process, we adopt the current German legal framework as it serves as a reference for regulating blockchain-based bond tokens. The German legal landscape is exciting, as national laws, EU directives, and regulations influence the regulatory landscape throughout the design process. For example, the digitization of the financial sector is driven by the "Markets in Crypto Assets Regulation" (MiCAR), which has been set into force in 2022 (Federal Financial Supervisory Authority, 2024) and thus will also apply in Germany. The eWpG in Germany is a legal framework that allows issuing securities electronically and recording them in a crypto securities registry (as one configuration

Table 2 List of identified meta-requirements

TAC dimension: frequency	
MR-1: Reduce time-intensity	Although the clearing and settlement processes have been improved and standardized, settlement and clearing time still vary across some markets and, in most markets, take two business days (Chen and Wang, 2020; Vakta et al., 2016). Our prototype shall minimize process times
MR-2: Reduce stakeholder complexity	Numerous intermediaries, such as banks, custodians, or clearing houses, are involved in a securities transaction, which causes significant complexity (Linciano et al., 2005; Vakta et al., 2016). Our artifact shall reduce this source of complexity
MR-3: Avoid manual and analog processes	The issuance of securities involves many manual processes; for example, less than 70% of bonds are traded electronically (Kleinbauer & Stone, 2021), which represents a potential cause of human error (Vakta et al., 2016). Furthermore, physical securities certificates or global notes cause an additional administrative burden, as they must be stored in safe custody, transferred, and managed during the bond's lifecycle (Biais et al., 2012). Our prototype shall avoid manual processes to a maximum extent and digitize securities certificates if possible
TAC dimension: asset specificity	
MR-4: Reduce dependency on CSDs	Every securities transaction inevitably has to use the services of Central Securities Depositories (CSDs) or delegated depository banks along the clearing and settlement chain. Thus, a centralized bottleneck exists (Milne, 2007). Our prototype shall avoid such central intermediaries if possible
MR-5: Reduce market barriers	The denomination of a bond issuance usually starts at 1000 euros to be economically feasible (Infelise, 2014), excluding some groups of investors from investing in bonds. Also, the actual processing of trades is restricted to business days due to the availability of third-party services, such as central counterparties, posing another utility threshold (Vakta et al., 2016). Our prototype shall reduce market barriers for all participants
MR-6: Provision of secondary markets	Bonds are usually traded on OTC markets rather than on exchanges, as most bondholders are institutional investors. Other than that, secondary markets for trading bonds remain insufficient (Bao et al., 2011; Edwards et al., 2007). Our prototype shall provide sufficient secondary markets
TAC dimension: uncertainties	
MR-7: Reduce room for opportunistic behavior	Information asymmetries can be found in many aspects of the bond token market. Potential issuers often lack financial and credit history (Duan et al., 2009). Further, counterparty and settlement risks exist (Linciano et al., 2005; Milne, 2007). Also, the processes are not transparent, hindering traceability and auditability (Vakta et al., 2016). Our prototype shall reduce information asymmetries as much as possible

of an electronic securities registry). Under the eWpG, electronic securities are not new or different types of security but rather the same underlying securities that are merely issued electronically. Even though we focus on Germany within our design process, some findings might also be generalizable to other jurisdictions. In compliance with this legal framework, the prototype shall allow for an uninfluenced tradability based on the current functionalities of the bond market. Thus, payment and trading systems should be separated. Instead of investor balances on a specific cut-off date and making coupon payments on this particular basis, the holding period shall be taken into account. Table 3 presents our final list of DOs.

Design and development

This section presents the design of the prototype's architecture. The ensuing step involves the tangible manifestation of our MRs and DOs through developing a prototype, which is a practical demonstration of the proposed design solutions.[2] The prototype's final version resulted from three design cycles following the approach by Peffers et al. (2007), which have been explained in more detail in the "Method" section.

Architecture

The resulting architecture encompasses several smart contracts, stakeholders, and other technical systems. In the following, we first present the static components of our prototype: technical framework, entities, smart contracts, system setup, and usage. Throughout the design process, the architecture was developed and optimized specifically to ensure the most effective and efficient implementation of a bond market's (core) functionalities in compliance with regulatory requirements according to MiCAR and eWpG.

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[2] The source code can be accessed via the following GitHub repository: https://github.com/- bondtokenimplementation/Repository.

Table 3 List of DOs

TAC dimension: frequency	
DO-1: Minimize latency of settlement processes	The prototype should enable nearly instantaneous settlement of trades (Guggenberger et al., 2023). Also, the delay between the initiation of a trade and the actual settlement of a transaction is to be reduced to a minimum. This is crucial to enhance efficiency in financial markets by leveraging the potential of blockchains
DO-2: Reduce complexity (standardized interfaces and consolidated roles as well as responsibilities)	Since the conventional securities landscape is quite complex, the number of separated entities and manual processes leading to extensive TAC should be reduced to a minimum. The issuance process should be as standardized as possible (Kaousar Nassr & Wehinger, 2014) to reduce costs and settlement times. This further increases the transaction frequency and, thus, the efficiency of the respective financial market
TAC dimension: asset specificity	
DO-3: Reduce access barriers (flexible issuance sizes and secondary market support)	The prototype should allow issuances of all sizes, reducing the barrier to consider bond issuances as a natural financing alternative, by addressing a larger group of investors (Schweizer et al., 2017) To further reduce utility thresholds, trading bonds should also be possible in secondary market options and not be restricted by business hours or geographics. Thus, asset specificity can be reduced, and subsequently, efficiency in the market increased
TAC dimension: uncertainties	
DO-4: Optimized information sharing	The prototype should reduce information asymmetries, thus creating transparency across permitted stakeholders and reducing risk, which ultimately leads to higher efficiency of our prototype. Depending on the authorization, i.e., investor balances, payments, and trades, and the documentation of coupon payments and repayments, the stored data should be publicly accessible (Guggenberger et al., 2023) Still, our prototype needs to ensure investor privacy for data protection reasons and banking confidentiality
DO-5: Ensure regulatory compliance (with MiCAR and eWpG)	The prototype must fully comply with the legal framework in Germany. This covers both the token and specific regulatory requirements such as Know-Your-Customer (KYC) and Anti-Money Laundering (AML) checks of the investors. Subject to judicial enforcement, it must also be possible to transfer tokens even if the token holder refuses or cannot transfer for unspecified reasons. Through the newly introduced German eWpG, crypto security registers enable the issuance of bearer bonds utterly detached from physical, paper-based securities certificates. The prototype should, thus, include a crypto securities registry (CSR)

Technical framework

The design and development of our IT artifact starts with selecting a suitable blockchain protocol, which serves as a set of rules and standards that defines how data in the peer-to-peer network is validated, recorded, and maintained (Rossi et al., 2019). In accordance with best practices drawn from related literature, the Ethereum protocol was chosen to design and develop the blockchain-based bond token prototype (Axelsen et al., 2023; Guggenberger et al., 2023). Of particular importance for the decision was its ability to create modular smart contracts, which are necessary for the development and the design of individual functions or components such as a CSR. Further, the Ethereum protocol serves as the fundament for a large ecosystem of blockchain networks, which provide best-practices for implementations and various guidelines for developers (Kranz et al., 2019). Also, various Ethereum Request for Comment (ERC) token standards exist, which can be inherited when building a token system (Di Angelo & Salzer, 2020). Additionally, many other blockchains use the same programming language and virtual machine, enabling our artifact to be transferable to other protocols. Hence, we used the popular programming language Solidity to create Ethereum-based smart contracts. The code was built using the Remix IDE, which allows interaction with different test environments and test nets.

Entities and smart contracts

The participating entities include the security token offering (STO) platform acting on behalf of the issuer, KYC service providers, a registrar, a regulator, and any number of investors. All contracts are deployed by the STO platform, which additionally manages (sets and updates) the addresses of the respective entities. The STO platform appoints both the KYC service provider and the registrar.

Overall, the prototype includes four connected smart contracts, as Ethereum's maximum contract size is limited. The contracts used are a main bond token contract, a CSR contract, a KYC contract, and a document contract. These four contracts can be accessed by respectively authorized stakeholders in standardized ways in compliance with the individual technical, procedural, and regulatory requirements. As soon as the original setup and legitimation of the regulator are completed, authorized companies can submit their bond offerings to the bond token contract via a designated platform, e.g., an STO platform. After successfully surpassing KYC processes (KYC contract), investors access the system and invest directly through the bond token contract, which updates the CSR contract.

The modular and task-specific structure helps keep individual smart contracts' complexity low and ensures reusability. Further, in the event of security issues, the prototype can be adjusted individually, delimiting functionalities without impacting the remaining components. First, the central bond token contract inherits the ERC-1155 multi-token standard, which allows the issuing and managing of multiple bond tokens within a single, reusable contract. The bond token contract represents the central counterparty through which a bond token can be minted. Essential information about the token is stored within a structure called *tokenData*, which can be accessed via a certain *tokenID*. Only data is stored, that needs to be accessed within the contract at a given time, e.g., *volume*, *parValueETHER*, *parValueEUR*, *coupon*, and *maturityDate*. Customized standard functions like minting or transferring the tokens are supplemented by purchase functions like *buyTokensETHER* and functionalities to execute corporate actions. These are carried out via *payCoupon* or *payRedemption*. Second, we implement a CSR contract. Utilizing a CSR enables the issuance of tokenized bonds from physical paper-based securities certificates. We aligned the design process of the CSR to the eWpG to ensure compliance. Third, we implemented a KYC contract, as the bond token should only be sold or transferred to known identities. The KYC contract registers investors within a whitelist, which is located on the blockchain, as well. Besides the investor's address, a boolean on the completion of KYC processes and additional information regarding the investor type is stored. Concerning necessary entry types in the CSR, an investor can either hold custody for themselves individually (single custody) or act as an institutional investor that functions as a collective custodian (collective custody). Finally, the document contract acts as a cache of document references, namely the InterPlanetary-File-System-specific hashes of individual documents (such as annual reporting or regulatory documents).

System setup and usage

The high-level model depicted in Fig. 4 illustrates the lifecycle of the blockchain-based bond token prototype. First, the STO platform approves the role of the KYC provider (1a) and the licensed registrar (1b). The latter needs to be licensed by the respective regulator (e.g., BaFin) and initializes the CSR with the bond data from the securities prospectus or the securities information sheet (2a). After the initialization, the regulator approves the CSR data (2b). In the following, the STO platform can mint the bond token (3a), which pulls the token data from the CSR contract into the bond token contract for future operations (3b). After the successful onboarding, investors purchase the bond token by sending a cryptocurrency (e.g., Ether) to the bond token contract (4a). The positive request of the whitelisting (4b) triggers an update of the CSR contract (4c) and sends the bond token to the investor (4d). In the following, the platform may execute corporate actions like coupon payments (5a) or paying redemption (7a) after the bond has matured and the investors send the bond tokens back to the platform (6).

Core functionalities

To illustrate the applicability of the prototype, we present the following selected core functionalities in detail (Sharp & Rountev, 2005): CSR initialization, minting (issuing) the bond token, initial bond token sale, bond token transfers, and corporate actions.

CSR initialization

The eWpG allows the registering of securities within a crypto securities register managed by the issuer or an appointed third party. A CSR must be stored on a tamper-proof recording system in which data is stored in chronological order and protected against unauthorized deletion and subsequent modification. In principle, implementing the CSR into a smart contract on the Ethereum blockchain fulfills these requirements, except for possible content modification. Subsequent modification of the content is then prevented in two ways. The modifier *onlyRegistrar* ensures that only a licensed registrar can insert or change data in the first place. Additionally, if the data is set completed via *setDataCompleted* by the registrar, the regulator can execute the function *setRegulatoryApproval* to set

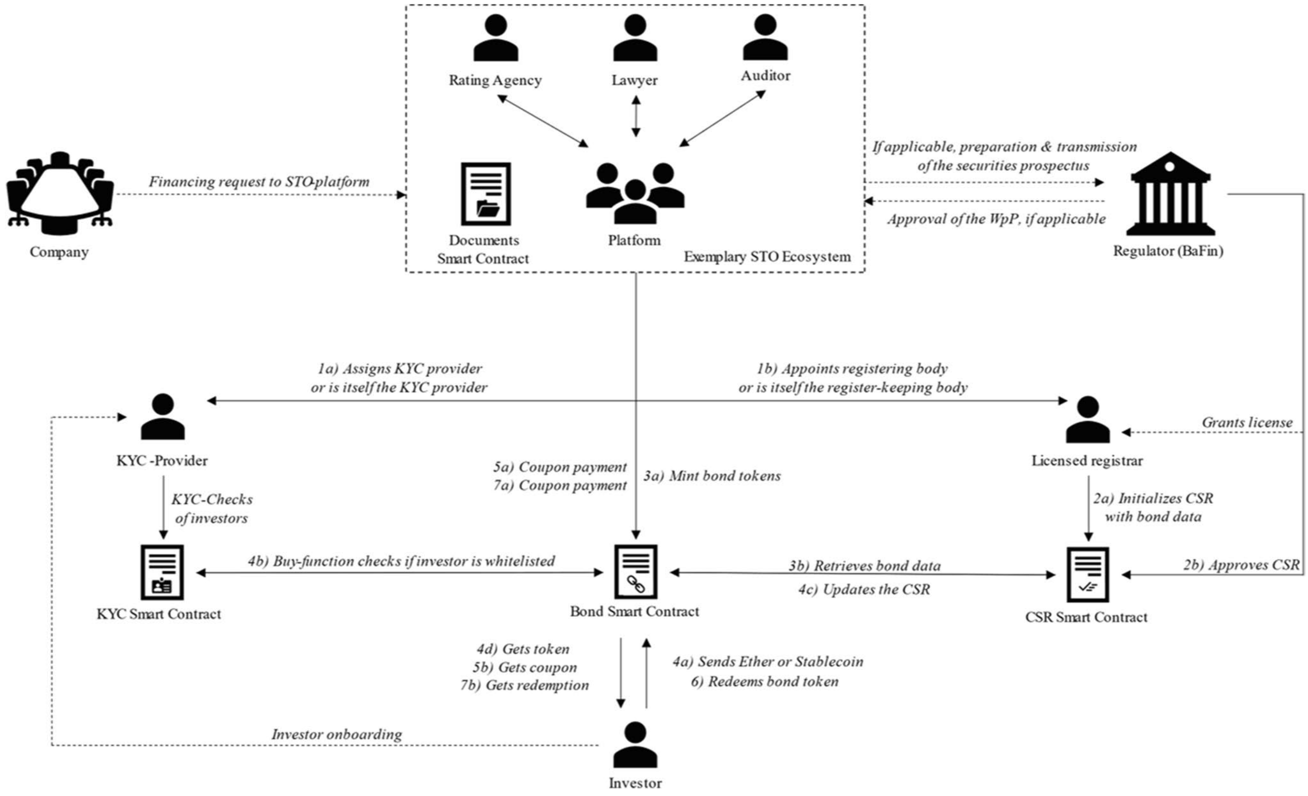

Fig. 4 Abstract bond token prototype architecture and processes. Own illustration

the final confirmation. This prevents further execution of content modification functions (even the registrar cannot change the data anymore).

Since no design recommendations or precedents exist yet, the design of the content is defined by the eWpG's minimum requirements and is supplemented by additional variables such as coupon, *settlementDate*, or *maturityDate* (see Fig. 5). In the case of a mixed entry type, a concrete distribution by type of entry must be available (*SingleEntry* or *CollectiveEntry*). Information about the composition of the mixed holdings is then stored within the *InvestorStructure*. Data is automatically derived and updated from the individual balances in the case of token transfers.

Each data input via the functions *setTokenData*, *setTermSheet*, or *setDates* queries whether the regulator had already approved the data. In the case of a successful entry, the data can be set to be completed via *setDataComplete* by the registrar. After checking the log data, the regulator can lock the data immutably via *setRegulatoryApproval*.

Minting (issuing) the bond token

After successfully initialing the CSR, the STO platform can mint the respective bond token via *mintToken* in the bond token contract using the respective *tokenID*. Thus, the contract releases the token for the general sale, and investors can purchase it. Platforms can only mint approved tokens to ensure regulatory compliance, as the bond token is linked to the CSR. As the data within the CSR needs to be readable in the future for investors and the STO platform, the *mintToken* function automatically retrieves and stores data in the bond token contract by using the *tokenID*. Purchase or transfer functions will later revisit these variables to calculate prices or check time-related restrictions.

Initial bond token sale

In our proposed infrastructure, the initial bond token sale can occur in two different ways. The investor can choose between spending the native token (i.e., Ether) by using the *buyTokensETHER* function or an ERC-20 stablecoin by using *buyTokensEUR*. The ERC-20 stablecoin might represent either commercial bank tokens or a central-bank-backed digital currency. The subsequent processes are as follows:

If a potential investor decides to purchase a certain amount of a bond token by sending Ether, the investor calls the function *buyTokensETHER*. The function queries three requirements. First, the token sale is in a pre-settlement state. The second statement checks whether the caller of the function (*msg.sender*) is whitelisted in the KYC contract.

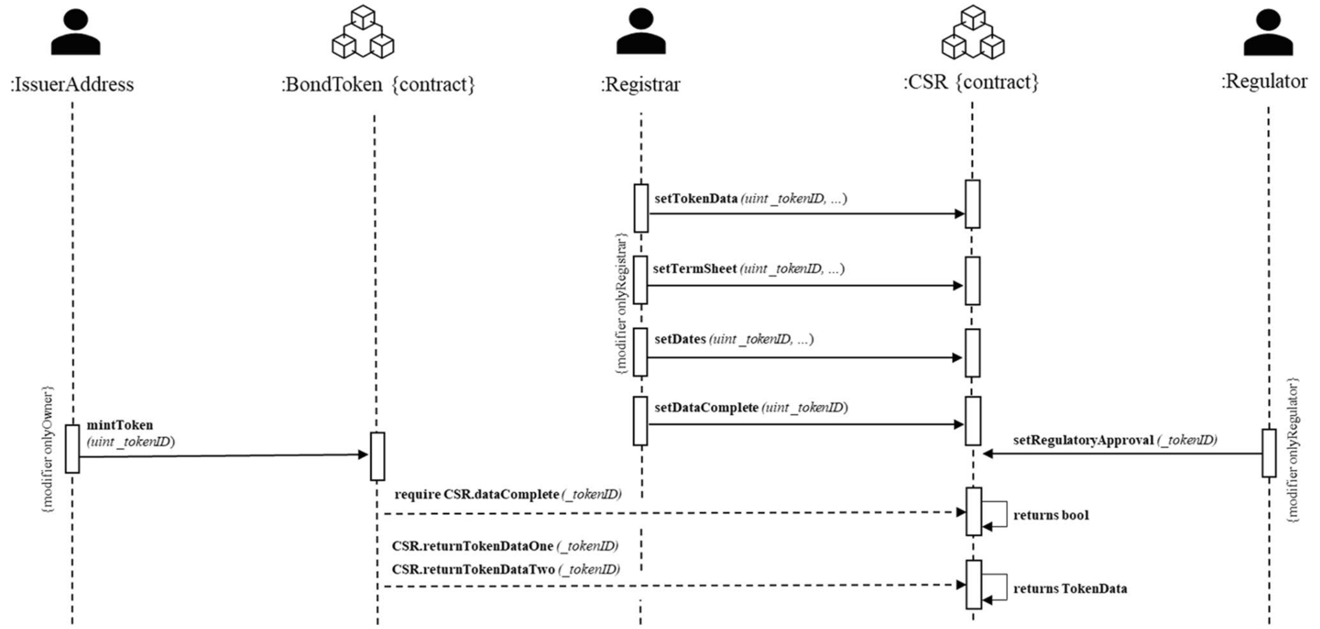

Fig. 5 Initialization of the CSR and bond issuance. Own illustration

The third statement checks whether the investor's *msg.value* matches the actual price to pay. Matching the logic of clearing and settlement systems, the bond must first be paid. The function transfers the *msg.value* to the *IssuerAddress* in the next step. In the case of *buyTokensEUR*, payment is executed via a simple ERC-20 *transferFrom* function. However, if the bond is paid successfully, the bond token is transferred to the investor via an internal ERC-1155 function called *_safeTransferFrom*. Next, the function checks whether this investor is already invested in this bond, and if the check returns false, the investor's address is appended to a list of *Investors*. This list is of particular interest when corporate actions need to be executed. Additionally, the *isInvestor* status is set to true. To keep track of the total *issuedAmount*, the *purchased _amount* increases, and the CSR is updated. Finally, the event *TokenBought* is emitted, and the function returns *true*, signaling success.

The complete clearing and settlement process of a bond token purchase can be executed within a single function. This includes the payment, the transfer, and the documentation of events. Require statements are automatically executed, ensuring regulatory-compliant purchases. Consequently, previously separated clearing and settlement processes merge, enabling an almost instantaneous settlement.

Bond token transfers

The bond token contract allows the transfer of any bond token using modified ERC-1155 transfer functions. As long as the bond has not matured, the owner of the tokens or authorized operators can send bond tokens to whitelisted investors. Next, the CSR is logically updated after each transfer. To enable the forced token transfer, thus, without the explicit approval of the token holder, we implemented a *forcedTransfer* function that can only be called by the regulator. Additionally, a particular *redemptionBuyBack* function allows transfers to occur only after maturity. Bond tokens of a specific *tokenID* are sent to the *IssuerAddress*, from which they can be burned. The function then stores the address and corresponding amount within a mapping, allowing a redemption.

Corporate actions

The execution of corporate actions within the bond token prototype is of particular interest, as the coupon payments and the final redemption of the bond should be automated to a maximum extent. Paying coupon-based on investor balances on specific cut-off dates may influence the bond's price and tradability. Thus, our prototype allows investors to receive coupon payments regardless of the holding period. The deployed calculation method requires data on investor trades, including sender and receiver, the transferred amount of the specific bond token, and the *block.timestamp*. Therefore, transaction data is stored within events, indexing critical data such as *msg.sender*, the recipient, the amount, and the *block.timestamp* to allow for later extraction. Average holding periods can then be calculated off-chain. Subsequently, the *payCoupon* function removes internal loops, simplifying the transfer of a specified amount of ether to a pre-defined investor address. In contrast, the payment of redemption is much more automated. First, investors must "return" their bond tokens to the *IssuerAddress* by calling the *redemptionBuyBack*. The function stores the amount of a specific *tokenID* to be repurchased from the *msg.sender* and emits an event. The issuer then triggers the *payRedemption* function for a specific *tokenID* and the investor's address to pay the redemption automatically. Finally, the stored data is emptied. Both functions, payCoupon, and payRedemption, can be designed to either pay Ether or a stablecoin. However, the latter variant requires additional manual authorization. The design choice of the currency needs to be defined ex-ante within the securities prospectus or the securities information sheet.

Evaluation

The evaluation of design artifacts as unique contributions to IS is a multifaceted endeavor contingent upon various factors, as emphasized by Hevner et al. (2004) and Peffers et al. (2007).

Following scholarly methodologies, our evaluative approach unfolded through several iterative steps covering all three relevant evaluation dimensions (Sonnenberg and Brocke, 2012; Venable et al., 2016). First, we conducted ex-post interviews to appraise our framework summatively, wherein demonstration sessions with interviewees were accompanied by integrating their constructive feedback (cycles 1 and 2). A criteria-based evaluation through additional semi-structured interviews (cycle 3) was then applied to scrutinize the attainment of solution objectives, recognizing the imperative role of environment-specific determinants in delineating evaluation criteria for IT artifacts (March & Smith, 1995). Within evaluation cycle 4, we conducted a focus group discussion with blockchain and finance technology experts, sequentially analyzing the overall problematization's adequacy, general architecture, regulatory compliance, and concrete technological implementation (Tremblay et al., 2010). As a result, we were able to concretize our problem statement further with an increased focus on inter-stakeholder communication and collaboration, as well as the potential to reduce respective delays through improved standardization and elimination of market access barriers. Ultimately, we conducted prototype testing in evaluation cycle 5 (ex-post to the general design's validation through semi-structured expert interviews) to demonstrate the technical feasibility of our architecture in a close-to real-world environment. To this objective, the solution developed was deployed on an Ethereum virtual machine and comprehensively tested regarding its effectiveness and efficiency in the DOs.

According to Hevner et al. (2004) and Peffers et al. (2007) primarily, the artifact's *efficacy* (functional completeness and regulatory compliance), *utility* (extent of TAC reduced), and *quality* (of the conceptual and technical implementation) must be evaluated in a rigorous way incorporating existing literature including kernel theories and design knowledge (Heger, 2020). The results of our evaluation, which was performed in multiple cycles as described above, are presented in the following according to the structure and three criteria of Hevner et al. (2004) and Peffers et al. (2007).

Efficacy: Design and architecture of the prototype

Even though our interviewees made minor suggestions regarding our prototype, in principle, all interviewees approved the proposed architecture and the issuance and trading processes. Further, E5 emphasized that within our prototype, only the infrastructure and the asset format have changed, while the underlying financial asset is still the same. E10 emphasizes this in the following comment:

> "[The prototype is] very close to what we are developing with the industry, and from my point of view, it is very close to practical solutions […] and now it is just a matter of really convincing the industry that you really need to implement this in production."

Our interviews show that corporate actions such as coupon payments or redemption should be carried out on-chain to achieve the most significant possible automation and take advantage of blockchain. Therefore, whether to use native coins or stablecoins remains to be discussed. Our interviewees acknowledged the price volatility of cryptocurrencies and advocated solutions such as stablecoins. Stablecoins might be a temporary solution until central bank digital currencies are available, which might be integrated in the future. E10 highlights this:

> "[…] hopefully the ECB comes up with a digital Euro on blockchain at some point, and then it might be possible to map the cash lag in this way. However, we are still building the solutions to pay the cash side entirely with fiat currencies."

Further, our evaluation highlights the necessity of regulatory oversight in a token-based bond market, especially regarding the analysis and auditability of transactions. This also includes KYC processes, whereas our interviewees have considered the proposed whitelisting a suitable solution. With the advent of the crypto asset transfer regulation (Federal Financial Supervisory Authority, 2024), the necessity for the identification of trading parties (sender and receiver) increases.

One of the most important findings regarding the design and architecture of the prototype throughout the evaluation included the decision to perform interest calculations off-chain. As gas limits could be exceeded when deciding for an on-chain design and certain investor thresholds are surpassed, this design decision helped to improve resilience and cost-efficiency.

Utility: Reduction of TAC

Throughout our evaluation stage, all experts highlighted the implications of our prototype, which we classified according to our background in transaction cost theory. Thus, we validated the general capability of our prototype to lower TAC. Even though our evaluation was conducted in a simulated environment, several dimensions emerged in which TAC can be lowered. E9 highlights the fact that lower TAC is imperative to achieve adoption by businesses:

> "The business case simply has to be right, which is why […] the business case works better than a 20-year-old system, which is, of course, also associated with very high costs."

Our bond token system builds upon smart contracts that automate various stages of the bond transactions within our ecosystem, reducing the complexity and time required for settlement. The immutability of blockchain records enhances the integrity of the transactions, mitigating the risk of errors and fraud, further contributing to cost savings. Additionally, the elimination of manual reconciliation processes and the instantaneous updating of distributed ledgers enhance efficiency and minimize the administrative burden associated with traditional bond markets. By leveraging the blockchain's attributes, such as decentralization, transparency, and automation, our prototype may realize lower TAC, fostering a more efficient and cost-effective financial ecosystem.

First, in the dimension of transaction frequency, our prototype holds the potential for a paradigm shift in the financial landscape, offering a viable avenue for mitigating the complexity prevalent in the current financial system. Regarding market structures, our decentralized ledger structure, coupled with the implementation of smart contracts, creates a transparent and automated framework that reduces the intricate layers of intermediation characterizing traditional financial processes. By removing several intermediaries, the prototype facilitates direct peer-to-peer transactions, streamlining the bond issuance and trading processes. E13 explains:

> "[...] So the idea at the end is that you do not have another party in between, so to speak, who then has to put another stamp on it and say we have proof that was just a real transaction, like Clearstream does now."

Further, our results hold considerable promise for alleviating inefficiencies inherent in the existing financial system. Using a distributed ledger architecture, the prototype offers the potential to streamline and automate issuance and trading processes. For example, payment-specific services, paying agents, in particular, can be replaced by blockchain components, resulting in higher efficiencies. By implementing smart contracts, blockchain-based bonds can execute predefined rules autonomously, reducing the need for intermediaries and minimizing the risk of errors or delays in settlement. E10 explains this:

> "The underlying technology can be seen as an infrastructure technology in order to simply create an infrastructure that can be significantly more efficient, allows significantly higher levels of automation, and simply streamlines and accelerates processes, removes complexity, and reduces costs along the value chain, for example in a settlement."

The standardized and programmable nature of smart contracts contributes to a simplified and more predictable set of rules governing bond transactions, mitigating the intricate web of regulations and compliance procedures. However, issuing a standardized bond token via a platform may result in faster settlements, but it comes at the expense of individual financing needs. Another primary concern is scalability, as large transaction volumes lead to high transaction costs on the Ethereum protocol, which inevitably affect the economic determination of minimum denominations. This is of less effect if institutional transfers of specific sizes are considered. On a second layer within the institution, bonds could be offered to retail customers, on the one hand allowing smaller denominations, but on the other hand necessitating a measured compromise, wherein a certain extent of the risk mitigation capabilities intrinsic to the blockchain is inevitably sacrificed.

Regarding the second dimension, our architecture holds promise for reducing asset specificity. Our prototype offers a standardized, transparent framework for representing and exchanging diverse financial assets. By leveraging smart contracts, blockchain-based bonds can be programmed to adhere to predefined rules, allowing for a more flexible and customizable approach to financial instruments. This flexibility, combined with the decentralized nature of blockchain, enables broader market access, reducing the reliance on specific intermediaries and facilitating a more open and inclusive financial ecosystem. The elimination of asset-specific constraints is further augmented by the increased liquidity and accessibility afforded by our bond tokens, potentially mitigating risks associated with asset concentration.

Despite being theoretically tradable worldwide and with no time restrictions, secondary markets are not widely available for bonds, e.g., OTC markets are conceivable for security tokens in Germany. Thus, our blockchain-based approach offers more possibilities to achieve accessibility of secondary markets by enabling direct communication with potential STO platforms or custodians, thereby establishing the foundation for efficient secondary markets, given sufficient trading volume within the ecosystem. E8 explains:

> "So, I think a very, very big aspect is the secondary marketability because that is something that is always pretended with many platforms. They advertise a secondary market, but in the end, it is not a secondary market. I think that is a bit misleading for an investor who thinks, 'I can sell at any time', but you do not have an efficient secondary market."

Ultimately, blockchain-based bonds might also reduce the market entry barriers for investors (e.g., retail customers) and issuers (e.g., SMEs) from an economic and geographic perspective. As a result, certain economic barriers remain, some of which are impossible or difficult for smaller organizations to overcome, leaving them below the market access threshold.

Third, our prototype offers significant improvements from multiple aspects in the dimension uncertainties. Notably, implementing blockchain technology introduces a heightened level of transparency, providing real-time insights and adhering to standards, consequently mitigating settlement risks, which—as explained above—reduces room for opportunistic behavior as a dimension of uncertainty. Through automated and enforced predefined rules, reducing the scope for asymmetric information, our prototype provides a standardized and transparent framework for bond transactions. The prototype ensures that all relevant information pertaining to bond issuance, ownership, and trading is securely recorded and readily accessible to all authorized participants in the network, ensuring the participant's privacy. E12 elaborates:

> "And that then helps to reduce the uncertainty [...], in an ideal context, the uncertainty is actually reduced because there is then a smart contract."

Building upon these advancements, E3 demonstrated that our blockchain prototype possesses the potential for broader attractiveness within the finance sector. Specifically, the meticulous documentation of trades and their corresponding timestamps could facilitate precise asset ownership tracking, thereby averting situations akin to cum-ex deals. Furthermore, the immutability of blockchain records ensures a single, incorruptible source of truth, thereby minimizing the need for reconciliation and reducing operational intricacies. Contrary to a CSD, which holds custody of securities certificates, tokenized bonds can be registered within a CSR. As the CSR is stored on the Ethereum protocol, documentation and data immutability within a block is ensured while protecting against later modifications through access restrictions. The blockchain's decentralized consensus mechanism expedites and fortifies the exchange of information, fostering accelerated decision-making processes and heightened operational efficacy. Furthermore, the pertinence of blockchain technology is particularly pronounced in the realm of substantial post-trade savings, notably in the processing of securities trades within centralized systems encompassing CSDs, custodians, and depository banks, all integral components of the comprehensive custody chain. Our interviewees further highlighted that a platform's core functionality is attractive for retail investors and organizations who issue bond tokens. Thus, a platform should perform an advisory function to inform investors of opportunities and risks, as technological and financial expertise remains scarce. Moreover, leveraging blockchain could streamline tax calculations and facilitate automatic payments to the tax office, showcasing the technology's multifaceted utility. In essence, the integration of blockchain technology emerges as a pivotal tool for furnishing accurate data for accounting purposes, exemplifying its transformative impact on financial processes and regulatory compliance. Further, our interviewees addressed concerns about the reliance on additional intermediaries, such as custodians, by market participants, including retail investors, who seek secure safekeeping of their private keys. E10 highlights this in the following:

> "[The blockchain-based bond market design] works like a traditional one but has slightly lower costs for the investor. The [retail] end customer would rather trade this product through their existing online banking broker without realizing it is a tokenized product. […] Thus, [a broker] has to offer a wallet for each customer on the basis of existing accounts, […] and act as a custodian."

Even though uncertainties can generally be reduced, custodians are likely to raise TAC for retail investors. Thus, the final effect on TAC in this particular regard remains unclear.

Our evaluation shows that our prototype allows for the reduction of TAC by replacing institutional intermediaries with blockchain-based infrastructure. By leveraging the technology's potential, we find the capability of our prototype to reduce TAC within the dimensions of transaction frequency, asset specificity, and uncertainty.

Some of the most valuable insights gained throughout our evaluation concerning the dimension of utility included the implementation of the (multi-) token standard ERC-1155 instead of ERC-20. More precisely, the ERC-1155 standard allows managing multiple token types within a single smart contract, offering greater efficiency and flexibility than ERC-20. Batch transfers and optimized storage management reduce gas costs and make transactions more efficient, in consequence. Due to the broad applicability of this improvement, regardless of this work's context, we further developed and presented it as a design principle in the subsequent section.

Quality: Functional testing

After the DOs were demonstrated to be adequately implemented and the potentials for TAC reductions elaborated, no explicit discourse has hitherto been presented regarding the technical instantiation beyond the insights gleaned from expert interviews. In adherence to established software development practices, the functionality of such software artifacts necessitates rigorous testing (Pries-Heje Baskerville Venable, 2008).

In the context of our study, smart contracts underwent meticulous testing throughout their developmental phases, involving compilation, migration, and deployment, with each function subjected to several executions through various test cases. The technical evaluation emphasized specific facets, including permissions, wherein access restrictions were rigorously examined by testing modifiers assigned to different roles within the smart contract. Additionally, functions containing required statements underwent execution and verification. The evaluation encompassed scrutiny of inputs and outputs, ensuring correctness in terms of data types and parameter quantities. Further, the assessment was extended to its functional design, wherein functions were executed to ascertain their alignment with the intended objectives. This involved defining assert and return values, allowing for a meticulous comparison with actual outcomes. Notably, this comprehensive testing encompassed checks related to data assignment to variables and modifications within data structures such as balances. The thorough exploration of these technical intricacies augments the credibility and reliability of the blockchain-based bond market prototype's functional robustness.

Some of the most important findings throughout the evaluation relating to the dimension of quality concerned the data protection-compliant implementation of crypto securities registers. In particular, the efficient implementation of encryption and decryption methods could be significantly improved with the help of the insights gained. Also, the evaluation disclosed a misconception of how it is determined whether individual or group entries are made. While the investor defined this information in the first version of the prototype, we changed this role to the issuer, since the investor already indicates whether he is a private investor or a company when registering. As a result, the investor no longer has to provide additional information for transactions.

Summary of the evaluation

This section described both the method and results of the evaluation conducted. The evaluation was carried out in several cycles along the standard criteria of efficacy, utility, and quality, according to Hevner et al. (2004) and Peffers et al. (2007). As a result, the design and architecture of the prototype in its final version as well as its added value in reducing TAC were confirmed. In addition, the quality of the implementation was validated. However, the evaluation results along the way to the final prototype were not only confirmatory but highlighted some problems and areas for improvement, too. Particularly relevant examples of this were shown, and their effects on the artifact design and development were described.

Design principles

To transcend the confines of mere practical utility, we developed emergent DPs for a blockchain-based bond market design. This theoretical endeavor aimed at contributing to the abstract and generalizable design knowledge discourse, aligning with the scholarly perspectives advocated by Gregor and Hevner (2013). The underpinning logic of DPs resides in their inherent capacity to facilitate subsequent researchers in the seamless creation of artifacts within a shared domain (Gregor et al., 2020). We formulate and present our DPs following the suggestions of Gregor et al. (2020).

To strengthen the transparency of the underlying DP development process and provide a structured overview of our results, Fig. 6 illustrates the relationship between the MRs, DOs, and DPs. In this regard, basic meta requirements mark the beginning of the process, from which concrete design objectives are derived and practical and transferable DPs are developed for each design objective, as proposed by Giessmann and Legner (2016). In addition to the relationship between MRs, DOs, and DPs, it can be observed that our DPs aim at different implementation levels. While DP 1 recommends an appropriate architectural structure, DP 2 explains how synergies of multi-token standards can be exploited in more detail. The subsequent DPs 3–5 then describe how specific functionalities and components can be implemented as effectively and efficiently as possible in line with the corresponding regulations like MiCAR and eWpG.

Design Principle 1: Apply modular design of distinctive system components

Addressing the complexity and functional nuances of specific systems, practical deployment on the Ethereum blockchain faces challenges, particularly due to the protocol's

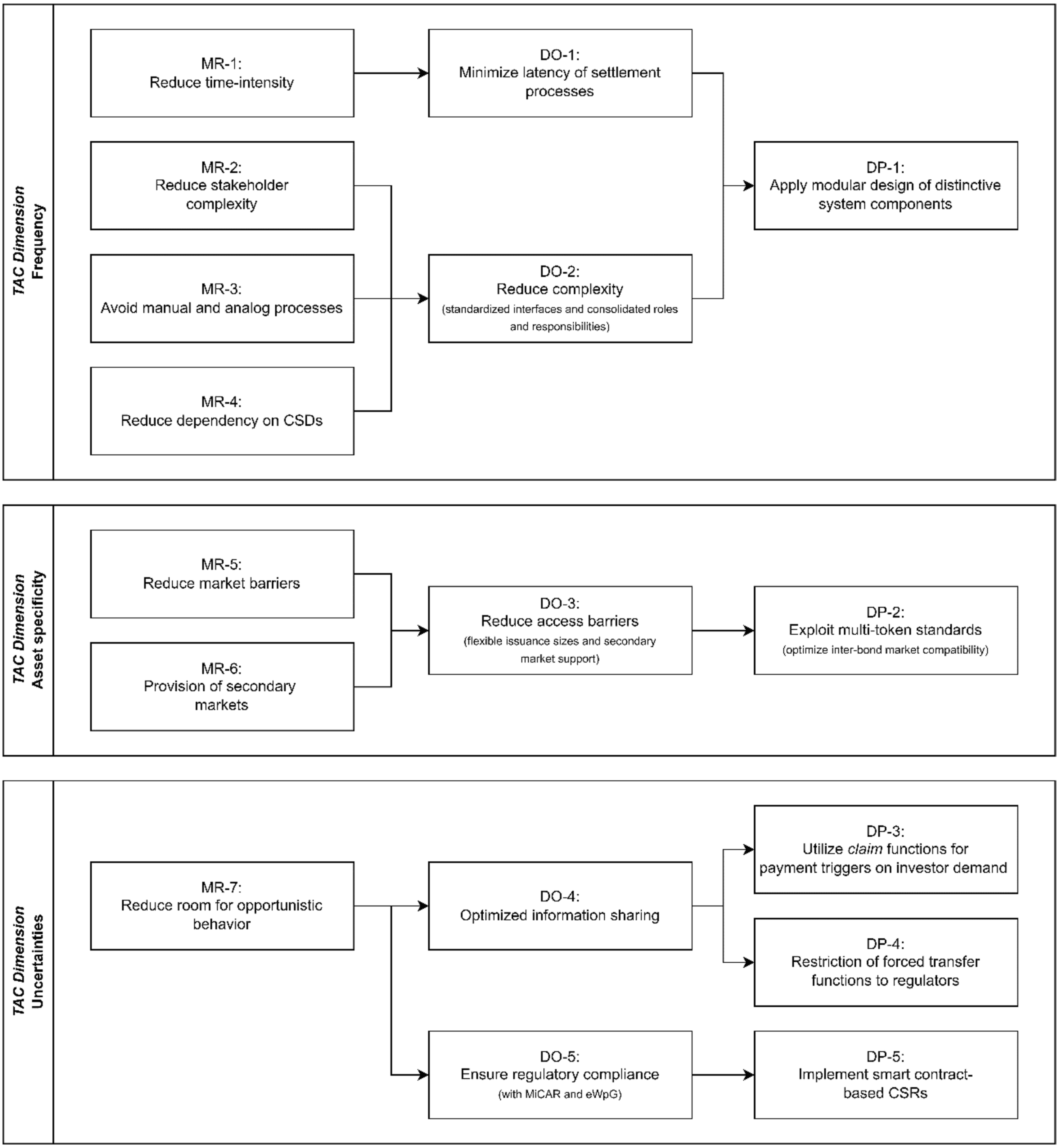

Fig. 6 Classification of meta requirements, design objectives, and design principles. Own illustration based on Giessmann and Legner (2016)

maximum contract size limit of 24 KB. This limit requires modularly structuring complex systems, such as bond market models, to ensure efficient and secure implementation. A modular approach is essential for projects that aim to develop large-scale token systems that exceed Ethereum's contract size limits. This involves dividing the system into distinct elements, each deployed as a separate contract. These contracts are then seamlessly interconnected through externally accessible functions, allowing the construction of a cohesive system within the Ethereum framework despite its contract size limitations. When designing these modular systems, it is critical to use modifiers and specify specific sender functions to protect individual components from unauthorized access via delegated function calls.

Design Principle 2: Exploit multi-token standards

The deployed ERC-1155 token standard allows the issuance of multiple token systems of fungible and non-fungible tokens. When STO platforms aim to issue multiple different security tokens deployed within the Ethereum protocol and share a minimum set of comparable characteristics, multi-token standards should be used. Given that smart contract deployment is one of the most resource-intensive operations in the Ethereum network, using multi-token standards offers significant advantages. It eliminates the need for multiple deployments of similar functionality across different contracts, thereby conserving blockchain storage and simplifying system architecture**.**

Design Principle 3: Automated on-chain payout mechanisms for investors

The integration of on-chain settlement mechanisms significantly enhances investor confidence by addressing common issues of opacity and the potential for manipulative practices by issuers or platforms. Such practices can include manipulating the timing of interest payments, changing calculation methodologies, or inequitably allocating technical transaction costs, such as gas fees, to investors. To mitigate these risks, the use of claims capabilities in disbursement processes is recommended. These features empower investors by allowing them to precisely monitor and control the timing and method of their interest payments, eliminating the need to rely on the trustworthiness of the platform or issuers with respect to off-chain actions.

Design Principle 4: Restriction of forced transfer functions to regulators

Although the use of the developed blockchain-based solution can eliminate or replace many sources of complexity and manual as well as analog processes, it also creates a significant risk and, thus, uncertainty that central actors may abuse their power. Therefore, particularly critical functions such as forced transfers, through which the transfer of values without explicit approval by issuers or investors can be performed, should be restricted to regulators only. Only in this way can a high and indispensable level of trust in the solution among all stakeholders be ensured while complying with corresponding regulatory requirements.

Design Principle 5: Implement smart contract-based CSRs

The introduction of the eWpG allows the issuing of bearer bonds as security tokens completely detached from physical, paper-based security certificates or global notes. Therefore, this design principle aims at STO platforms that intend to use CSR. If a company wants to issue an entirely digitally tokenized bearer bond capable of applying the eWpG while specialized entities that can fulfill the role of a register-keeping authority are present, a crypto securities register should be implemented within a smart contract. Registering a bearer bond within a CSR disrupts the traditional custodian chain, thus fastening settlement speed, as the transfer of ownership can be processed automatically.

Discussion

Based on our findings from our DSR process, incorporating a TAC theory perspective, we can contribute to research on specific applications concerning debt tokens in general and bond tokens in particular. We contribute to literature in the following ways.

First, our findings provide novel design knowledge on blockchain-based bonds. However, to the best of our knowledge, no generic design knowledge on blockchain-based bonds exists. We thereby complement existing work on the tokenization of other asset groups, such as equity tokens (Guggenberger et al., 2023) and green bond markets (Axelsen et al., 2023). While we confirm existing design knowledge, such as the recommendation to exploit multi-token standards (DP 2), we derive novel design recommendations from our use-case, such as the utilization of claim functions for payment triggers (DP 3). Our research reifies higher-level concepts of blockchain-based bonds by Chen and Wang (2020), Kölbel et al. (2022), and Pana and Gangal (2021). While we reveal the promising efficiency gains offered by a CSR, our research highlights the central role of the STO platform, which includes several functions from previously separated intermediaries. This confirms research on the effect of blockchain market infrastructure on intermediation by Feulner et al. (2022).

Second, we contribute innovative insights to the body of blockchain technology research by applying TAC as a specific theoretical framework. Our investigation underscores a notable departure from conventional bonds, predominantly traded through OTC markets, as bond tokens exhibit the capacity for multi-market trading (Chen and Wang, 2020). This interconnectedness emanates from their reliance on a shared foundational infrastructure and database, mitigating the asset specificity inherent in bond tokens and consequently reducing transaction costs within the market. Simultaneously, our prototype implementation facilitates expeditious transactions while concurrently diminishing counterparty risks, following the suggestions of Axelsen et al. (2023). This risk mitigation is achieved by incorporating predefined post-trade actions within the smart contract, thereby automating relevant processes specific to corporate bonds. Consequently, a substantial proportion of the extensive financial resources expended in the post-trade processing domain, amounting to billions of dollars (Edwards et al., 2007), can be circumvented. Our research underscores the indispensability of such efficiency enhancements for successfully instantiating blockchain technology. It elucidates that, to establish a compelling business case, each application scenario for novel technologies (e.g., blockchain) must ultimately yield a net positive business case.

Finally, we extend the body of knowledge by providing novel design knowledge on implementing blockchain protocols for different use cases. Our prototype demonstrates the feasibility of a blockchain-based infrastructure for corporate bonds, as Pana and Gangal (2021) suggested. In addition, our research extends the body of knowledge as to the best of our knowledge, our approach is one of the first to applying the kernel theory of TAC as a theoretical lens throughout our design science research approach.

Implications

Our results further provide implications for practitioners. To facilitate the dissemination of our results in practice, we published our fully functional open-source prototype on a GitHub repository. Thereby, we provide a comprehensive documentation enabling stakeholders to deploy the artifact and adapt it for their applications. In addition, we published practitioner-focused results in respective outlets, such as the online blog platform Medium.[3] The aforementioned dissemination practices expedite the communication of the following practical implications.

First, we provide a starting point for practitioners by proposing a generic blockchain-based bond solution with the aim to reduce TAC. The digitization of the bond issuance process is only made possible by implementing a modified crypto securities register based on the eWpG. As the entire custodian chain can be bypassed, the system largely operates without intermediaries except for a few process participants. Nevertheless, the system does not entirely work without intermediaries, as the coupon calculation process is to take place off-chain in order to reduce the complexity of this particular corporate action. Managers of current market intermediaries could make use of this finding to engage in a more nuanced discussion about potential benefits of such blockchain-based markets for their companies in the future and explore future market positions (Fridgen et al., 2021).

Second, we provide insights into different areas of consideration for reducing transaction costs and, thus, subsequently achieving a positive business case for a potential STO platform. As highlighted in the evaluation of the artifact, companies shift their focus from exploration of potential blockchain use cases, towards the exploitation of use cases with a potentially net positive business case. Hence, managers might use our TAC perspective to evaluate their current use cases and identify potential action fields to further decrease operational expenditure.

Third, our findings on the exploitation of multi-token standards could guide further work on efficient financial markets beyond the limitation on corporate bonds. We therefore collaborated with a publicly funded research project focused on the tokenization of financial products and markets. The interdisciplinary consortium, with diverse backgrounds in economics and law, derived possible economic, social, and legal consequences of tokenization based on our study. Additionally, the design principles derived from our work laid the groundwork for a holistic and interdisciplinary understanding of asset tokenization.

Fourth, regulators from other jurisdictions might use our results to gain insights on how to transfer the regulatory regime in Germany to their territory. Thereby, regulators could use our architecture to foresee potential market structures and stakeholders. This could help to identify necessary measures and regulatory boundaries to achieve the respective policy objectives.

Limitations and future research

Our findings are subject to limitations. First, our artifact was only tested at the proof-of-concept level. We conducted our technical evaluation on the virtual test network Remix development IDE. Although Remix contains virtual test networks, it does not represent the real Ethereum main network. For this reason, simulation findings may vary in terms of transaction efficiency and actual costs. Still, our prototype provides a starting point to evaluate blockchain-based systems from a TAC perspective. Second, our evaluation cannot give a definitive answer on whether private or public networks should be utilized, as transaction costs and scalability were among the most significant concerns. In this context, scalability refers to both the protocol and application layer within the smart contracts. As transaction throughput within the Ethereum protocol differs significantly compared to centralized systems, possible congestion needs to be considered when deploying our artifact into practice. Nevertheless, future technological advancements in blockchain protocols (e.g., sharding) might mitigate these limitations.

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[3] A series of articles regarding this research project from a more practical perspective can be accessed under the following link: https://medium.com/@davidcisar.

Conclusion

In conclusion, despite the democratization of financial access facilitated by our prototype, its operationalization remains contingent upon intermediaries and their requisite services, notably those offered by STO platforms. This dependence is predicated not only on the presumption that essential technical expertise and temporal resources may be lacking outside the core business domain but also on compliance with regulatory prerequisites for issuing tokenized bonds. Although this reliance poses a notable bottleneck, it is noteworthy that concurrent efficiencies can be harnessed by consolidating multiple issuances within a singular contract, thereby effecting a reduction in individual fixed unit costs per placement. Consequently, STO platforms orchestrating numerous issuances possess the potential to ameliorate the limitations above.

Our findings affirm that the prototype's issuance mechanism significantly diminishes TAC. However, it is imperative to acknowledge these costs as inherent barriers that, given the current Ethereum-based prototype design's associated expenditures, remain impervious to subversion. These costs, while formidable, must be considered within the broader context of the prototype's overall efficacy and contribution to the field of information systems, recognizing that advancements in technology and regulatory frameworks may eventually alleviate these inherent limitations.

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