Design Principles for Blockchain-based Applications in Green Bond Reporting

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Abstract

Emerging sustainable capital markets are crucial in reaching global climate goals. These markets' credibility depends on the trustworthiness of data used to report the green impact of projects financed by sustainable financial instruments such as green bonds. To ensure credibility and thereby support these types of markets, the information systems field has the potential to create designs that leverage emerging technologies (in our case, blockchain) for green bond reporting. In this paper, we employ a design science research method to derive a set of design principles. These design principles discuss the most relevant blockchain concepts and reflect the characteristics of today's green bond process. Through an artificial evaluation and demonstration of the design principles, we report on how to make informed design decisions to develop blockchain applications for green bond reporting. These findings are also significant for practitioners to develop new services or re-design current processes.

Keywords: Blockchain, green bond reporting, design science.

1. Introduction

The Paris Climate Agreement has set a goal of limiting the global temperature increase in this century below 2 degrees Celsius compared to pre-industrial levels. As such, calls for climate action are intensifying and becoming increasingly important for individuals, organizations, and governments (Dale et al., 2019; Johannsdottir & McInerney, 2016). Among various initiatives, sustainable finance is promoted as a way to encourage and facilitate financial instruments—such as green bonds—that fund projects with a positive environmental impact (Scholtens, 2006; Waring & Edwards, 2008). Green bonds, which offer "a mechanism to assist in financing the costs of transitioning to a zero-emissions economy" (Freeburn & Ramsay, 2020, p. 419), are predicted to exceed $1 trillion in green bond market issuance by 2023 (Fatin, 2021).

However, the increasing demand in the green bond market poses challenges. Investors, bond issuers, and organizations face uncertainties regarding green bonds' reporting metrics and transparency (Doran & Tanner, 2019). Although several frameworks aim to counteract these concerns by providing guidelines for the reporting process and for allocating proceeds (e.g., the Climate Bond Standard and the Green Bond Principles), using frameworks remains voluntary (Climate Bonds Standard, 2021; ICMA, 2021). Thus, with no universal standard with which issuers must comply, proving a bond's green impact might open the path for organizations to engage in greenwashing behavior (Flammer, 2021). There are several well-known cases where the investments' proceeds were not used as suggested, illustrating greenwashing, such as the Mexico Airport and Repsol (Doran & Tanner, 2019; Krebbers, 2019); these circumstances call for new technological solutions to increase transparency and facilitate the reporting process in the context of green bonds.

One well-recognized technology that holds the promise of transparency is blockchain—a type of distributed ledger technology that records transactions using cryptographic hashing (Iansiti & Lakhani, 2017; Nakamoto, 2008; Tönnissen & Teuteberg, 2020). Some of this technology's defining characteristics are immutability and the decentralization of the network, which allow for transparency, traceability, and auditability of the transaction record. These properties can also facilitate the increased transparency of the reporting process for green bonds (Bhutta et al., 2022; Dorfleitner and Braun, 2019). Thus, blockchain solutions may allow investors to view real-time data, cut overall bond issuance costs, and open the green

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bond market to a more extensive investor base (HSBC & Sustainable Digital Finance Alliance, 2019). This technology is not yet mainstream, and many use cases outside the cryptocurrency domain have remained in perpetual piloting stages (HSBC & Sustainable Digital Finance Alliance, 2019). In general, knowledge is limited on when, how, and what blockchain to use (Belotti et al., 2019). Given the need for increased transparency in green bond reporting and the potential of blockchain to provide that, this study aims to establish a set of design principles for a specific class of information systems (systems for sustainability reporting) to guide the development of blockchain-based applications for green bond reporting. We define sustainability reporting systems as information systems that support green impact reporting activities.

This paper is structured as follows. We first discuss the paper's background. We then describe the method we used in this study. Then, we present our initial design principles, followed by an evaluation and demonstration. Finally, we conclude with implications for research and practice.

2. Background

In 2007, the European Investment Bank (EIB) issued the first green bond as a climate awareness bond. Green bonds are fixed-income securities issued to raise capital in support of climate and environmentally friendly projects (Bhutta et al., 2021; Flammer, 2021), such as renewable energy or clean transport.

The GBP defines a green bond as, "any type of bond instrument where the proceeds will be exclusively applied to finance or refinance, in part or in full, new and/or existing eligible green projects and which are aligned with the four core components of the GBP" (ICMA, 2021, p. 3). These four components provide guidance detailing the use of proceeds, the process for project evaluation and selection, managing proceeds, and reporting (Migliorelli, 2021). Further, the GBP suggests that a minimum of one external reviewer should confirm the alignment between the green bond and the four components. This review can be a second party opinion, verifications, certifications, and green bond ratings (ICMA, 2021). The second opinion is conducted to establish that the proceeds from the green bond are used according to the stated environmental purpose (Freeburn & Ramsey, 2020). This enhances the green bonds' validity because they are not governmentally regulated. However, the green bond standards and frameworks are voluntary within the green bond market (Berrone et al., 2017; Dorfleitner et al., 2022; Flammer, 2021; Freeburn & Ramsey, 2020). Green bond standards and frameworks are voluntary, which may increase the risk of greenwashing within the green bond market (Berrone et al., 2017; Dorfleitner et al., 2022; Flammer, 2021; Freeburn & Ramsey, 2020)

2.1 What is blockchain?

A blockchain is a distributed ledger composed of blocks that contain cryptographic hashes and time stamps linked to each other, enabling peer-to-peer communication without intermediaries (Aste et al., 2017; Beck et al., 2018). With each transaction, the blockchain is extended by an additional block, thus representing a complete ledger of the transaction history (Nofer et al., 2017). This entire history is auditable (Yu et al., 2019). One of blockchain's key characteristics is a decentralized network structure made possible by peer-to-peer infrastructure and a consensus mechanism. Data stored in a decentralized manner are immutable and cannot be censored or taken down (Seebacher & Schüritz, 2017), which thereby increases user confidence that the stored information is not tampered with (Beck et al., 2018). Indeed, blockchain's immutability and decentralized structure have an additive effect on technical trust. The transparency that blockchain provides "alienates behaviors" (dal Mas et al., 2020, p. 1614), and because every transaction is recorded, actors avoid malicious behaviors, in turn leading to decreased fraud (Roriz & Pereira, 2019; Xu, 2016).

Blockchain has been suggested for applications regarding information storage, such as recording transaction details, storing credit records, and verifying payments (Ali et al., 2021). Several usage domains are possible, including healthcare, the energy industry, the stock market, voting, insurance, and identity management (Monrat et al. 2019). Blockchain is also potentially relevant for international financial institutions, including making green bonds more accessible to small issuers, creating a traceable trail of money flow, and allowing for real-time communication between investors and issuers on a dedicated blockchain node (Davradakis & Santon, 2019). Yet, implementing blockchain within green finance has faced challenges primarily because of a lack of standardization and development of definitions and frameworks in this particular area (Dorfleitner & Braun 2019).

Research has identified two main categories of blockchain, which differ in how participants join the blockchain network: permissionless and permissioned. (Miller, 2019). A permissionless blockchain, illustrated by the first blockchain, Bitcoin, is "shared by all network nodes, updated by miners, monitored by everyone, and owned and controlled by no one" (Swan, 2015, p. 1). Private keys are used to sign transactions (Carson et al., 2020). While a permissionless blockchain is open and transparent (Helliar et al., 2020), the speed of transactions and scalability can create challenges for permissionless blockchains (Liu et al., 2019). In contrast, permissioned blockchains depend on some external selection process to gain access (Miller, 2019, p. 194), most often involving a trust party or a consortium of organizations. In this case, vetted entities verify transactions, as opposed to random, anonymous miners (Helliar et al., 2020). Many of the permissioned blockchain applications are in the financial sector—for example, JP Morgan's settlement service with 200 banks (Grover et al. 2019). A high level of access control and the ability to comply with an organization's other goals (such as financial regulators) have made permissioned blockchains a suitable choice for many organizations.

2.2 Blockchain design

Different published taxonomies highlight infrastructural aspects of blockchain technology (Ballandies et al., 2021; Spychiger et al., 2021; Tasca & Tessone, 2019). Below, we delve into some blockchain infrastructure's core components and governance for this particular system (Pelt et al., 2021). See also Table 1 (below).

Blockchain Type: Blockchains can be grouped into four types: public, private, consortium, and hybrid. A public blockchain infrastructure allows anyone to join the network without permission (Mik, 2017; Morkunas et al., 2019). In contrast, in a private blockchain, only authorized users can participate in the blockchain network (Dutta & Saini 2021). A consortium blockchain is a specific type of private blockchain (Schaffers, 2018). Consortiums may consist of individual users or organizations. Still, the focus on consortiums is more on off-chain governance than it is on mechanism design or incentive schemes (such as monetary gains for joining or maintaining the network) (Miscione et al., 2019). Consortium agreements form the basis for governance (Schaffers, 2018). The fourth kind of blockchain, a hybrid blockchain, is most commonly controlled by one organization (Wang & Wegerzyn, 2021) using a custom architecture that combines some of the benefits of both public and private blockchains (Desai et al., 2019; Wu et al., 2017).

Consensus Mechanism: The underlying idea of consensus mechanisms is, "performing frequently secure updates [of the state] on the distributed ledger" (Lashkari & Musilek 2021, p. 43624). This is a key requirement for any blockchain network (Nguyen et al., 2019). Today, the most common consensus mechanisms are proof-of-work (PoW) and proof-of-stake (PoS). In PoW, the nodes achieve consensus by competing in a solution-searching process (Nguyen et al., 2019), where the rewards are directly proportional to the computing effort. Being energy intensive, this mechanism draws heavy criticism regarding its environmental friendliness. For example, Bitcoin relies on securing enough computing power (and consequently energy) to secure the chain's integrity (Schinckus, 2021; Vranken, 2017; Nakamoto, 2008). In more detail, mining relies on a process where the miners solve cryptographical puzzles that are made arbitrarily complex (the difficulty of the puzzle depends on the aggregate computing input to the system)—this, in turn, guarantees that enough computing is continuously invested in protecting the chain from a 51% attack (Nakamoto; 2008). In PoS, a verifier is randomly selected to create a block. To become a verifier, a node needs to lock or stake tokens. The larger and older the tokens are, the greater the chance of being chosen (Nguyen et al., 2019). PoW and PoS are mainly used in public permissionless blockchains, and proof-of-authority (PoA) is the underlying consensus mechanism for permissioned blockchains. In PoA, the reputation of the known validator plays the role of stake. It is a consensus method in which several vetted participants validate activities such as transactions and interactions on the network (Lashkari & Musilek, 2021).

Smart Contracts: Smart contracts are programmable contracts implemented on top of blockchains that activate once the conditions are met, thus "[e]nabling the deployment and execution of contract agreements via programming logics" (Chang et al., 2019, p. 2). Smart contracts may also be used to manage access controls (Zheng et al., 2020). Because blockchain is decentralized and immutable, it makes smart contracts a safe way to interact between parties without needing third parties, thus reducing transaction costs (Cong, 2018; Swan, 2015; Zheng et al., 2020).

Incentives: Incentives are central to IS design and they motivate agents to act (Ba et al., 2001). They can vary from direct monetary rewards (e.g., in Bitcoin) for the continuous engagement of Bitcoin users (Nakamoto; 2008) to non-monetary incentives (Yu et al., 2018).

Decision-making: There are two types of decision-making in the blockchain: on-chain and off-chain (Reijers et al., 2018). In on-chain decision-making, the stakeholders communicate through the blockchain protocol. In particular, on-chain governance "refers to rules and decision-making processes encoded directly into the underlying infrastructure of a blockchain-based system" (Reijers et al., 2018, p. 822). In contrast, off-chain decision-making refers to the internal and external rules—everything that happens outside of the encoded rules of the system (Reijers et al., 2018).

Roles: Roles are an essential part of governance. Roles are hierarchically defined structures that allow different actors capacities to perform specific actions on a blockchain (Liu et al., 2021). According to pre-defined governance, some roles could, for example, only have read rights, while other roles could have read and edit rights (Alketbi et al., 2020). It is also equally important to appoint specific authorities (via a consensus mechanism) who validate and build new blocks (Allen & Berg, 2020).

Domain	Concept	Component
Infrastructure	Blockchain types Consensus mechanism Smart Contracts	private, public, consortium, hybrid, permissioned, permissionless, consensus models, proof-of-work, proof-of-stake, proof-of-authority, smart contracts
Governance	Incentives Decision-Making Roles	roles, distribution of roles, rules, enforcement, regulation control mechanism, decision rights, incentive, nature of incentive, on-chain/off-chain, participation in decision-making, communication

Table 1. Fundamental concepts of our Blockchain design

3. Design Science Research Approach

This study's main goal is to develop a set of design principles for blockchain-based applications that support green bond reporting. We adopt the Design Science Research Methodology (DSRM) (Peffers et al., 2007). According to DSRM, six activities are conducted in creating an artifact, which can take the form of a "construct, model, method or instantiation" (Peffers et al., 2007, p. 55).

In the problem identification phase, we relied on ten expert interviews and the blockchain literature to explore the problem space in green bond reporting (for a complete list of respondents, see Table 2). All interviews conducted were semi-structured interviews (Harrell & Bradley, 2009). The literature review informed our interview guide. Aiming to obtain an overarching overview of green bonds, we selected interviewees with different experiences of and perspectives to the topic (Etikan, Musa, & Sunusi, 2016). The interviewees were identified on their organizations' websites as well as on the social media website LinkedIn. We used search terms, such as green bonds, sustainable finance, green finance, and sustainable finance analyst, to identify the respondents. Respondents were scattered around the Nordics, so we conducted interviews via video call using either Microsoft Teams or Zoom.

In the second phase, we defined the objective criteria for the artifact (Peffers et al., 2007). The artifact's objective was to assist practitioners in making informed design decisions regarding blockchain applications for green bond reporting.

Third, we presented a description of the design's first iteration and development activity. Here, we developed the first design principles based on the findings from the problem identification phase coupled with blockchain literature.

Fourth, we provided details regarding the artifact's evaluation. The evaluation was conducted through a semi-structured artificial ex-ante evaluation (two evaluation interviews). To assess whether the objective and criteria for the artifact were accomplished, we established three evaluation criteria (Prat et al., 2015): (1) understandability (i.e., the degree to which the design principles can be comprehended), (2) operational feasibility (i.e., the degree to which stakeholders will support the proposed design principles and use them), and (3) usefulness (i.e., the degree to which the design principles positively impact task performance).

Fifth, we explained the second iteration of design and development. During this second iteration, we redesigned the design principles of the first blockchain based on the feedback from artificial ex-ante evaluation interviews with the two blockchain experts. Iterating back to the design and development activity is a standard procedure to improve the artifact's accuracy and effectiveness (Peffers et al., 2007).

Finally, to demonstrate that the objective and criteria of the artifact were achieved (Peffers et al., 2007), we conducted an artificial ex-post evaluation through a demonstration interview (Venable et al., 2012). We ran the demonstration in an artificial setting and aimed to reflect how the criteria were met. The interview was conducted with a Nordic organization developing a green loan application for homeowners with a blockchain backend. Blockchain was used in the application to increase trust in green loans and to trace the money flow. The blockchain design principles are retrospectively demonstrated. The demonstration aims to reflect the following criteria: (1) the design principles should reflect the prerequisites and needs of the different stakeholders in green bonds, (2) the design principles should capture the most relevant blockchain concepts, (3) the design principles should be comprehensible to practitioners who aim to create a blockchain-based application for green bonds, and (4) the design principles should positively aid the development of a blockchain-based application for green bonds.

Consensus Mechanism: The underlying idea of consensus mechanisms is, "performing frequently secure updates [of the state] on the distributed ledger" (Lashkari & Musilek 2021, p. 43624). This privacy guarantees). We suggest a consortium blockchain because it is partially decentralized, the roles are defined, and the users are known (Miscione et al., 2019; Schaffers, 2018). To ensure a level of assurance among the participants, there needs to be some kind of gatekeeping to participate in the network. Our respondents discussed several ways this could be done. Our first design principle (DP) for blockchain type is: *DP1: Use a consortium blockchain.*

#	**Current position**	**Organization**	**Experience**
1	Investment banker	Nordic bank	1 yr
2	Sustainability analyst	Nordic bank	1yr
3	Business developer	Government funding agency	9 yrs
4	Sustainability analyst	Nordic investment company	2 yrs
5	Head of Sustainability	Export credit agency	11 yrs
6	Director, Funding and Investor Relations	International finance institution	10 yrs
7	Director	International finance institution	3 yrs
8	Analyst	Second opinion provider	2 yrs
9	Head of Corporate Bonds Listing	Market exchange	6 yrs
10	Sustainability analyst	Nordic bank	2 yrs

Table 2. Table of interviews

4. Design Principles for Green Bond Reporting

We identified a consortium blockchain to be the most suitable blockchain type for green bond reporting based on the literature review and initial round of interviews. This design allows specific access to different users and complies with the legal and regulative requirements (public information and privacy guarantees).

Consortium blockchains are a good match for PoA consensus mechanisms because participants are known and vetted. The PoA consensus mechanism seems to be a logical choice. In PoA, the validator's reputation is used to approve different transactions (Lashkari & Musilek, 2021). As the reputation of the second opinion provider plays a crucial role in validating the green bond framework today, replicating this through PoA is suitable. Additionally, from the permissionless side, the PoW consensus mechanism form has been widely criticized for high energy consumption to solve cryptographic equations (Schinckus, 2021; Vranken, 2017), which would not fit the usage in this domain.

Choosing a suitable blockchain consensus mechanism is harder compared to implementing ready consensus mechanisms such as PoA into the system. Hence, this design principle is valuable because it compares some of the most common consensus mechanisms to help guide practitioners. Because trusted parties decide on the selected authorities, there should be no governance-related issues. The design principle for the consensus mechanism is as follows: *DP2: The proof-of-authority consensus mechanism is suitable due to some level of trust already existing.*

Smart contracts can be used to ensure that only certain parties can upload and sign documents. This allows for a more controlled, digitally enabled environment where each role has clear access rights. Smart contracts are beneficial because they are designed to be shared, meaning they will not inflict issues for other participants active on the blockchain (Berdik et al., 2021). The respondents were already thinking of methods to digitize and process information: *"I think there needs to be some flexibility but still standardized and digitized so that you can work with the data in a machine-readable format"* (Interviewee 9). The design principle for smart contracts is as follows: *DP3: Smart contracts can validate that an authorized party uploaded and signed the file.*

Incentives are core to blockchain to ensure activity. Yet, initiating a blockchain consortium implies that interested actors already have incentives to participate. Direct monetary incentives are not favored in green investments. As one respondent stated: *"There are no price incentives for the investors, but what you will do as an investor is (...) invest with an impact. So, there is a normal return plus the impact you do by investing in a green bond where we then promise to steer your money into something that is sustainable"* (Interviewee 6).

In contrast, nonmonetary incentives can ensure that the different stakeholders act according to the guidelines the consortium sets. Incentives such as reputation scores will also contribute to the actors' trustworthiness (Huang et al., 2021; Yu et al., 2018). Similarly, the blockchain cements reputation to the outside world regarding confidence in the green impact and allocation of proceeds. The design principle for incentives is as follows: *DP4: Design for reputation rather than monetary incentives.*

Considering that the financial sector is more conservative, we propose that the status quo decision-making process remains unchanged and takes place off-chain. As one of the respondents described: *"we [the issuers] kind of control the process all the way through because it is our transaction, so we have to make sure that we are in control and on top of things"* (Interviewee 6). Still, smart contracts facilitate the decisions that stakeholders take that can be digitized and digitalized (Reijers et al., 2018). Nonetheless, introducing real-time data could be seen as a new medium of communication that would allow investors to access their data at their convenience and track green projects rather than relying solely on the annual reports companies publish. The design principle for decision-making is as follows: *DP5: Off-chain decisions different stakeholders take remain in their current format. On-chain decisions are facilitated through smart contracts.*

Decentralization is central to the blockchain. However, this might not be entirely feasible in a green bond reporting application because the three most involved stakeholders have clearly defined roles and responsibilities (Schaffers, 2018). First, the issuer exerts the most control over the green bond process, considering they oversee the issuance process and bring together the different stakeholders. We foresee two additional stakeholders in this use case—validators and investors. The validator's role is to verify that the frameworks comply with the Green Bond Principles set by the ICMA and align with the EU Taxonomy or other approved standard. Finally, the investor can access different frameworks and consequent sustainability and allocation reports in one tamper-proof, immutable, and auditable source. One of our respondents stated: *"I would say that the three most involved stakeholders in the full green bond process are the issuer, those who are in charge of building the green bond; the investors, who seek to finance projects with an environmentally friendly impact; and of course, the second opinion provider who establishes that the framework used to assess the greenness of a bond is correct"* (Interviewee 2). The design principle for roles is as follows: *DP6: The issuer, second opinion provider, and investor are identified as different roles with different privilege rights, such as access and editing rights and building and approving blocks.*

5. Demonstration and Evaluation of DPs

We used the input from the two artificial ex-ante interviews of blockchain experts to improve the first version of the blockchain design principles. Overall, the results demonstrate good understandability of the initial blockchain design principles. The results also show that the blockchain design principles are relevant for identifying the design decisions necessary for building blockchain-based applications for green bond reporting.

The feedback received from the blockchain experts centered on how to improve the current blockchain design principles. Both blockchain experts' main critique and recommendation was to expand on some design principles, such as blockchain type and incentives. They also recommended contextualizing and defining each design principle's limitations.

Overall, the demonstration interview with a Nordic organization solidified that the blockchain design principles can support organizations in making informed decisions regarding blockchain, describing it as a "blueprint." By conducting this retrospectively, they also validated the suggestions recommended in these design principles. The main criticisms were that the principles were missing system requirements; adding legislation as an added concept; and removing governance-related parameters, incentives, and decision-making from the design principles because the infrastructure design principles were more straightforward and informative. Interestingly, the interviewee suggested that these principles could be used to bridge the engineering team with the business teams because the language used was precise yet still on a high level. Table 3 (below) summarizes our revised design principles.

6. Conclusion and implications for research and practice

We outline six blockchain design principles for green bond reporting. These design principles encompass relevant blockchain aspects such as blockchain type, consensus mechanism, smart contracts, decision-making, incentives, and roles. By evaluating and demonstrating the use of the blockchain design principles through considering the criteria of understandability, operational feasibility, and usability, we conclude that the design principles fulfill the objective of supporting practitioners in making informed design decisions regarding blockchain for green bond reporting.

Our study has implications for both theory and practice. For theory, we contribute to the body of blockchain literature by examining how different forms of blockchain infrastructure and governance fit into the use case of blockchain for green bond reporting. We also contribute to the literature on challenges in the green bond market by confirming findings in previous research that suggest current standards, as well as transparency and quality in reporting, are inadequate. To build our design principles, we formed a conceptual framework encompassing different literature on blockchain and identifying some of the most central concepts in the blockchain. For design science researchers, the design knowledge we have generated is applicable for the class of sustainability reporting systems that rely on blockchain technology.

For practitioners, the blockchain design principles communicate on blockchain projects and outline relevant design knowledge and design tradeoffs. In addition, the design principles serve to support blockchain-related investments. These design principles may apply to other similar reporting contexts but this requires future studies to investigate further.

Concept	**Initial Blockchain DP**	**Revised Blockchain DP**
Blockchain Type	Use a consortium blockchain.	A consortium blockchain is suitable when composed of multiple stakeholders. However, a public blockchain with permissioned smart contracts is suitable for larger consortiums.
Consensus Mechanism	The proof-of-authority consensus mechanism is suitable due to some level of trust already existing.	The proof-of-authority consensus mechanism is suitable due to some level of trust already existing
Smart Contracts	Smart contracts can be used for validating that an authorized part uploaded and signed the file.	Smart contracts can be used for validating that an authorized party uploaded and signed the file. Smart contracts can also be used to select files randomly for auditing; feeding data into blockchain from different sources, including IoT devices; and ensuring that there is no double reporting.
Incentives	Design for reputation rather than monetary incentives.	Design for reputation rather than monetary incentives. This incurs incentivizing proper behavior from the different stakeholders through credit-based systems and track records rather than cryptocurrency rewards.
Decision-making	Off-chain decisions the different stakeholders take remain in their current format. On-chain decisions are facilitated through smart contracts.	Off-chain decisions the different stakeholders take remain in their current format. On-chain decisions are facilitated through smart contracts representing off-chain decisions.
Roles	The issuer, second opinion provider, and investor are identified as different roles that have different privilege rights.	The issuer, second opinion provider, and investor are identified as different roles with different privilege rights, such as access and edit rights.

Table 3. Revised design principles.

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