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Forum: Practical Perspectives

Using *blockchain* technology for sustainable public procurement of road works

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Governments worldwide face recurrent challenges in incorporating environmental variables into bidding processes. In this context, sustainable public procurement is an important tool for reducing the environmental impact of public organizations. Despite the emergence of digital technologies such as blockchain, which offers potential solutions to complex public sector problems, and the existing implementation of blockchain in databases by some countries, the Brazilian government has not developed the capability to adopt such instruments to improve environmental effectiveness and efficiency. This study proposes a conceptual model for the application of blockchain in sustainable public procurement of road works to facilitate the incorporation of environmental criteria into bidding procedures. Through a content analysis of 25 bidding processes related to road works, the research mapped out key activities, providing insights to propose an integrated solution for the Brazilian National Public Procurement Portal to address environmental issues in procurement processes. The study's main contribution lies in outlining potential applications of blockchain in public procurement to embrace environmental aspects, demonstrating the feasibility of implementing this technology. Given the emergence of new perspectives to optimize bidding process management and foster environmental sustainability in public administration, the research provides evidence that blockchain can help promote a reliable, decentralized, transparent, and environmentally sustainable bidding structure.

Keywords: blockchain; sustainable public procurement; bidding; environmental criteria; road works.

Uso da tecnologia *blockchain* nas contratações públicas sustentáveis de obras rodoviárias

A dificuldade de incorporar a variável ambiental nos processos de contratação é recorrente no mundo. Nesse contexto, as contratações públicas sustentáveis são um instrumento importante para reduzir o impacto ambiental das organizações. No Brasil, há incapacidade para incorporar instrumentos que permitam uma atividade pública mais eficaz e eficiente. Em contrapartida, as tecnologias digitais, como a *blockchain*, podem ser a solução para problemas complexos no setor público. Nos últimos anos, governos têm adotado a *blockchain* em diversas áreas,

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sendo que, no âmbito internacional, a tecnologia é utilizada em bancos de dados de alguns países. No sentido de facilitar a implantação dos critérios ambientais nos procedimentos de licitação, este estudo propõe um modelo conceitual de aplicação da *blockchain* para contratações públicas sustentáveis de obras rodoviárias. Com base na análise de conteúdo de 25 processos de licitação, foi realizado o mapeamento das principais atividades, o que permitiu propor uma solução integrada ao Portal Nacional de Contratações Públicas. A principal contribuição do estudo é apresentar as potenciais aplicações referentes aos aspectos ambientais para *blockchain* nas contratações públicas e demonstrar a viabilidade da implementação dessa tecnologia. Diante das novas perspectivas para otimizar a gestão dos processos licitatórios e prover a sustentabilidade ambiental na administração pública, entende-se que a *blockchain* pode auxiliar na promoção de uma estrutura de licitação confiável, descentralizada, transparente e ambientalmente sustentável.
Palavras-chave: *blockchain*; contratações públicas sustentáveis; licitação; critérios ambientais; obras rodoviárias.

Uso de la tecnología *blockchain* en la contratación pública sostenible de obras viales

La dificultad de incorporar la variable ambiental en los procesos de contratación es recurrente en todo el mundo. En este contexto, la compra pública sostenible es un importante instrumento para reducir el impacto ambiental de las organizaciones. En Brasil hay incapacidad para incorporar instrumentos que permitan una actividad pública más efectiva y eficiente. Por otro lado, las tecnologías digitales como la *blockchain* pueden ser una solución a problemas complejos en el sector público. En los últimos años, los gobiernos han adoptado la *blockchain* en varias áreas y, a nivel internacional, la tecnología se utiliza en bases de datos en algunos países. Con el fin de facilitar la implementación de criterios ambientales en los procedimientos de licitación, este estudio propone un modelo conceptual para la aplicación de la *blockchain* a las contrataciones públicas sostenibles de obras viales. A partir del análisis de contenido de 25 procesos de licitación, se mapearon sus principales actividades, lo que permitió proponer una solución integrada al Portal Nacional de Contrataciones Públicas. La principal contribución del estudio es la presentación de aplicaciones potenciales relacionadas con aspectos ambientales para la *blockchain* en la contratación pública, así como demostrar la viabilidad de implementar esta tecnología. Ante las nuevas perspectivas para optimizar la gestión de los procesos de licitación y dotar de sostenibilidad ambiental a la administración pública, se entiende que la *blockchain* puede ayudar a promover una estructura de licitación confiable, descentralizada, transparente y ambientalmente sostenible.
Palabras clave: *blockchain*; contrataciones públicas sostenibles; licitación; criterios ambientales; obras viales.

1. INTRODUCTION

Concerns regarding the environment have become prominent on the global stage and have led to increased environmental awareness on the part of people and organizations. In the context of road regulatory agencies, given the environmental impacts generated by highways, the need to subject them to appropriate environmental treatment from the planning phase is evident, thus including public bidding processes.

With the aim of incorporating environmental sustainability issues into government procurement, green public procurement (GPP), also called sustainable public procurement or sustainable tendering, is defined by the European Commission (EC, 2008) as a process through which public authorities seek to acquire goods, services, and construction with a reduced environmental impact throughout their life cycle, compared to goods, services, and construction with the same primary function and which would otherwise be acquired.

Public authorities, as consumers of products, services, and construction on a large scale, move resources of approximately 14% of the Gross Domestic Product (GDP) in European Union countries (2019) and 12% in Brazil (Instituto de Pesquisa Econômica Aplicada [IPEA], 2021).

The difficulty of incorporating environmental variables into hiring processes is common around the world. Cheng et al. (2018) warn that GPP practices need to overcome significant challenges, such as lack of knowledge and environmental awareness, objectives and structure, political commitment, and financial issues.

In Brazil, current public management is often perceived as slow and bureaucratic (Cardoso et al., 2021). It is estimated that 10% to 20% of procurement budgets may be wasted, depending on the degree of corruption and inefficiency of public management (Casallas et al., 2020).

In contrast, digital technologies can be seen as a potential solution to complex problems in the public sector, facilitating the promotion of more sustainable public procurement. According to Gunasekara et al. (2021), some technologies allow the digitization of processes, such as building information modeling (BIM), blockchain, the internet of things (IoT), big data technology, augmented reality, and the construction of information standards. Given this context, Casallas et al. (2020) assess whether blockchain technology can be applied to public entities.

Blockchain is a system of records that contains all transactions processed in the system, being a set of information linked to previous and subsequent blocks of information. These blocks are public, as all network participants have access to them. However, once processed, they cannot be deleted or altered. This implies the following characteristics, which make blockchain technology promising in public administration (Cardoso et al., 2021; Maesi & Mori, 2020; Zhang et al., 2020):

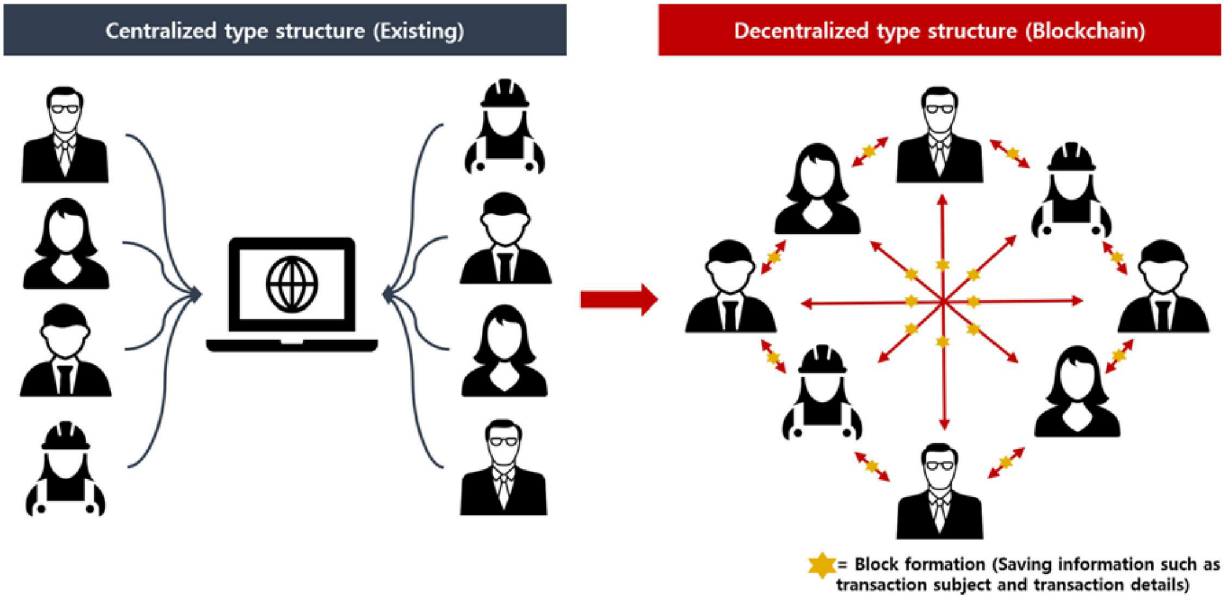
- Security/reliability – Immutable and inviolable system.
- Decentralization – Shared system in which the network validates transactions and the system.
- Transparency – The rules apply to everyone.

Although in public administration, terms such as "open government," "transparency," and "electronic administration" have been introduced in order to modernize public management, there is an inability to incorporate instruments that allow for more effective and efficient public activity (Cardoso et al., 2021; Tribunal de Contas da União [TCU], 2020). In this context, the present study proposes a conceptual model for applying blockchain to sustainable public procurement (SPP) for road construction in order to facilitate the implementation of environmental criteria in bidding procedures.

2. *BLOCKCHAIN*: CHARACTERISTICS AND APPLICATIONS IN THE PUBLIC SECTOR

The concept of blockchain emerged with the whitepaper of the virtual currency bitcoin, written by Satoshi Nakamoto in 2008. The main characteristic of this technology is its decentralized and distributed structure, which allows all participants in the network to store and verify transaction information together, ensuring integrity and reliability without having an authorized central agency. In contrast, in the centralized structure, only one controller manages data integrity in a concentrated database (Kim et al., 2020), as shown in Figure 1.

FIGURE 1 COMPARISON BETWEEN CENTRALIZED AND DECENTRALIZED STRUCTURES



Source: Adapted from Kim et al. (2020).

Each participant's view of the shared database coincides with the view of everyone else, which solves problems of double billing, file duplication, or data corruption. For this reason, blockchains can facilitate the transfer of assets and data without the need for a trusted central authority. As a result, any incorrect change to the data – for example, tampering by a malicious user – would be immediately detected, rejected, and deprecated by all participants (Cardoso et al., 2021; Zhang et al., 2020). Thus, according to the Federal Audit Court (TCU, 2020), block technology is recommended when there is a need to increase the reliability of information and processes in situations involving many heterogeneous interested parties.

In recent years, governments have adopted blockchain in several areas, and, internationally, the technology is used in databases in some countries. Estonia has implemented a system called e-Estonia, which connects national justice, health, security, legislative, and commercial systems. In the legislative process, the country uses the e-Law system, which, through the blockchain network, allows the public to access information regarding bills sent since 2003 (Araújo et al., 2021; Cardoso et al., 2021; Casallas et al., 2020; TCU, 2020). In 2018, Canada successfully conducted the first use of blockchain in public management to enable transparent contract administration (Casallas et al., 2020).

In the US state of Delaware, the Delaware Blockchain Initiative was launched, a program with a legal and regulatory environment for the development of this technology (Casallas et al., 2020; Zhang et al., 2020). In Peru, the government public procurement agency Perú Compras included blockchain in 2018 for the electronic recording of purchases. Since then, the country has registered around 50 thousand purchase orders through its electronic catalog platform (Casallas et al., 2020).

In Brazil, the initiatives of the governments of Bahia and Rio Grande do Norte stand out, which developed the Online Bidding Solution, which consists of an application that allows public administration agencies to carry out bids for the purchase or contracting of goods, services, and construction. It also allows suppliers from across the country to submit proposals and monitor the results of biddings (Solução Online de Licitação [SOL], 2023; TCU, 2020).

In the context of Law No. 14,133/2021, the New Bidding Law, an important step towards the establishment of the modernization of Brazilian public administration can be evidenced with the creation of the National Public Procurement Portal, which, according to the new law, must serve as a digital platform for the mandatory disclosure of electronic purchasing and contracting procedures, applied to the spheres of the Executive, Legislative, and Judiciary Powers (Portal Nacional de Contratações Públicas [PNCP], 2023).

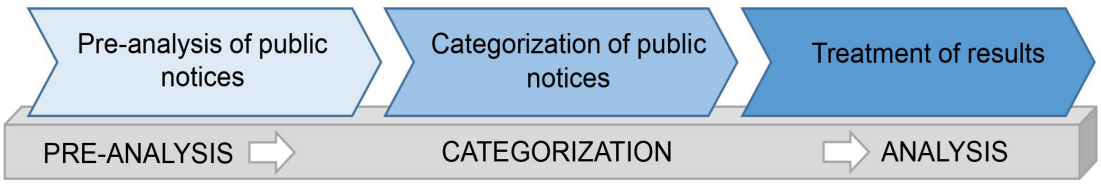
Despite the various initiatives employed in the public sector, blockchains face obstacles to widespread adoption by organizations, as their government regulatory status is uncertain. According to the Federal Court of Accounts (TCU, 2020), the number of professionals with mastery of the technical aspects and concepts involving blockchain is still low, which may be a limiting factor in the adoption of this technology by the government. According to Araújo et al. (2021), the legislation ends up making it difficult for the public sector to opt for solutions provided by technological innovations in tenders and contracts.

After regulation, problems would possibly arise from automatic mechanisms (self-execution), the insertion of incorrect data, as well as potential security violations and non-compliance with rules, generating the need to build a new jurisprudence for administrative sanctions. According to Rane and Thakker (2020), resolving crucial technological aspects such as transaction speed, data limits, and verification processes is one of the challenges of blockchain.

3. METHOD

The present research is exploratory and observational in nature, and the technique used was content analysis of bidding documents combined with a bibliographic review of the topic under study. As shown in Figure 2, this technique consists of the following phases: pre-analysis, categorization, and analysis (Bardin, 2016). The proposed methodological design resulted in the mapping of the main activities carried out for the contracting of public construction by the National Department of Transport Infrastructure.

FIGURE 2 CONTENT ANALYSIS PHASES



Source: Adapted from Bardin (2016).

For greater understanding, the research phases are detailed in the following sections.

3.1. Pre-analysis of public notices

Initially, a bibliographical review of the topic under study was carried out, and subsequently, a survey of the bidding processes for road construction that comprise the federal network of Paraná, which took place between 2017 and 2020, was carried out, generated with a management tool of electronic documents and processes called the Electronic Information System (SEI). The sample of 25 bidding processes was obtained from the bidding entity and through an online Dnit database (Departamento Nacional de Infraestrutura de Transportes [Dnit], 2021), under the filter "SUP. REG. DNIT PARANÁ," in the field "Sup. Regional."

3.2. Categorization of public notices

In order to facilitate content analysis, categorization is a classification operation based on the common characteristics of the elements (Bardin, 2016). Thus, the 25 selected notices were categorized into five groups of processes according to the similarity of the types of intervention, as shown in Table 1.

TABLE 1 DESCRIPTION OF PROCESS GROUPS

Process group	Notice number	SEI process number	Bidding modality	Type of intervention	Highway
Group 1	0105/2018-09	50609.000764/2018-61	Electronic auction	Conservation (single track)	BR-163 and BR-272
Group 1	0274/2018-09	50609.002088/2018-61	Electronic auction	Conservation (single track)	BR-487
Group 1	0316/2018-09	50609.002182/2018-10	Electronic auction	Conservation (single track)	BR-163
Group 1	0338/2018-09	50609.002221/2018-89	Electronic auction	Conservation (single track)	BR-277 and BR-469
Group 1	0341/2018-09	50609.002178/2018-51	Electronic auction	Conservation (single track)	BR-163 and BR-280
Group 1	0448/2018-09	50609.002142/2018-78	Electronic auction	Conservation (single track)	BR-476
Group 1	0452/2018-09	50609.002143/2018-12	Electronic auction	Conservation (single track)	BR-476
Group 1	0459/2018-09	50609.002513/2018-11	Electronic auction	Conservation (single track)	BR-153
Group 1	0460/2018-09	50609.002539/2018-60	Electronic auction	Conservation (single track)	BR-153
Group 1	0020/2019-09	50609.002515/2018-19	Electronic auction	Conservation (single track)	BR-272
Group 1	0307/2019-09	50609.003115/2019-01	Electronic auction	Conservation (single track)	BR-376

Continue

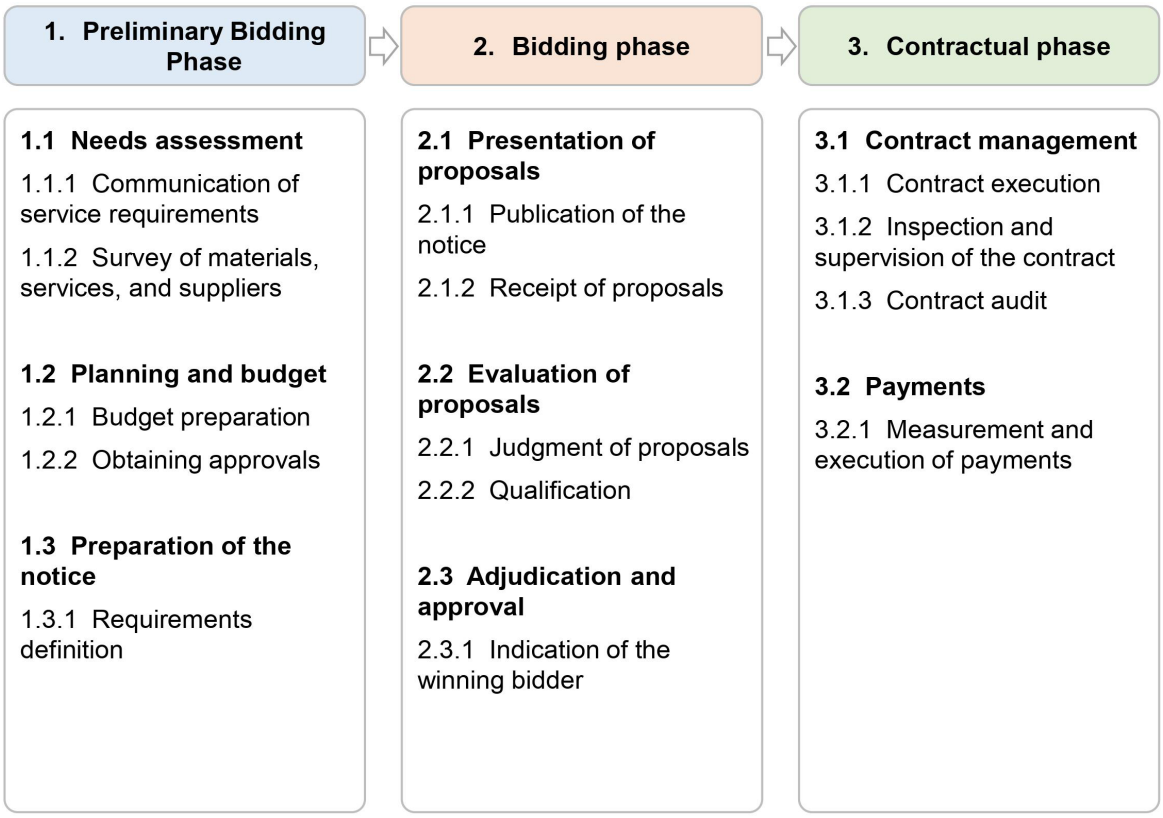
Process group	Notice number	SEI process number	Bidding modality	Type of intervention	Highway
Group 1	0371/2019-09	50609.003094/2019-16	Electronic auction	Conservation (single track)	BR-158 and BR-373
Group 1	0340/2020-09	50609.003047/2019-72	Electronic auction	Conservation (single track)	BR-476
Group 1	0486/2020-09	50609.001572/2020-97	Electronic auction	Conservation (single track)	BR-153
Group 2	0488/2017-09	50609.500879/2017-71	Electronic auction	Conservation (double track)	BR-116 and BR-376
Group 2	0145/2018-09	50609.000953/2018-34	Electronic auction	Conservation (double track)	BR-163 and BR-467
Group 2	0396/2018-09	50609.003191/2018-28	Electronic auction	Conservation (double track)	BR-163
Group 2	0018/2019-09	50609.002146/2018-56	Electronic auction	Conservation (double track)	BR-116, BR-277, BR-376 and BR-476
Group 2	0023/2020-09	50609.003945/2019-21	Electronic auction	Conservation (double track)	BR-116 and BR-376
Group 2	0044/2021-09	50609.002288/2020-38	Electronic auction	Conservation (double track)	BR-153
Group 3	0010/2018-09	50609.920003/2017-47	Electronic auction	Restoration	BR-272
Group 3	0089/2018-09	50609.000603/2018-78	Electronic auction	Restoration	BR-163
Group 4	0028/2018-09	50609.000863/2018-43	Electronic auction	Supervision	All network in Paraná
Group 5	0189/2020-09	50600.012194/2018-32	Electronic auction	Special artwork	BR-163
Group 5	0049/2021-09	50600.028803/2020-90	Electronic auction	Special artwork	BR-158, BR-163, BR-280 and BR-373

Source: Elaborated by the authors.

3.3. Treatment of Results

According to Bardin (2016), it is at this stage that the results are processed and the information for analysis is condensed and emphasized, resulting in inferential interpretations. Based on the content analysis of documents generated in the respective process groups in the SEI and the structure proposed by Gunasekara et al. (2021), a survey of the main activities for contracting a Dnit public construction was carried out, as shown in Figure 3.

FIGURE 3 MAIN ACTIVITIES OF THE DNIT PUBLIC CONSTRUCTION CONTRACTING PROCESS



Source: Adapted from Gunasekara et al. (2021).

The mapping of bidding process activities, together with the established theoretical framework, allowed the proposition of a list of applications of blockchain technology related to environmental aspects for the phases of the public procurement process. The proposed solutions were consolidated by a conceptual model to be structured on a blockchain platform inserted in the environmentally sustainable bidding process.

4. RESULTS

4.1. Applications of blockchain technology related to environmental aspects in public procurement processes

Box 1 shows the applications of blockchain technology in public procurement processes, among which those that directly refer to environmental aspects stand out in bold.

BOX 1 APPLICATIONS OF BLOCKCHAIN TECHNOLOGY IN PUBLIC PROCUREMENT PROCESSES

Stage of the hiring process		Application
1. Preliminary bidding phase		
1.1. Needs assessment	1.1.1. Communication of service requirements	Single messaging system
	1.1.2. Survey of materials, services and suppliers	Database of environmentally sustainable materials, services, and suppliers
		Database of good environmental practices in bidding sectors
		System integrated into a dashboard on environmentally sustainable acquisitions
1.2. Planning and budget	1.2.1. Budget preparation	Environmental Cost Database
	1.2.2. Obtaining approvals	Automation of approval processes
1.3. Preparation of the notice	1.3.1. Requirements definition	Environmental Criteria Database
2. Bidding phase		
2.1. Presentation of proposals	2.1.1. Publication of the notice	Sending notice as a transaction via blockchain
	2.1.2. Receipt of proposals	Using the encryption mechanism
2.2. Evaluation of proposals	2.2.1. Judgment of proposals	Decentralization of proposal evaluation
	2.2.2. Qualification	Mechanisms for authenticating competitors' environmental commitments
2.3. Adjudication and approval	2.3.1. Indication of the winning bidder	Use of public keys
3. Contractual phase		
3.1. Contract management	3.1.1. Contract execution	Contract automation using smart contracts Insertion of environmental criteria
	3.1.2. Inspection and supervision of the contract	Automation of environmental inspection and supervision
	3.1.3. Contract audit	Automation of environmental auditing
3.2. Payments	3.2.1. Measurement and execution of payments	Automatic electronic payments

Source: Elaborated by the authors.

In line with Box 1, applications directly related to environmental aspects are presented below.

a) Database of environmentally sustainable materials, services, and suppliers: This is a type of database that allows multiple users to share information and modify it in a secure and reliable way. The possibility of tracking a product from its production to its disposal via blockchain provides better visibility and control over processes, making it easier to calculate the value of the product's entire life cycle and to create a basis for increasingly secure estimates (A. Luttenberger & L. Luttenberger, 2017).

b) Database of good environmental practices in bidding sectors: Historical performance and sustainability data from suppliers can be made available, making it easier for employees to examine internal energy-saving and pollution reduction practices and records, for example, in order to determine the relative proactiveness of suppliers' environmental practices (Silveira & Costa, 2020).

c) System integrated with a dashboard on environmentally sustainable acquisitions: the development of blockchain integrated with the dashboard on environmentally sustainable acquisitions provides a visual panel that centrally presents a set of information, indicators, and metrics to monitor the extent to which acquisition expenses are achieving specified sustainability goals.

d) Environmental cost database: Integration with a price panel is proposed through the provision of a catalog of reference price tables and cost compositions, related to the environmental services budget group.

e) Environmental criteria database: Integration into the standard list of criteria relating to EC green public contracts is proposed (Garbarino et al., 2016). The EC standard list establishes clear, verifiable, justifiable, and ambitious environmental criteria for products and services in a life-cycle approach based on scientific evidence.

f) Mechanism for authenticating the socio-environmental commitment of bidding companies: The data requested by the bodies can be made available via blockchain by the administration itself, guaranteeing the veracity of the information contained therein in an accessible and quick way (Araújo et al., 2021).

g) Insertion of environmental criteria: Many environmental impacts only arise during the execution of the contract. Therefore, it is suggested to insert digital instructions into smart contracts in the form of environmental criteria and requirements, such as:

- Efficient use of resources and waste management on construction sites.
- Communication of information on environmental problems encountered during the execution of the contract and the adoption of corrective measures.
- Reduction of CO2 emissions or other greenhouse gases associated with the transport of materials.

h) Automation of environmental inspection and supervision: In the inspection and supervision stage of the contract, it is possible to automate the monitoring of documents, data, and processes related to environmental issues. In the event that any contractual clause has been violated, it is possible to program self-executing behavior that is adopted by the public administration, generating warnings, fines, and suspensions (Araújo et al., 2021).

i) Automation of environmental auditing: Automation of auditing can be an extremely important management tool for improving environmental management performance, as it serves to track activities and processes aimed at environmental protection as well as provide support for decision-making.

4.2. Conceptual model for using blockchain technology in sustainable public procurement for road construction

After mapping the main activities of the bidding process in Dnit and presenting the blockchain applications, it is proposed to consolidate these solutions through the conceptual model of using blockchain technology in the SPP process of road construction, as shown in Figure 4.

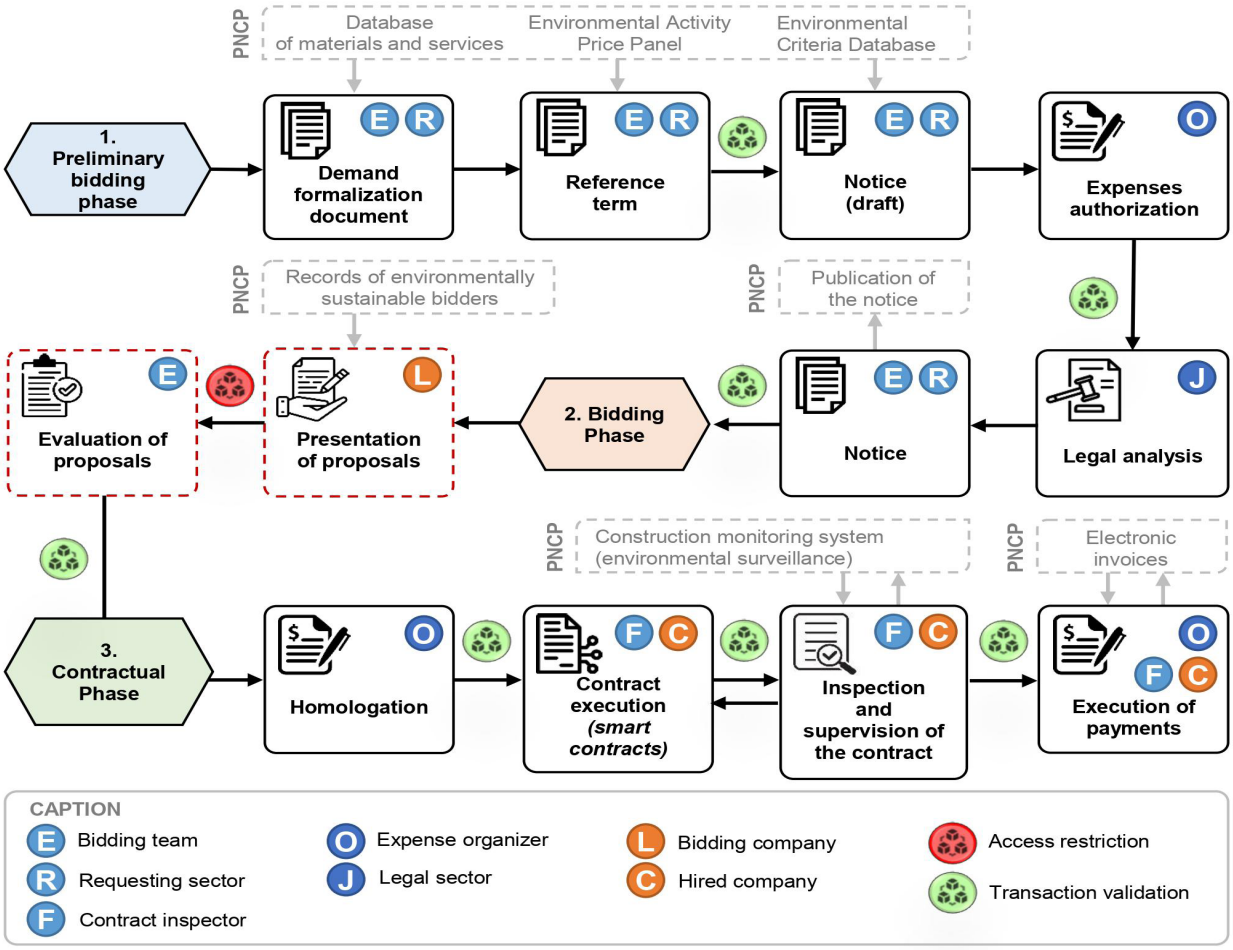
The application of the conceptual model must be developed by public managers and technical engineering sectors, together with a team specialized in information technology (IT) management, as the solutions presented initially depend on the provision of an interface based on the platform blockchain. Therefore, from a technical point of view, it is necessary that the transactions of the parties involved in the contracting process and the validation and restriction mechanisms are developed in a blockchain system integrated with the PNCP for the dissemination of electronic purchasing and contracting procedures, with the guarantee of the identity of the participants, the immutability and reliability of the documents introduced, as well as the data shared.

FIGURE 4 CONCEPTUAL MODEL FOR USING BLOCKCHAIN TECHNOLOGY IN SUSTAINABLE PUBLIC PROCUREMENT OF ROAD CONSTRUCTION

Source: Elaborated by the authors.

In order to elucidate the proposed solution in operational terms, Figure 5 presents a procedural flowchart on a blockchain platform.

FIGURE 5 FLOWCHART OF THE PUBLIC PROCUREMENT PROCESS ON A BLOCKCHAIN PLATFORM



Source: Elaborated by the authors.

The contracting process begins with the formalization of the demand by the requesting sector, in collaboration with the bidding body's planning team. The blockchain platform, linked to the PNCP, would contain all the information necessary to prepare the terms of reference (TR) through access to databases of materials and services and the registration records of environmentally sustainable bidders and prices of environmental activities. Based on the TR and the environmental criteria data available on the network, it would be possible for the bidding agency to formulate the convocation (bidding notice).

The expense organizer would give authorization using an electronic key and forward it for consideration by the agency's legal department. Once approved, the notice would be released for publication in the PNCP and bidders would receive it and register their proposals. In the proposal evaluation stage, access restrictions could be adopted using cryptographic keys, in which only the team responsible for the judgment could process confidential information until defining the winner of the bid (homologation), a stage in which final acceptance would be made by the expense organizer.

Subsequently, the smart contract would be formulated in compliance with the rules agreed upon in the contract. The execution of the contract would be auditable both by whoever is being hired and by the body responsible for managing and supervising the contract. Payments would be made automatically upon delivery of the product and validation by the managing body. Auditing and process control can be carried out at any time by control agencies.

In order to guarantee the integrity and reliability of information, the proposed model must be applied under the following conditions:

- Data must be available to all participants at any time.
- Data is never changed or deleted, and new information is added to the network.
- Data integrity is guaranteed by encryption techniques using public key cryptographic algorithms, hash functions, and digital signatures.
- Data recording and processing must be restricted to a pre-selected set of participants, according to the stage of the bidding process, even if reading is open to any participant. Recording permissions must be pre-established by the bidding body (data manager).
- The data manager must guarantee the legitimacy of the information provided (data quality).

In the end, the blockchain platform must be a single, integrated and decentralized system, allowing the operationalization and control of several stages throughout the life cycle of public purchasing, in which purchases shared between different public entities stand out, aiming at acquisition of sustainable products and services. Thus, it is possible for managers and public servants, suppliers, control bodies and citizens to have greater interaction in the system, combined with the provision of aspects such as security, reliability, decentralization and transparency to the bidding processes.

5. FINAL CONSIDERATIONS

In addition to the inherent benefits of blockchain technology in terms of providing aspects such as security, reliability, decentralization and transparency to bidding processes, the results reveal that there is great potential in the use of blockchain related to environmental issues in road construction.

The main contribution of this research is to present the potential applications linked to environmental aspects of blockchain in public procurement and demonstrate the feasibility of implementing this technology by proposing a conceptual model.

In order to guarantee the implementation and improvement of the proposed conceptual model, it is considered that integration between the technical sectors of public administration and IT professionals is essential. To this end, it is initially suggested to implement the solution with an experimental approach, integrated with the PNCP, to disseminate electronic purchasing and contracting procedures.

A limitation of this study can be considered the fact that it did not take into account the opinions of those involved in the bidding processes, as it would be important to combine the use of content analysis and interviews to identify the difficulties encountered by bidding organizations and their perceptions in relation to the topic addressed.

When introducing blockchain technology into public sector administrative procedures, it should be borne in mind that the lack of a favorable regulatory environment, as well as technological aspects such as transaction speed, data limits, and potential security breaches, may constitute obstacles to the application of blockchain. Despite these obstacles, it is believed to be only a matter of time before public entities begin using a bidding structure based on blockchain technology.

Given the new perspectives for optimizing the management of bidding processes and providing environmental sustainability in public administration, the intrinsic characteristics of blockchain can help resolve some of the problems detected in the various activities of public procurement processes towards promoting a bidding structure that is reliable, decentralized, transparent, and environmentally sustainable.

REFERENCES

Araújo, V. S., Freitas, M. G., & Martin, M. V. A. (2021). *Blockchain* e o futuro dos contratos administrativos. *Revista Quaestio Iuris*, *14*(1), 481-503. https://doi.org/10.12957/rqi.2021.48956

Bardin, L. (2016). *Análise de conteúdo*. Edições 70.

Brasil (2021). *Lei nº 14.133, de 1º de abril de 2021*. http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2021/lei/L14133.htm

Cardoso, H. R., Cerqueira, R. S., & Andrade, A. B. (2021) A aplicabilidade da tecnologia *blockchain* às licitações públicas. *Revista do Cejur*, *9*(1), 1-24. https://doi.org/10.37497/revistacejur.v9i1.368

Casallas, J. A., Lovelle, J. M., & Molano, J. I. (2020). Smart contracts with blockchain in the public sector. *International Journal of Interactive Multimedia and Artificial Intelligence*, *6*(3), 63-72. https://doi.org/10.9781/ijimai.2020.07.005

Cheng, W., Appolloni, A., D'Amato A., & Zhu, Q. (2018). Green public procurement, missing concepts and future trends: a critical review. *Journal of Cleaner Production*, *176*, 770-784. https://doi.org/10.1016/j.jclepro.2017.12.027

Comissão Europeia. (2008). *Comunicação da Comissão ao Parlamento Europeu, ao Conselho, ao Comitê Econômico e Social Europeu e ao Comitê das Regiões*. https://eur-lex.europa.eu/legal-content/PT/TXT/PDF/?uri=CELEX:52008DC0400&from=PT

Comissão Europeia. (2016). *Critérios relativos aos contratos públicos ecológicos da UE para concepção, construção e manutenção de estradas*. https://ec.europa.eu/environment/gpp/pdf/toolkit/roads/PT.pdf

Comissão Europeia. (2019). *Painel de avaliação do mercado único*: desempenho por área política. Licitação pública. https://ec.europa.eu/internal_market/scoreboard/performance_per_policy_area/public_procurement/index_en.htm

Departamento Nacional de Infraestrutura de Transportes. (2021). *Consulta: editais de licitações*. http://www1.dnit.gov.br/editais/consulta/editais2.asp

Garbarino, E., Quintero, R. R., Donatello, S., Caldas, M. N., & Wolf, O. (2016). *Revision of green public procurement criteria for road design, construction and maintenance: technical report and criteria proposal*. https://ec.europa.eu/environment/gpp/pdf/report_gpp_roads.pdf

Gunasekara, H. G., Sridarran, P., & Rajaratnam, D. (2021). Effective use of blockchain technology for facilities management procurement process. *Journal of Facilities Management*, *20*(3), 452-468. https://doi.org/10.1108/JFM-10-2020-0077

Instituto de Pesquisa Econômica Aplicada. (2021). *Cadernos Brasil na OCDE: compras públicas*. https://www.ipea.gov.br/portal/images/stories/PDFs/210707_cb_ocde_compras_publicas.pdf

Kim, K., Lee, G., & Kim, S. (2020). A study on the application of blockchain technology in the construction industry. *KSCE. Journal of Civil Engineering*, *24*, 2561-2571. https://doi.org/10.1007/s12205-020-0188-x

Luttenberger, A., & Luttenberger, L. (2017) Sustainable procurement and environmental life cycle costing in maritime transport. *WMU Journal of Maritime Affairs*, *16*, 219-231.

Maesi, D., & Mori, P. Blockchain 3.0 applications survey (2020). *Journal of Parallel and Distributed Computing*, *138*, 99-114. https://doi.org/10.1016/j.jpdc.2019.12.019

Portal Nacional de Contratações Públicas. (2023). *Sobre o PNCP*. https://www.gov.br/pncp/pt-br

Rane, S. B., & Thakker, S. V. (2020). Green procurement process model based on blockchain - IoT integrated architecture for a sustainable business. *Management of Environmental Quality. An International Journal*, *31*(3), 741-763. https://doi.org/10.1108/MEQ-06-2019-0136

Silveira, V., & Costa, S. (2020). Percepção de gestores públicos acerca da utilização de sistemas informatizados baseados em *blockchain* como facilitador para compras sustentáveis. In *Anais do 8º Simpósio de Engenharia de Produção*, Caruaru, PE, Brasil. https://doi.org/10.5151/viisimep-251532

Solução Online de Licitação. (2023). *Inovação para o Estado: conheça o Sol*. https://www.sol-app.net/

Tribunal de Contas da União. (2020). *Sumário executivo: levantamento da tecnologia blockchain*.

https://portal.tcu.gov.br/data/files/59/02/40/6E/C4854710A7AE4547E18818A8/Blockchain_sumario_executivo.pdf

Zhang, R, Xue, R, & Liu, L. (2020). Security and privacy on blockchain. *ACM Computing Surveys*, *52*(51), 1-34. https://doi.org/10.1145/3316481

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Guilherme Gonçalves Giamberardino: Conceptualization (Lead); Formal analysis (Lead); Investigation (Lead); Methodology (Lead); Supervision (Lead); Writing - original draft (Lead); Writing - review & editing (Lead).

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DATA AVAILABILITY

The entire dataset supporting the results of this study is available upon request to the corresponding author (Guilherme Gonçalves Giamberardino). The dataset is not publicly available due it contains information that compromises the privacy of research participants.