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Analysis of the Impact of Blockchain and Internet of Things (BIoT) on Public Procurement

MARINELA MIRCEA, MARIAN STOICA, AND BOGDAN GHILIC-MICU
Department of Economic Informatics and Cybernetics, Bucharest University of Economic Studies, 010374 Bucharest, Romania

Corresponding author: Marinela Mircea (mmircea@ase.ro)

ABSTRACT Most countries in the world are currently faced with a series of public procurement challenges. Moreover, the large volumes of public procurement and the impact it may have of the global economy, the environment and the society at large justify a research study aimed at achieving sustainable and smart procurement. Smart public procurement intensively relies on emerging technologies and it is both an international priority and a challenge to achieve it. This paper is aimed at addressing such procurement-specific challenges. This study reflects the current status and the trends in public procurement, as well as the manner in which Blockchain and the Internet of Things (BIoT) may lead to a beneficial change in the field. In order to analyse the impact of BIoT, we are putting forward an assessment model comprising the definition and the description of six hypotheses. They are validated both by reference to the current knowledge status and via the analysis of the data collected in a survey which was conducted in Romania. It was aimed at collecting and analysing the data from the main stakeholders as well as at formulating recommendations/actions related to the modernisation of the current system. The study uses structural equation modelling (SEM) to validate the proposed model and to establish the relationships between the adoption of BIoT and smart, sustainable and transparent public procurement. At the same time, we analyse the links between the adoption of BIoT and aspects such as corruption and fraud, the challenges related to technological integration and the need to reengineer organisations, as well as national and international policies. Following our analyses, there emerged that BIoT adoption has a positive impact on the achievement of sustainable public procurement processes (the highest effect), on transparency and the trust in public procurement, on reducing corruption and fraud in public procurement and on the achievement of smart public procurement. The paper provides theoretical and practical contributions that should support solutions to the current major challenges and represent a vehicle for innovation and sustainable development alike.

INDEX TERMS Blockchain technology, Internet of Things, green public procurement, public procurement 4.0, smart contracts, smart public procurement, structural equation modeling, sustainable public procurement.

I. INTRODUCTION

Our contemporary society is faced with profound changes, on the one hand, owing to the revolution in information and communications technology (ICT) and, on the other hand, to the environmental protection policies. One of the promoters of this kind of changes is the European Commission (EC), an institution that strives to encourage digitalisation, sustainability and innovation, through European policies. One of the fields of national and international interest is public procurement. The large publicly procured volumes, the corruption that may seat within some public institutions, the major environmental and generally societal impact of procurement, the fact that public procurement is a key component in the global economy, all of that point to a major interest in restructuring and improving this field of activity. The different research studies recently carried out reveal major challenges in this field as well as attempts at transforming public procurement in smart and sustainable procurement.

Currently, Europe is confronted with a series of problems related to creating an adequate public procurement architecture. Thus, at the level of the EC: clear and consolidated data on public procurement are still not available; there is

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no consensus across the European Union (EU) regarding the data that should be collected and on the purpose that the data should serve; public control is absent by and large; there is no possibility to develop data-based policies and budgetary control is hindered [1]. Moreover, public procurement is a complex and sensitive topic. The wrong use of public money is chiefly associated with corrupt practices and things such as and privileged treatment, fake information, corruption/bribery are incompatible with reasonable governance. It was found that large cities and country capitals in the world evince a wider predisposition to the potential over-presence of bribery [2], according to an in-depth empirical analysis of corruptible behaviours manifest in different European cities [3].

When carried out correctly, public procurement may represent a promising vehicle of social progress, by promoting fair treatment, non-discrimination and equal chances. This way, it is possible to follow/monitor the benefits of sustainable development, the opportunities for vulnerable groups, the fight against child labour and against social dumping [4]. Furthermore, the implementation of sustainable public procurement is a strategic instrument for sustainable development as well as for the larger goals of environmental, social and innovation policies. Since public authorities possess a significant purchasing power, they can play a key role in promoting sustainability, by integrating in their procurement strategies [4] sustainable and innovative considerations.

Originating from this research, this paper is aimed at supporting solutions to important challenges and problems in the field of public procurement (e.g., corruption, lack of transparency, lack of sustainability and of the smartness which may feature in public procurement) and at offering recommendations/alignment solutions of public procurement to the new directions (digitisation and innovation). In order to attain this desideratum, we reviewed the public procurement trends as well as the potential impact of emerging technologies such as blockchain and the Internet of Things (IoT) on this field. In regard to the use of emerging technologies in public procurement, current research consists in hardly a few studies/practices/uses, in particular in the sphere of the Internet of Things. In addition to that, our aim is also to pave the way to new research directions with a specific focus on public procurement as well as to develop knowledge in this field.

The spectacular development of ICT in the last few years has left a mark on specific activities from all spheres of human existence, from the individual to the social scale. Consequently, the emerging technologies are nowadays no longer developed in a biunivocal relation with a certain sector of activity, but, through their interoperability, they can address an increasingly large number of activities and services, as well as daily individual and/or organisational concerns. The most aggressive of them are artificial intelligence (AI), cloud/fog computing, the internet of things and blockchain. The ICT developments make is possible to resort to new technological approaches, which may support the achievement of smart and sustainable public procurement processes and thus generate benefits and innovation both at national and international levels. Among the emerging technologies that come with the promise of real benefits, we will review blockchain technology and the IoT (BIoT).

Should blockchain be integrated with the IoT, we expect a higher speed, better security and an easier traceability throughout the supply chain. The IoT may enable the interaction with the input data resources and the output applications within various field of activities [5] and [6]. The adoption of smart contracts will represent a step forward, because they are perceived as a result emerging from two lines of technological developments: electronic contracting and cryptography [7].

Blockchain comes in support of central administrations through a series of potential benefits, such as [8]: a reduction of economic costs, of the time and complexity involved in intergovernmental and public-private exchanges of information; less red tape, discretionary power and corruption through the use of the distributed ledger technology and smart contracts; increased automation, transparency, audit and importance of information in the governmental ledgers, all of them to the benefit of the citizens; increased trust of the citizens and of the companies in governmental processes and record-keeping according to algorithms that are no longer under exclusive control by the government.

Different urban infrastructure systems may thus incorporate smart digital technologies [9] assisted by a cognitive IoT that would supply real-time sustainable data (in regard of energy, pollution, the carbon footprint and climate change) that are essential in the circular economy. The digitalisation of public procurement may support the daily business tasks, facilitate complex decision-making and lead to the development of those activities that are strategic by nature [10]. The technologies currently used in procurement focus on some of the specific processes, such as e-sourcing, contract management and e-procuring [11].

Starting from the current problems in the field of public procurement as well as the potential benefits that the two emerging technologies may contribute to achieving the proposed research objectives, this paper is structured into the following sections: section II describes public procurement trends and the outcomes of the blockchain and IoT technologies when used to achieve smart public procurement; section III introduces the research objectives and the assumptions regarding the impact of adopting BIoT in public procurement; section IV presents aspects related to methodology and data sources; section V presents the results of a survey – conducted in Romania – on the use of BIoT in public procurement, as well as general recommendations and actions. The final part of the paper introduces the main conclusions, the limits of the study and future research directions.

II. LITERATURE REVIEW ON PUBLIC PROCUREMENT

The chief trend in public procurement, which emerges even on the background of the pandemic crisis, is still the centralisation and the uniformity of the requests launched by the contracting authorities. The instrument that enables such public procurement developments is a dynamic procurement system. On top of this chief trend, discussions increasingly focus on the notion of sustainability in public procurement as well as on the use of emerging technologies in order to modernise public procurement, which are the trends subject to our further review.

A. SUSTAINABLE PUBLIC PROCUREMENT

The notion of sustainable public procurement rests on three pillars: the economic, environmental and social pillars. A Sustainable Public Procurement (SPP) refers to the unanimously accepted triad of sustainability – environmental protection and the identification of alternative resources, the social dimension and economic growth [12].

From the environmental perspective, green public procurement (GPP) is a process by which contracting authorities procure goods and services with a low negative environmental impact throughout their life cycles. The public procurement mechanism is at the core of procurement in any public organisation, because the related activities have a major influence on achieving the final performance, which either strengthens or hinders policy decision-making [13]. The European public authorities are among the largest consumers. They may make a significant contribution to GPP [14] by using their purchasing power to select goods, services and works which comprise a significant green component.

Sustainable public procurement is considered a wider procurement practice aimed at striking an adequate balance between the pillars of sustainability in procurement [4]. Sustainable public procurement may contribute to sustainable economic growth – now and after the pandemic crisis. The reforms implemented in the last few years have come with increased flexibility in the manner in which procurement is carried out by public authorities across the EU and have made it possible to consider the sustainability performance of the goods, works and services procured by the public sector. Nevertheless, sustainable public procurement is not yet the standard [15].

There is clear evidence that SPP has had a positive influence on national economies as well as on the world, as a whole. An efficient SPP programme may show how seriously a government addresses the efficient use of the resources, so that the individuals and the private sector may follow suit – "the demonstration effect". There are also other, indirect benefits [12]: the reduction of the CO2 emissions; lower costs; the transfer of skills and technologies; fostering innovative solutions to the local needs; empowering underrepresented groups; job creation. Sustainable procurement may reduce costs, boost innovation and market competitiveness and thus generate savings across the life cycle of the public procurement process [4].

The different experiences in the field have outlined concrete sustainable procurement scenarios. Most of these scenarios point to three main elements [15]: (1) the professionalisation of the contracting function; (2) the obligation to follow up and monitor risks across the supply chain (3) the creation of a "friendlier" legal environment for public procurement. Nevertheless, sustainable public procurement is faced with challenges and barriers, such as [12] the scope of application; legislation; governmental capacities; increasing supplier capacity; certification/checking; life cycle analysis; life cycle cost; inter-departmental cooperation.

B. SMART PUBLIC PROCUREMENT

Smart public procurement can be defined as the kind of procurement that intensively relies on advanced technological approaches and incorporates a smart component at every step of the process coupled with the procurers' creativity and their expertise in solving complex issues. In order to attain sustainability in procurement, smart public procurement requires the use of new technologies, such as the artificial intelligence, robotic process automation (RPA), IoT or blockchain.

Artificial intelligence, through different forms of machine learning (ML), natural language processing (NLP), big data or advanced analysis, is best suited to collecting and analysing data. Different AI forms have experimentally been put into practise, but not all of those experiments have led to the desired results - an ML pilot project was run in Finland to classify data according to UNSPSC (the United Nations Standard Products and Services Code), but the solution did not lead to the desired results and it is not currently in use; in Ukraine, a solution was created to predict the product CPV code (Common Procurement Vocabulary), but it was not integrated in the public procurement systems; Australia developed and AI – CAITY instrument which automatically classifies the data and was also fully implemented, countries such as Belgium, Belarus, Slovenia and Brazil carried out experiments with advanced analyses and Big Data and disclosed their positive experiences [16]. Moreover, AI is also an important component in the architecture of the 6G system and plays a significant role in the self-organisation and self-configuration of the wireless 6G systems used in IoT [17].

RPA makes it possible to automate repetitive steps and may perform basic tasks, for instance, it may check the filling out of a form or update a calculation sheet, by following the steps established by the procurers. Different countries, such as Finland or USA have obtained positive results by implementing RPA [16].

The IoT makes it possible to create a global network of smart devices, which enables data collection and sharing, the monitoring of inventory levels (stock management), the creation of virtual prototypes of real-world products, as well as the design of assistance gateways or virtual markets.

Nevertheless, the IoT comes with security challenges related to the internet-connected devices.

Blockchain offers a safe and transparent manner of following public money as well as other data, since all the transactions are indefinitely recorded and publicly visible (the officials will not be able to hide official payments or records, or manipulate things from the inside or the outside, which grants process traceability and transparency [18], [19]). Blockchain enables individuals to independently check transactions, ensures data and signature security, enhances price transparency and helps cutting down red tape. Thus, blockchain enables responsibility and security in the management of official records [20], [21] and obstructs corruption, altogether making governmental services more transparent and efficient [22].

Blockchain-based techniques are viewed as technical and economic innovations [23]–[25], especially in fields such as governance, healthcare, science, literature and arts [26], and have turned into a key factor in solving the scalability, confidentiality and reliability issues directly linked to the IoT paradigm [27]–[29]. Blockchain has a considerable potential of facilitating inter-organisational verified data sharing, which is also confirmed by a series of already implemented projects (Public Services and Procurement Canada, Province of British Columbia, Indigenous and Northern Affairs Canada, Department of Health and Human Services, USA [16]). Blockchain may also be successfully integrated with other digital technologies in order to grant transparency and auditability in the evaluation of procurement procedures (Blockchain-based Proposal Evaluation System proposed by the Republic of Korea, the blockchain ecosystem implemented in Mexico [16]).

One of the practical blockchain uses in public procurement is what is known as a smart contract. A smart contract possesses an autonomous and automated self-performance capacity. It involves no intermediary agency, does not depend on the authorities or third parties [23] and builds on the consensus of the network users [30] and [31]. Among other things, smart contracts can be used to automate bid evaluation, to negotiate contracts or make the payments attached to them [32].

When used in public procurement, emerging technologies may represent a strategic instrument for building smart cities, because they allow municipalities to signal their investment intentions, to engage in long-term planning and promote values through sustainability and inclusion criteria [33]. Smarter public procurement approaches should be further developed and adopted on a large scale [4]. Considering the main focus of this article, we will further analyse blockchain and the IoT technologies as well as the consequences of BIoT on public procurement.

C. BIoT IN PUBLIC PROCUREMENT

At the time of this research, we are not aware of any concrete achievements regarding the exhaustive implementation of the BIoT paradigm throughout the entire public procurement chain. From a functional perspective, this paper further explores the main conceptual aspects of the adoption of BIoT in public procurement. Figure 1 shows the stages in the process of public procurement as well as suggestions on the use of technologies such as blockchain (**B**), smart contract (**SC**) and the **IoT** at each of these stages, as pillars of sustainable and smart procurement. These emerging technologies may be appropriate to avoid unwanted situations within the framework of public procurement procedures, such as, for instance: **N1**: corruption in the system by internal manipulation of the documents; **N2**: preferential drafting of the awarding specifications **N3**: biased evaluation of the bids, either because of incompetence or corruption; **N4**: potential favouring of one bidder; **N5**: excessive use of resources and environmental pollution; **N6**: delays in supply and/or the supply of other products/ services.

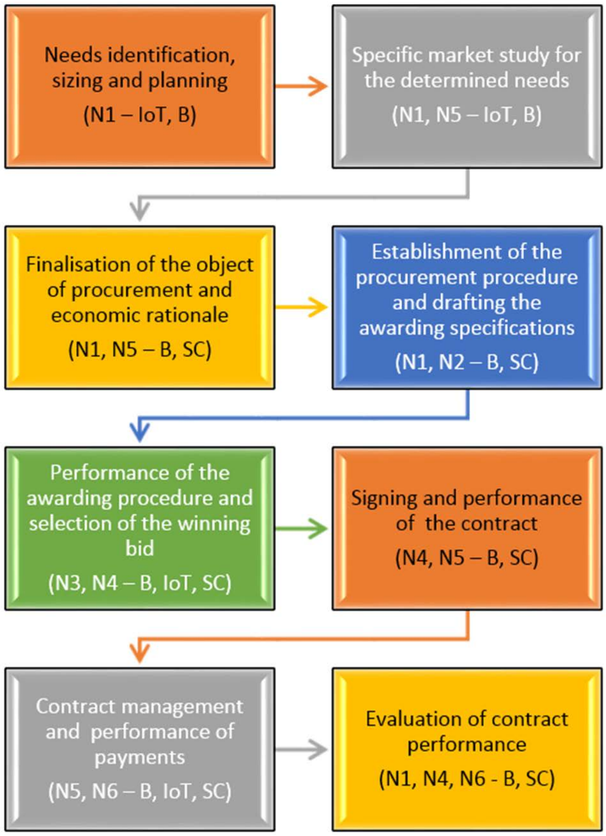

FIGURE 1. A BIoT-based conceptual environment in support of sustainable and smart procurement.

The six unwanted situations are among the most frequent drawbacks that the public procurement process is faced with. These situations are confirmed through the public complaints filed by the economic operators interested in the ongoing procedures (N1, N2), through the complaints lodged by the participants in the procedure (N3, N4), or through the reports written by the related contracting authorities charged with monitoring public procurement (N1-N6).

Doing away with such unwanted situations will ensure better quality in the procurement procedures. The IoT, for instance, may be used to enhance the efficiency of stock management (through warning sensors when the security levels of stocks are reached etc.) and eliminate the **N1** kind of situations, blockchain may be implemented to eliminate the badly-intended bids and so on.

As it emerges from figure 1, blockchain may be used at all the stages of public procurement. For instance, at the stage of *Performance of the awarding procedure and selection of the winning bid* which is highlighted in figure 1, the working framework for the use of blockchain, IoT and smart contract is detailed in the SDL diagram (Specification and Description Language) shown in figure 2.

Generally speaking, the blockchain generating flow may be achieved in six steps: step 1 starts when one party demands a transaction; step 2 consists in the fact that the demanded transaction is transmitted in a peer-to-peer network (to every network node); under step 3, once every node receives the data, the network will validate the transaction (together with the status of the applicant) according to an algorithm; step 4 consists in the representation of the transactions which are validated as a block and in adding them to the public blockchain register; at step 5, the blocks are added to the existing chain and afterwards the transaction is completed (step 6) [34]. In regard of the BIoT infrastructure, most of the research studies suggest their own different implementation frameworks in different fields of activity: BIoT architecture including a composite blockchain layer with a middleware function between the IoT and industrial applications [34], a service oriented architecture for BIoT [35], BIoT system operation and BIoT architecture [36], a comparison between two proposed architectures to incorporate blockchain into IoT scenarios [37].

The current status analysis must consider both the papers/reports that introduce the advantages of using blockchain and the IoT and those which describe the challenges/risks/issues. According to [1], in the EU at least, there are rather limited short and medium-term perspectives of a significant revolution based on data and a blockchain-activated automation in the governance of public procurement.

Table 1 shows a summary of the necessities and motivations which supported the setting up of the research objectives as well as the formulation of the six hypotheses (to be detailed and verified in the next sections), which also evinces the main contributions of the proposed model.

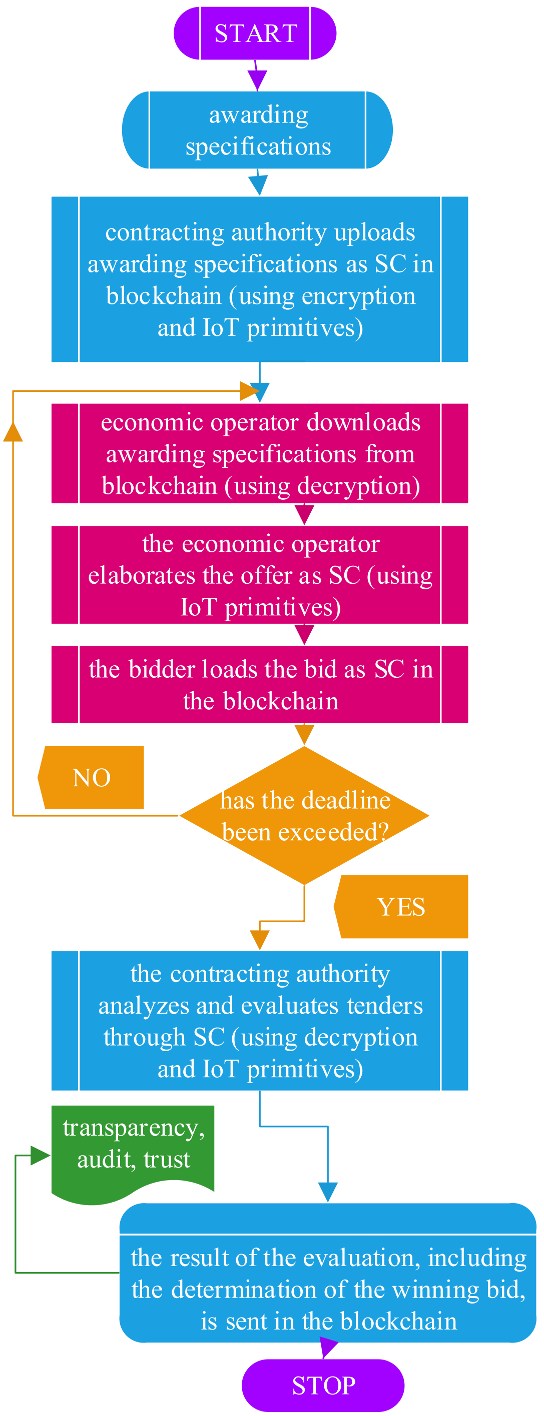

FIGURE 2. SDL diagram of the bid evaluation stage in the public procurement process.

III. RESEARCH OBJECTIVES AND HYPOTHESES

This paper is a qualitative study on the impact of BIoT when used in public procurement. This section is aimed at defining the hypotheses related to the main benefits and challenges of adopting BIoT in public procurement. The hypotheses will be further analysed and validated through a survey conducted within the ranks of the main stakeholders involved in public procurement in Romania.

Similar to other fields, it is not enough to adopt one technology in the domain of public procurement to generate well-performing procedures and support a smart public procurement ecosystem. This is the reason why our research focuses on the adoption of interoperable emerging technologies such as blockchain and the IoT as a means to support the achievement of smart public procurement. When

TABLE 1. Summary of the necessities/motivations and contributions of the proposed conceptual model.

Necessity	Motivation based on related literature	Contributions
Smart public procurement	- smarter approaches to public procurement should be developed and adopted on a large scale [4]; - low public procurement efficiency and their pulse for some countries in Europe [38], [39].	- the paper analyses the manner in which BIoT may support the implementation of smart public procurement - hypothesis validation: H1. The adoption of BIoT has a positive impact on carrying out smart public procurement
Sustainable public procurement	- sustainable public procurement may reduce costs, may stimulate innovation, may generate savings [4]; - sustainable procurement is faced with challenges and barriers [12]; - sustainable public procurement is not a standard yet [15]; -not all countries have adopted the GPP plan which the EC recommended as early as 2006 [40].	- the authors analyse the extent to which blockchain and IoT may support economic, environmental and social sustainability in the field of public procurement - hypothesis validation: H2. The adoption of BIoT has a positive impact on carrying out sustainable public procurement
Current problems/challenges in public procurement	- hampered budgetary control [1]; - many times, for reasons of lack of transparency, governmental organisations do not achieve their own objectives [41]; - in some cases, there is an excessive presence of the bribery phenomenon [2], [3]; - relatively high corruption levels perceived in the public sector [42];	- the authors tackle the current challenges and problems related to lack of transparency and/or trust in public procurement as well as the problems generated by corruption and fraud and identify the manners in which the two technologies may support the limitation of these problems - hypotheses validation: H3. The adoption of BIoT has a positive impact on transparency and trust in public procurement and H4. The adoption of BIoT has a positive impact on reducing corruption and fraud in public procurement
Advanced studies related to blockchain and BIoT	- blockchain comes to support central administrations through a series of potential benefits [8], [16]; - a blockchain-based automation in the governance of public procurement is rather limited on the short and medium term [1], which also implies real implementation concerns [43]; - in regard to forecasting, the creation of an inventory register and automatic orders, no case was found related to the IoT use in the context of public procurement [16]; - the confidentiality of the users of the IoT devices is a major concern [44]; - the IoT and blockchain integration may result in several challenges (e.g., low throughput, network scalability) [45], data security and technological interoperability [46]); - other studies are required on the relevant aspects related to the security of complex systems such as blockchains (different types of attacks on the networks) [47], [48] and - the sharing schemes that make use of the blockchain method to store IoT information [49].	- the authors identify the main problems/challenges related to the integration of blockchain and IoT in public procurement and formulate recommendations for the modernisation of the public procurement system - hypotheses validation: H5. The adoption of BIoT causes challenges related to technological integration and organisational reengineering and H6. National and international policies have a positive effect on the adoption of BIoT in public procurement

applied in conjunction, the two technologies may converge in supporting new platforms, products and/or services.

The research objectives in our study are the following:

O1. The identification of the main benefits and challenges related to the adoption of blockchain and IoT in public procurement;

O2. The validation of the proposed theoretical model based on studies/practices in the field and empirical data and recommendations on the modernization of the public procurement system.

The following section details the six proposed hypotheses addressing the impact of the adoption of BIoT in public procurement. In developing the hypotheses, we considered the current status of the research on blockchain and the IoT technologies as well as of their adoption in the public procurement activity.

H1: The adoption of BIoT has a positive impact on carrying out smart public procurement

Many times, hybrid technological solutions may represent the way ahead to ensuring the efficiency and profitability of different economic activities. Consequently, the use of the BIoT combination in the field of public procurement may open new operational and commercial opportunities. For instance, the parties involved may resort to the IoT to label the goods and connect to a cloud system all the relevant information included in these labels. The IoT offers a profitable solution and enables faster decision-making, which facilitates the main goal of stock management (a suitable product, in adequate quantities, in a proper location, at the right time and at affordable prices). Moreover, this strategy comes with a lower unit cost, a reduction of the manufacturer's retail price and of the pending order quantities. Whenever a shortage occurs, it is communicated to the other component through the cloud uploaded data [50], [51]. Concurrently, when the IoT is adopted, the transaction may be independently performed. Whenever the sensors find a shortage of specific products, they will relay their identity data to a computer, based on the supply renewal agreements and the price decisions. Consequently, the necessary quantity will be automatically calculated and sent over to the supplier side of the agreement [52]. By introducing special labels, the IoT system is also able to identify and recognise the changes of different elements (materials, price, and quality) and select the adequate suppliers for cooperation at a later time [53]. The IoT also allows to prioritise different issues that may occur in this smart system, whereas the smart calculation systems and the entities at play will adopt an adequate solution and communicate every aspect that should be changed/adapted across the network [54].

The adoption of the IoT may facilitate communication and the exchange of information between the parties. Most of the performance-related information collected through machine learning for instance, may be shared with different parties at play across the procurement management system [55]. Moreover, there are other aspects which may be improved through the use of the IoT technologies, such as costs, contracting, launching orders and audit, since the IoT components may be directly connected to databases and directly accessed from there [56].

In spite of this potential, there is only limited evidence regarding the use of the IoT by the public procurers with the purpose of transforming the specific operations. In respect of aspects such as automatic forecasting, counting of stocks and orders, we failed to identify any situation in which the IoT is used in the context of public procurement [16].

One reason for this status quo reflects one of the major challenges of the IoT, i.e., security. In answer to that, blockchain comes to counter the IoT challenges, by building trust, reducing costs, promoting an accelerated data exchange and ensuring security [57].

Blockchain technology also makes it possible to reduce the time needed to cover the public procurement process through the digital approval of the document flow. Furthermore, transactions are stored in an indestructible (read-only) format, which enables public institutions to follow the way funds are allocated as well as the expenditure patterns. The use of smart contracts also provides for the automatic performance of more complex transactions, which cuts down the reporting and meeting time.

On top of that, blockchain-based smart contracts deliver other benefits such as the immutability, decentralisation, transparency, representation, self-execution and verifiability of the agreements [58]. Additionally, smart contracts vouchsafe the execution of a contract (the neutrality principle) as well a more efficient delivery of the digital and/or tangible services and goods [19]. These aspects may also represent a massive simplification of the audit process, since they suppose an automatic follow up and the alert of the parties, precisely at the right time. Moreover, the blockchain-specific distributed ledger is a source that informs the audit and facilitates an audit-response. Intelligent contracts have been experimented both at the external stage (supplier verification, selection of the offer) and at the contract management stage (delivery check) [58].

H2: The adoption of BIoT has a positive impact on carrying out sustainable public procurement

In regard of increasing sustainability in public procurement, it is necessary to make significant research efforts in order to investigate more closely the benefits as well as the drawbacks of the adopted technologies. Reference [59] makes reference to several papers in support of the fact that, altogether, the IoT, blockchain and smart contracts generate more sustainability across the supply chain for each of the three pillars: economic, environmental and social.

A. ECONOMIC SUSTAINABILITY

In the scenario in which the BIoT is used in the procurement process, each actor possesses RFID (Radio-Frequency Identification) sensors, an IoT infrastructure and blockchain. This way, the products are completely followed and certified, whereas the use of smart contracts may enable the automatic management of the orders between the client and the supplier.

Blockchain allows for a lower time to delivery, for faster monitoring of the goods and may help reducing potential losses due to human error or futile bureaucratic activities. All these things result in optimising quality by eliminating dead time, reducing costs and by resource savings [59]. The development of digital technologies for information and communications has made it possible to create new organisational and operational processes and methods that may potentially improve an organisation's productivity and competitiveness.

B. ENVIRONMENTAL SUSTAINABILITY

The fast-paced development of the IoT leads to using more devices and more of the limited resources as well as to higher energy consumption for all these devices, which may harm the environment. On the other hand, the use of emerging technologies allows for: the elimination of useless travel and the optimisation of container loading plans; the use of digital documents, which is an improvement in environmental protection; product features' screening (origin, quality, quantity, owners and time-to-delivery) in order to improve recyclability and the carbon footprint; the identification of the carbon emissions for each company, which spotlights aspects such as pollution and the exhaustion of the energy sources; defining incentives for the organisations that are more environmentally friendly; streamlining the transport activity and reducing greenhouse gas (GHG) emissions; lower waste volumes [59]. Moreover, the BIoT combination may identify the necessary resources and their allocation algorithm in order to deliver on economic competitiveness, on efficient waste disposal and on reducing energy consumption [60].

C. SOCIAL SUSTAINABILITY

The IoT's aggressive emergence may cause an impact on the social pillar, because it restrains human contact and cuts down those lucrative activities which may be automated [61]. Furthermore, blockchain automates numerous working processes and flows, which causes intermediate jobs to disappear and compound the traditional unemployment. A solution to such problems supposes a radical change of at the level of employee skills and obsolete jobs. Consequently, the companies implementing such systems may establish semi-permanent relations with partner entities dealing with professional reskilling and training [59].

H3: The adoption of BIoT has a positive impact on transparency and trust in public procurement

On the global arena, there are several initiatives regarding blockchain in public procurement, such as those in Peru, Mexico, Canada, USA, Chile, Japan [19]. These countries have made their experience public and advocate the use of blockchain in public procurement. This approach should be adjusted to fit different models, in line with the legislation of the country where they are implemented. We may recall, however, the common themes and activities which support the adoption and implementation of an IoT-blockchain combination in public procurement [32]. Essentially, a BIoT solution in public procurement supposes that the IoT should allow the internet-connected devices involved in the procurement process to send over the data to private blockchain networks and thus create forgery-resistant records of the shared transactions. The owners of the blockchain networks are either the contracting authorities or the economic operators, as the case may be. The blockchain components enable business partners to share and access the IoT data, while there is no need for central control or management. Each transaction is verifiable, which prevents disputes and builds trust across the authorised members of the network associated to the public procurement process [62].

By means of consequence, blockchain-facilitated public procurement may help achieving a higher number of efficient, transparent and less dispute-inclined procurement procedures [63]. A report published by IBM in 2017 considered the involvement of the government in the distributed ledger technology. The report describes how blockchain technology can achieve transparency in public procurement and explains that governmental organisations often fail to attain their own goals because they lack transparency [41].

Blockchain facilitates the use of the smart contracts, which results in higher system transparency, improved speed in payment processing and lower intermediate expenses. Any record can be checked and safely transferred in a blockchain network, which results in better public procurement transparency. Blockchain may also be expanded so as to include the automatic sharing of the performance data administered by different organisations that manage ongoing contracts with the same suppliers.

The BIoT technology may provide security to the public procurement data, facilitate e-procurement and contract signing [64]. Transactions will be permanently recorded and kept unaltered in blockchain, a feature that builds trust across the system. Blockchain also provides an unchangeable audit trail which makes it possible for the participants to know who performed which action and when. This blockchain feature creates transparency and mitigates the risk of losing the data in the interaction with third party systems [65]. Blockchains may offer security and anonymity, improve the integrity of the transaction-associated data and eliminate the need to have a third party involved [55]. The security feature is ensured by the distributed nature and the encryption algorithms, all of which create transparency and trust in the blockchain data for all the stakeholders [16].

H4: The adoption of BIoT has a positive impact on reducing corruption and fraud in public procurement

Lack of transparency at the internal stage of assessing the needs and drafting the contract specifications is one of the reasons why corruption is high in public procurement. The specifications can be developed in such a way as to privilege specific bidders (the so-called *dedicated bid writing*) [66]. Other fraudulent practices creep in at the stages of formalizing the call, planning a contract or selecting the suppliers. Fraud also commonly occurs in the process of contract management. We may consequently look at accepting counterfeit or damaged goods as if they were legitimate or perfect, or at approving the delivery of products which depart from those specified in the contract. Fraud may practically occur at all the stages of the public procurement process. According to the research in the field and the actual experiences of a series of countries, BIoT may contribute to cutting down fraud across the stages of the public procurement process.

Corruption and fraud in public procurement may be counteracted by adopting IoT-based systems which are able to identity counterfeit products. It is possible for such systems to be put in place either through a blockchain solution or traditional identifiers. Either way, the basic functionality includes a unique identifier coupled with traceability along the movements of the products, in order to offer transport related data across the value chain. All the suppliers and producers must adopt a single system, such as a blockchain platform and use ''smart labels'' to follow and confirm the origin and location of each item. By using the IoT instruments and the operational research models, metaheuristic networks or machine learning, we can define the metrics needed to evaluate the procurement processes and to narrow the penetration of corruption [67].

In regard of blockchain, the main characteristics addressing the reduction of corruption are divided into two categories: (1) the decentralisation of information and (2) the transparency of information flow [68]. The decentralised nature of smart contracts is a potential attribute at play in mitigating corruption and fraud in procuring [63]. When blockchain-based smart contracts are used, we can no longer deal with the monopoly of centralised control throughout the process [58]. To reduce corruption and fraud, it is essential to use smart contracts at the stage which potentially involve forged records or the disclosure of information when it is not justified.

Additionally, the use of BIoT in public procurement may result in the elimination of the intermediaries, which, in turn, reduces the likelihood of bribery and corruption [2]. Attempted fraud in procurement can also be mitigated by using immutable data, since they allow no intervention. Since all events are transparent and verifiable by all bidders, blockchain can also prevent corruption and fraud in the management of the awarded contracts.

In spite of all its potential benefits, BIoT is far from being the panacea for the purpose of eliminating corruption and fraud at all the stages of the public procurement process. In other words, the levels of corruption and fraud in procurement cannot be limited with one technical solution, as long as there are decisions endorsed by different individuals acting outside the electronic procurement systems [66], [68].

H5: The adoption of BIoT causes challenges related to technological integration and organisational reengineering

Similar to any other change in paradigm, the adoption of BIoT in public procurement calls for a cost-benefit analysis of its use in comparison with other specific solutions. Such an analysis should consider the already reviewed potential benefits on the one hand, and a host of challenges related to the public procurement processes, on the other. These challenges are divided into two levels: those specific to technological integration in the context of BIoT and those related to organisational reengineering from the perspective of ensuring the operational status of the new public procurement paradigm.

The contracting authorities in the public sector may be faced with integration challenges stemming from the use of the IoT in the procurement processes. Thus, public employees may show reluctant to using technology, chiefly because they lack the IoT-specific skills, the organisation is short of a strategic vision and of leadership and there pervades a refusal to take the associated risks in procurement. We can add to all that the main aspects of the procurement policies within an organisation, the relative incertitude related to the privacy of actions, data security and technological interoperability [46]. These integration challenges are first of all rooted in the universal model of change that the employees should adopt. This model accompanies an employee that is "forced to change" through the stages of denial, awareness, internalisation and integration.

A real concern in the field of data protection is the potential discrepancy between blockchain and the General Data Protection Regulation (GDPR), hence another challenge. According to [43], the discrepancy regards two major aspects: 1 – the absence of a data controller (an entity that safeguards individual rights according to the legislation that governs personal data protection in the EU) and 2 – the impossibility to alter/delete the recorded data, which is specific to blockchain (in contradiction with in the GDPR).

Another challenge is connected to the fact that smart contracts are typically designed to be unalterable. This element may give rise to inconsistencies in the alignment with the legislation that governs the procurement procedures. An additional obstacle that smart contracts should overcome stems from the fact that there is hardly any harmonisation in the regulation of evidence and the interpretation given by courts is largely dependent on the national judiciary systems [69]. Consequently, when it comes to public procurement, one major issue is the extent to which public contracts can be turned into smart contracts, either partially or on the whole. We should also ask the question whether the benefits that smart contracts provide, such as cost savings and increased efficiency may be turned to good account for the contracting authorities and the suppliers alike and also for the citizens, in the long run [69].

Last but not least, the adoption of a new technological paradigm in the daily business of an organisation necessarily means reengineering that organisation. Organisational reengineering shall focus on at least three aspects (generated by the particular architectural profile of an enterprise): (1) information system reengineering, (2) ICT reengineering and (3) business reengineering. The BIoT governance will generate a specific impact on all three aspects, such as on information redundancy, information/decision-making flows, the semantics of information etc., as well as on the network levels, transmission speed, bandwidth, data centre capacity etc., and on workflows, management paradigm, legislative adjustment, business intelligence etc.

H6: National and international policies have a positive effect on the adoption of BIoT in public procurement

The adoption of BIoT in public procurement requires specific resources and generates new costs, such as the cost of training the related staff, the borrowing cost, or the cost related to the time resource. In addition to that, any technological metamorphosis involves development costs as well costs related to operational complexity and flexibility. Moreover, a large amount of additional cost is generated by the energy consumption required in the operation of blockchain technology [66]. We can add to that the costs generated by the operation of the IoT infrastructure and the transaction costs, which proved higher for the permissionless blockchains than for centralised solutions [8].

The BIoT-dedicated national and international regulations are important drivers of the modernisation of the procurement system as well as of securing the research and modernisation funds in this field. The IoT and blockchain are emerging technologies that are considered in the modernisation of different fields of activity, both at national level and across the world. Elsewhere in the world, we can witness large IoT and/or blockchain implementation initiatives in China, The United States of America, Japan, India, South Korea, Canada, the EU as well as in other countries where complex programmes have been implemented through private-public partnerships – a potential starting point for other countries as well. These initiatives are complemented by the experience of using the IoT and/or blockchain in public procurement, an additional step in promoting the benefits of these technologies and towards their increased integration in the systems of more countries in the world.

As far as Romania, an EU member state, is concerned, we must also consider the European policies/strategies aimed at fostering/supporting the implementation of the IoT and blockchain. Every country will also add its own initiatives and efforts to these EU strategies. In spite of all this work, the use of blockchain and of the IoT is still incipient and calls for advanced research.

On the IoT side, there are several European support initiatives such as: The European IoT Hub, Alliance for Internet of Things Innovation, Horizon 2020, which allocate funds for the IoT-centred research and development, with projects funded as early as 2017, based on the DEI (Digitising European Industry) strategy.

From the perspective of the development and implementation of blockchain technologies, the EU promotes several initiatives in order to achieve a coordinated approach in Europe, such as: The European Blockchain Partnership, The European Blockchain Services Infrastructure, The European Blockchain Observatory and Forum, The International Association for Trusted Blockchain Applications. Although by April 2020, only five of the EU27 had a national blockchain strategy published [70], there are ongoing blockchain use initiatives in several other member states, among which Romania. Romania ranks 23 in EU27 [70] in point of number of small and medium-sized enterprises (SMEs) that make use of AI and blockchain. In regard of financial support, the EC is planning to allocate grants for blockchain through several programmes under the EU multiannual financial framework for 2021-2027 [70].

Figure 3 introduces a theoretical model based on the six hypotheses already described. Based on these hypotheses, together with the ICT and public procurement experts, we next identified the questions to be included in the survey aimed at the validation of the hypotheses that we included in the model.

IV. METHODOLOGY AND DATA SOURCES

This section introduces information about the implemented instruments, data about the current status in Romania as well as the features of the data collected in order to analyse the BIoT impact.

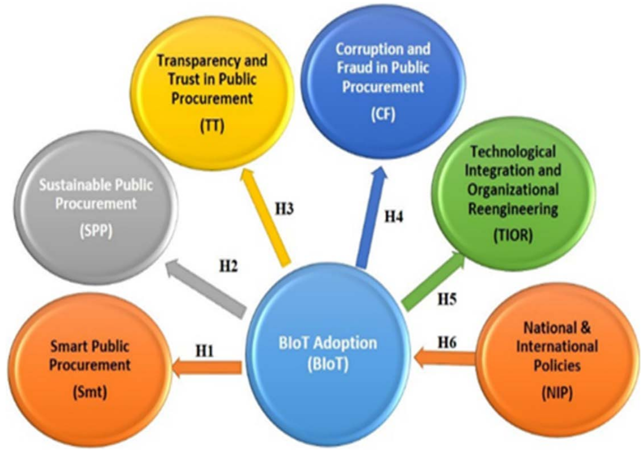

FIGURE 3. Proposed theoretical model and the developed hypotheses.

A. IMPLEMENTED INSTRUMENTS

In order to validate the proposed model, we used the Partial Least Squares Structural Equation Modelling (PLS-SEM) and the SmartPLS software. The selection of the SEM approach relied on the features and the objectives that distinguish the two SEM methods, i.e., CB-SEM (Covariance-Based SEM) and PLS-SEM, on the advantages of the PLS-SEM method [71], [72] as well as on the particulars of the proposed model (a theoretical framework to be tested from the predictive perspective, a model of high complexity due to the high number of constructs and indicators, a small size sample). Moreover, we looked at the research dealing with the most appropriate tools and at the research studies on how to test the hypotheses when a study is exploratory in nature, the model is complex and the sample is small.

The model described in figure 3 was analysed in two different instances: the measuring model, which defines the relations between the indicators and the latent variables and the structural model, which comprises the relations established between latent variables. By using SEM, we developed a model with seven latent constructs and 42 indicators that influence the quality of the observed variables.

B. CURRENT STATUS IN ROMANIA

The electronic public procurement system (SEAP) in Romania has gradually developed since 2002, not only because the country had to align to the European public procurement legislation, but also in response to the different national challenges/problems [73]. In March 2021, The Authority for Digitation in Romania (ADR) announced a new functionality of the SEAP platform – The Dynamic Public Procurement System (SAD). SAD consists in a completely electronic system, an *open market* designed to help public institutions access a group of economic operators able to perform the required activities. The new functionality is already available on the ADR-managed SEAP platform [74].

In regard of *public procurement efficiency* and the pace of procurement in Europe, the EC included in the Single Market Scoreboard a set of 12 quality-price reporting indicators for public procurement. Thus, the EC actively developed a set of functional performance measures and indicators (in a matrix format) that makes it possible to compare relative public procurement performance across member states [38]. Romania has reported a series of unsatisfactory results for the matrix of indicators. The same unfavourable situation of the Romanian procurement system is also reflected in the paper [39], which relies on its own system of indicators.

In regard of *environmental* protection, in 2006, the EC already recommended that at least 50% of all public procurement should be green procurement [40]. To be able to achieve this desideratum, the Commission recommended every member state to adopt a GPP National Action Plan. Although, in 2016, Romania committed to implementing this plan (Law no. 69 of 2016 on green public procurement), it is among the last five countries which still have to adopt the GPP action plan. In 2018, the government approved a guidebook on green public procurement (Order no. 1068/1652/2018 of November 4, 2018) which included the minimum environmental protection standards for certain products and services. Nevertheless, there is currently no monitoring and measurement system in place for the adoption of green public procurement in Romania [40].

In order to measure *transparency, correctness and integrity of activities/processes/procedures*, we may resort to the Corruption Perceptions Index (CPI), an indicator that measures the levels of corruption perceptions in the public sector. Romania ranks 66 out of the 180 reviewed countries in 2021, with a score of 45 points (0 meaning highly corrupt and 100 meaning very clean) [42]. The CVM (Cooperation and Verification Mechanism) reports of the EC are a source that allows us to see the corruption trends in public procurement. Starting 2014, the Romanian Government has acted on the requests and the criticism expressed by the EC and has made efforts to counter corruption and fraud in public procurement.

In regard of the *emerging IoT and blockchain technologies*, they are not used yet in the public procurement system in Romania. There are, however, a series of related initiatives in place in Romania such as: there have been launched IoT-based governmental programmes aimed at increasing social engagement in e-governance; there has been created the ECOnsultare.ro platform, the first online consultation and voting instrument in Romania based on a blockchain system; the development of advanced digital competencies for emerging technologies (AI, blockchain, IoT etc.) of ICT experts; the adoption of the legal framework and secondary norms for Romania's digital transformation through policies such as digital first, cloud first, the support for projects such as AI, blockchain, RPA, Open Data etc. (through the 2020-2024 Governmental Programme).

This status quo, in corroboration with the local SEAP development measures and the initiatives aimed at adopting the BIoT emerging technologies do represent the necessary premises for this research, with Romania as a case study advocating for modernisation and increased efficiency in public procurement.

C. DATA COLLECTION

The data were collected though a survey mainly addressed to public institutions (contracting authorities) in Romania as well as to the economic operators involved in public procurement contacts. The survey used a Google-web form and was sent out to 318 potential respondents, entities that currently operate in public procurement or in related fields (management, legal, financial-accounting, ICT etc.). The survey targeted both the public sector (universities, local administrations, national authorities in the field of public procurement), as well as the private sector (SEAP-enrolled economic operators – potential participants in public procurement procedures around the country, non-governmental organizations (NGOs)).

The authors of this research had a major role to play in the materialisation of the survey, since, they collectively possess more than 12 years of experience in the performance and management of public procurement and more than 20 years of experience in the adoption of ICT in different fields of activity. Additionally, their participation in public procurement training programmes and their connections with experts from complementary fields made it possible to select the survey participants and obtain an adequate number of valid answers.

The questions included in the survey took into account the respondents' profiles, their level of education, the field of activity, the domain in which they are currently active, the length of their experience (seniority) in the field, their knowledge about blockchain and the IoT and, on top of that, 42 of the questions addressing the measurement of latent variables (table 2). We used a 5-point Likert scale (where 1 is strong disagreement and 5 is strong agreement) to measure the answers to the items included in table 2.

V. RESEARCH OUTCOMES AND RECOMMENDATIONS

In regard of outcomes, the research was aimed at the analysis of the collected data, at checking the validity of the model and extracting the main conclusions. All of that was complemented by discussions and the development of recommendations regarding the modernisation of the public procurement system.

A. RESPONDENTS' PROFILES

The survey was conducted in January-February 2022. Upon its conclusion, we collected 240 forms, i.e., 75.47% of the total number of questionnaires that we sent out (318). The analysis only considered 210 of the received forms (66.04% of the total sent out forms – enough to use the

TABLE 2. Survey questions used to validate the hypotheses in the model.

Construct	Construct items
Smart Public Procurement (Smt)	Smt1. IoT facilitates communication and data sharing between the parties, which results in faster and smarter decision-making; Smt2. IoT helps improving stock management in the procurement activity; Smt3. Blockchain cuts down manual work (through smart contracts) and improves process efficiency; Smt4. BIoT cuts down the time allocated to public procurement; Smt5. BIoT diminishes complexity and enhances the reliability and flexibility of public procurement; Smt6. BIoT results in higher data quality; Smt7. BIoT stimulates anticipatory thinking and the establishment of measurable objectives.
Sustainable Public Procurement (SPP)	*Economic sustainability* SPP1. BIoT improves productivity; SPP2. BIoT results in creating new organisational and operational processes and methods, able to generate efficiency and effectiveness; SPP3. BIoT facilitates data sharing between the participants in the procurement procedures in order to find innovative solutions for economic growth; *Environmental sustainability* SPP4. BIoT results in a deeper understanding of the environmental impact throughout the ecosystem; SPP5. BIoT improves the energy efficiency of the existing resources and ensures efficiency in waste management; SPP6. BIoT results in sustainable and proactive decision-making; SPP7. BIoT supports the reduction of carbon emissions through the optimisation of the transport activity; *Social sustainability* SPP8. BIoT offers more channels to engage the citizens in public procurement policies; SPP9. BIoT stimulates the professional reskilling of the staff involved in the procurement processes; SPP10. BIoT exerts an influence on social isolation, by limiting human contact;
Transparency and Trust in Public Procurement (TT)	TT1. BIoT results in increased accuracy in public procurement decisions; TT2. BIoT results in capabilities of public procurement integration at international scale; TT3. BIoT allows for active interaction as well as engagement; TT4. BIoT ensures data opportunity and multi-functionality in procurement; TT5. BIoT supplies safe data to build trust in procurement procedures; TT6. BIoT offers visibility on the bidder-contracting authority-client/citizen relationship, which results in higher trust among the parties;
Corruption and Fraud in Public Procurement (CF)	CF1. BIoT allows to counter product counterfeiting by tracking the movements of the product along the transportation chain; CF2. BIoT offers automated functionalities by eliminating potentially forged manual records; CF3. BIoT supports decentralised decision-making; CF4. BIoT facilitates the elimination of intermediaries in procurement.
Technological Integration and Organizational Reengineering Challenges (TIOR)	TIOR1. BIoT causes challenges related to human resources professional training and/or reskilling; TIOR2. BIoT causes challenges related to the interoperability of applications in the field of public procurement; TIOR3. BIoT causes challenges related to personal data protection (GDPR); TIOR4. BIoT causes challenges related to the use of smart contracts and their alignment to legal changes; TIOR5. BIoT causes challenges related to organisational reengineering; TIOR6. BIoT causes challenges related to the maturity of emerging technologies;
National & International Policies (NIP)	NIP1. The European policies encourage BIoT adoption through the directives that they promote; NIP2. The European budgetary policy influences BIoT adoption through financial support measures; NIP3. The current European legal framework supports the use of emerging technologies as public procurement instruments; NIP4. The practices/experiences made available at international level influence BIoT adoption in different fields of activity (public procurement, for instance); NIP5. National digitisation policies encourage the adoption of emerging technologies such as the IoT and blockchain in economic activities.
BIoT Adoption (BIoT)	BIoT1. The adoption of BIoT is an imperative or may be a strategic priority in public procurement; BIoT2. The internal policy in your institution or organisation is compatible with BIoT adoption in current activities; BIoT3. The current economic/social/environmental/technological context is favourable for BIoT adoption in the economic environment; BIoT4. The global post-pandemic ecosystem is a premise for BIoT adoption.

PLS-SEM method). The other 30 forms were left out from our review because they featured respondents that did not possess enough knowledge on the IoT, blockchain and smart contracts.

Table 3 sums up the features of the sample under review. It clearly shows that the respondents are generally people with a higher education (44.8% hold a master's degree, 18.1% have a PhD and 27.6% hold a bachelor degree). Most of the respondents worked in their current field of activity for more than 7 years (63.8%), which ensures a more-than-reasonable expertise and generates an important relevancy of the answers that they provided. This element becomes highly significant since 64.7% of the respondents currently work in procurement and ICT – two of the critical domains for the adoption of emerging technologies in public procurement.

Last but not least, it is noteworthy the number of respondents who at least tried their hand at the specific terms of emerging technology in public procurement. Thus, 48.6% out of the total number of respondents are familiar with the terms but they never used them in their projects, whereas 26.5% already have some experience with these technologies and their benefits.

In conclusion, from the perspective of their level of education, experience in the current field of activity and familiarity with the emerging technologies as well as their

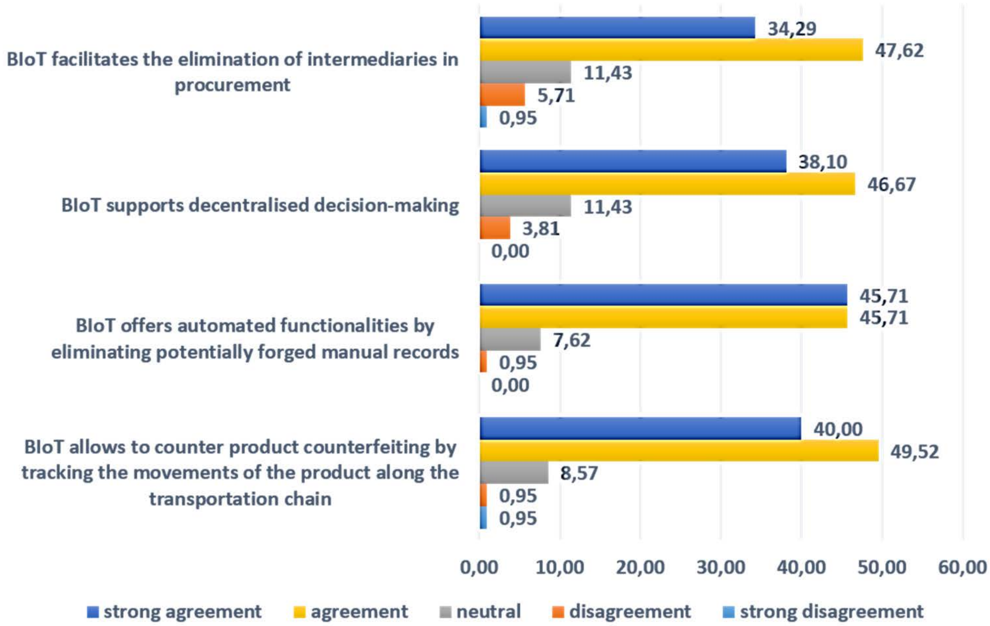

FIGURE 4. The respondents' perception on corruption and fraud (%).

TABLE 3. Characteristics of the study sample (N=210).

Characteristics	Variants	(N)	(%)
Gender	Male	110	52.4
	Female	100	47.6
Age	21-30 years old	58	27.6
	31-40 years old	24	11.4
	41-50 years old	74	35.3
	51 + years old	54	25.7
The sector in which you carry out your core activity	Public sector	112	53.3
	Private sector	98	46.7
The current field of activity	Management	20	9.5
	Procurement	60	28.5
	Financial-Accounting	20	9.6
	Legal	8	3.8
	ICT	76	36.2
	Others	26	12.4
The time you have worked in the current field of activity	less than 2 years	46	21.9
	between 2 and 7 years	30	14.3
	more than 7 years	134	63.8
	High school	20	9.5
Characteristics	**Variants**	**(N)**	**(%)**
Level of formal education	Bachelor degree	58	27.6
	Master's degree	94	44.8
	PhD	38	18.1
Your level of knowledge on the IoT, blockchain, smart contracts	I am familiar with the terms	52	24.8
	I know the terms, but I have not used them in projects	102	48.6
	I have some experience with these technologies and their benefits	56	26.6

benefits, the respondents were able to provide answers related to the BIoT impact on public procurement.

B. ANALYSIS OF THE COLLECTED DATA

An elementary analysis of the collected data reveals several interesting characteristics related to how familiar the respondents are to ICT in general and emerging technologies in particular. Thus, the age-based analysis evinces a fairly uniform distribution of at least an average knowledge about IoT, blockchain and smart contracts. The current field of work of the respondents is, prevailingly, the ICT field, with most of the female respondents originating from the public sector (70%), while the private sector is represented by 61.82% of the male respondents.

The values of the collected data make us notice that in most of the cases the respondents embrace a favourable position to the situations introduced in the body of the questions about the benefits and the challenges of BIoT in public procurement. This is something that also emerges from the graphical representations of the data on the most obvious challenges in the field: corruption and fraud (figure 4), transparency and trust (figure 5) as well as sustainability (figure 6).

From the perspective of the data provided by the survey respondents, this research is evidential for supporting and recommending the adoption of BIoT as emerging technologies in public procurement (figure 7).

C. OUTER MODEL ASSESSMENT

The first step in PLS-SEM analysis is to assess the outer model (measurement model). This evaluation supposes to examine the reliability of the indicators, the reliability of internal consistency, the convergence validity and the discriminant validity [75]. Table 4 shows the results obtained after the execution of the PLS algorithm.

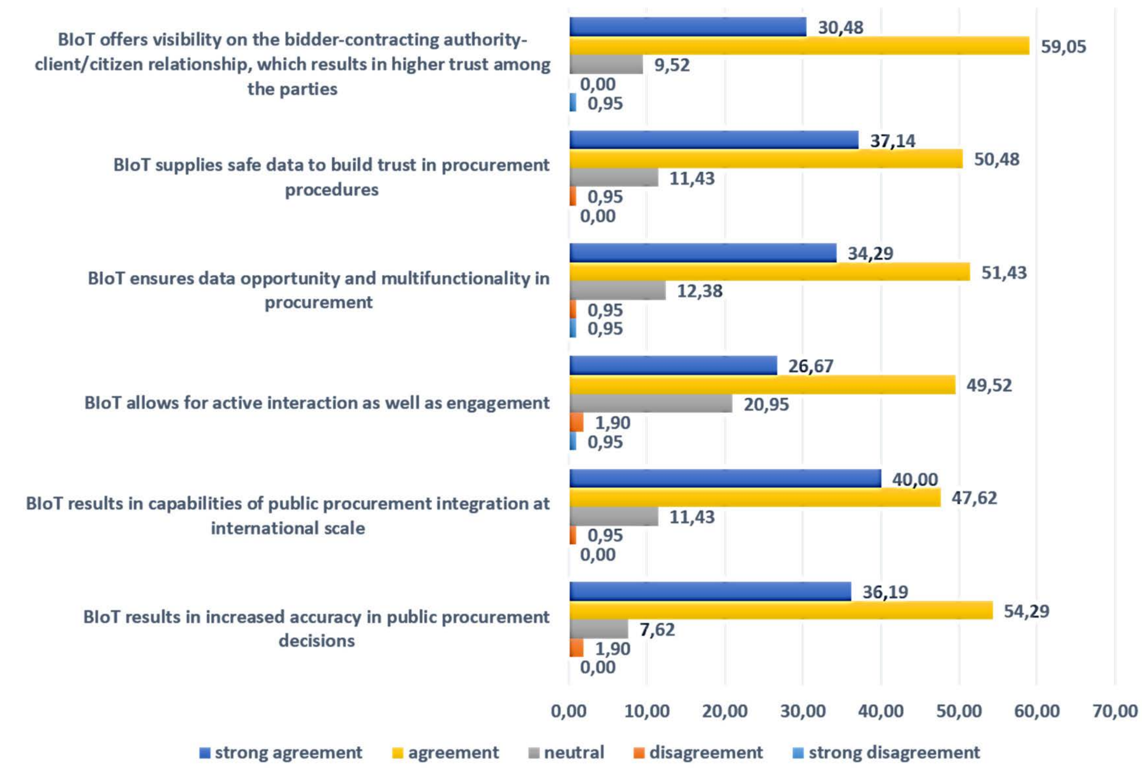

FIGURE 5. The respondents' perception on transparency and trust (%).

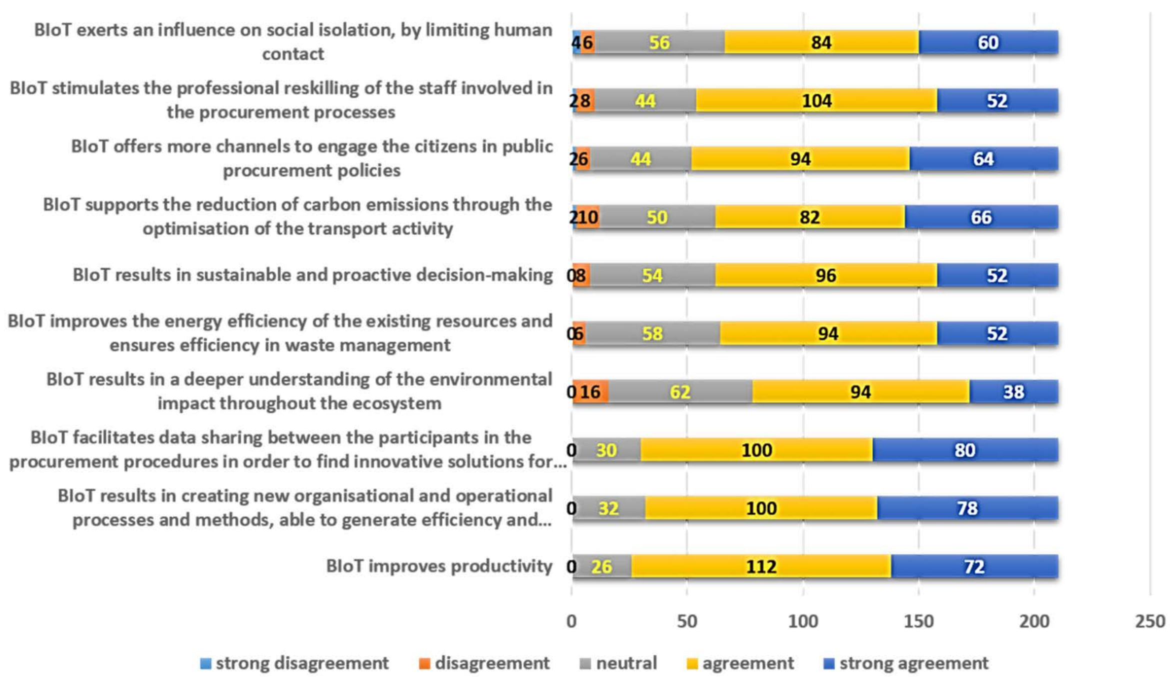

FIGURE 6. The respondents' perception on sustainability.

1) RELIABILITY OF THE INDICATORS

The reliability of the indicators is checked by investigating the ''outer loadings'' values, ranging 0-1 [76]. These values show the absolute contribution of each observable element to defining the construct (latent variable). Generally speaking, we expect higher values than 0.6 in exploratory research [77]

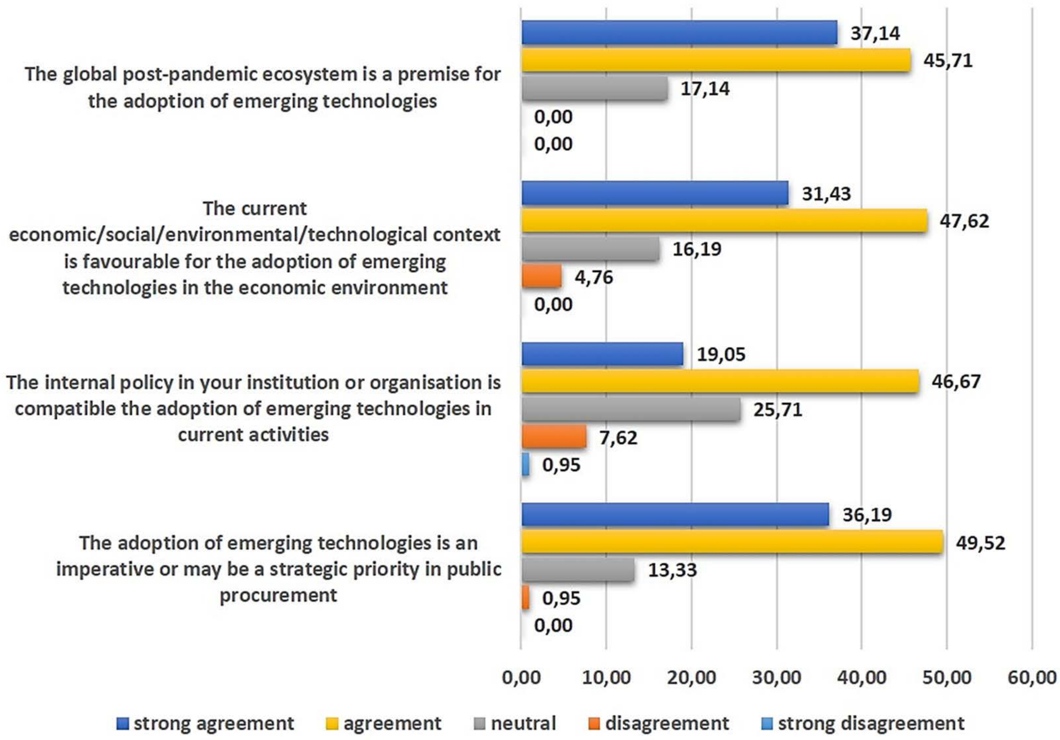

FIGURE 7. Multi-contextual perception on the adoption of emerging technologies (%).

or values of 0.7 for research studies that are based on established measures [75], [78]. The results comprised in table 4 show that all the outer loadings values are accepted (≥6) and that they ensure the reliability of the indicators.

2) RELIABILITY OF INTERNAL CONSISTENCY

The variant most frequently used for internal consistency is Cronbach's Alpha and composite reliability (CR). Cronbach's Alpha general values for the reliability and validity of a latent variable are the following: 0.60 inacceptable; 0.60–0.70 minimally acceptable; 0.70–0.80 acceptable; 0.80–0.90 very good [78]. CR checks whether a construct is measured through its indicators. The acceptable CR values are at least 0.7 [77], [78]. Values of 0.95 and higher are problematic [75]. Following the check of the Cronbach's Alpha values, we found that the value associated with the BIoT construct is 0.719, which is acceptable, whereas the remaining values range 0.8-0.9 – very good. Together with the CR values of 0.82-0.92 showed in the table that means that internal consistency is indeed ensured.

3) CONVERGENCE VALIDITY

Convergence validity represents the extent to which a construct converges to explaining the variance of its items [75]. Convergence validity emerges from the AVE values. It is typically required for AVE to be at least higher than 0.5 [77]. The results show that the actual values are above those recommended, which verifies convergence validity.

4) DISCRIMINANT VALIDITY

Discriminant validity represents the measure to which an empirical construct is distinct from other constructs in the structural model [75]. One way to check discriminant validity (correlations between the measure of interest and the measure of other constructs) is to use the Fornell Larcker criterion. Latent variables are considered to fulfil the criterion if the square root of AVE (the element on the main diagonal) is higher than all the values found on the row and the column [78]. Table 5 shows that discriminant validity is fulfilled under this criterion.

More recent papers show that the Fornell Larcker criterion does not work well, especially when the loadings of the construct indicators only differ by little (e.g., all the loadings of the indicators range 0.65-0.85) [79]. Another suggested variant is the Heterotrait-Monotrait Ratio (HTMT). In this case, the recommended threshold values range from 0.85 – a conservative reference point to a more liberal limit value of 0.90. A HTMT value higher than 0.85 suggests that discriminant validity is not present [79]. Table 6 shows that discriminant validity is achieved through the model, since all the values are lower than 0.85.

The model obtained after the execution of the PLS algorithm is presented in figure 8. The figure shows the values of the determination coefficients (R^2) for the latent variables (in the circle), the path coefficients and the outer loadings.

TABLE 4. Summary of the results in the reflexive model.

Construct	Items	Outer loadings	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
BIoT Adoption (BIoT)	BIoT1 BIoT2 BIoT3 BIoT4	0.766 0.666 0.714 0.788	0.719	0.824	0.540
Corruption and Fraud in Public Procurement (CF)	CF1 CF2 CF3 CF4	0.776 0.819 0.853 0.843	0.841	0.894	0.678
National & International Policies (NIP)	NIP1 NIP2 NIP3 NIP4 NIP5	0.791 0.868 0.867 0.833 0.759	0.882	0.914	0.680
Smart Public Procurement (Smt)	Smt1 Smt2 Smt3 Smt4 Smt5 Smt6 Smt7	0.788 0.672 0.814 0.785 0.845 0.656 0.689	0.871	0.901	0.567
Sustainable Public Procurement (SPP)	SPP1 SPP2 SPP3 SPP4 SPP5 SPP6 SPP7 SPP8 SPP9 SPP10	0.600 0.652 0.642 0.702 0.793 0.828 0.817 0.701 0.622 0.693	0.888	0.909	0.503
Technological Integration and Organizational Reengineering (TIOR)	TIOR1 TIOR2 TIOR3 TIOR4 TIOR5 TIOR6	0.823 0.808 0.748 0.830 0.832 0.805	0.894	0.919	0.653
Transparency and Trust in Public Procurement (TT)	TT1 TT2 TT3 TT4 TT5 TT6	0.788 0.794 0.782 0.853 0.739 0.829	0.886	0.913	0.637

TABLE 5. Fornell-larcker criterion.

	BIoT	CF	NIP	Smt	SPP	TIOR	TT
BIoT	**0.735**						
CF	0.560	**0.823**					
NIP	0.574	0.344	**0.825**				
Smt	0.476	0.507	0.374	**0.753**			
SPP	0.639	0.460	0.564	0.578	**0.709**		
TIOR	0.471	0.228	0.431	0.330	0.502	**0.808**	
TT	0.591	0.716	0.492	0.480	0.555	0.394	**0.798**

TABLE 6. Heterotrait-monotrait ratio (HTMT).

	BIoT	CF	NIP	Smt	SPP	TIOR	TT
BIoT							
CF	**0.703**						
NIP	**0.697**	**0.392**					
Smt	**0.567**	**0.599**	**0.428**				
SPP	**0.770**	**0.542**	**0.622**	**0.666**			
TIOR	**0.558**	**0.246**	**0.481**	**0.359**	**0.558**		
TT	**0.723**	**0.816**	**0.550**	**0.555**	**0.639**	**0.433**	

D. INNER MODEL ASSESSMENT

The second stage supposes the assessment of the inner model. The stage consists of the analysis of the collinearity issue (Variance Inflation Factor - VIF), Outer Weight (P-Value), of the determination coefficients (R^2), of the size and significance of the path coefficients, of the size of the effect (f^2) and of predictive relevance (Q^2) [78]. We further executed the Bootstrapping algorithm to assess the statistical significance of the loadings and of the path coefficients [72]. Table 7 shows the values of different variables that indicate the summary data for testing the hypotheses in the model.

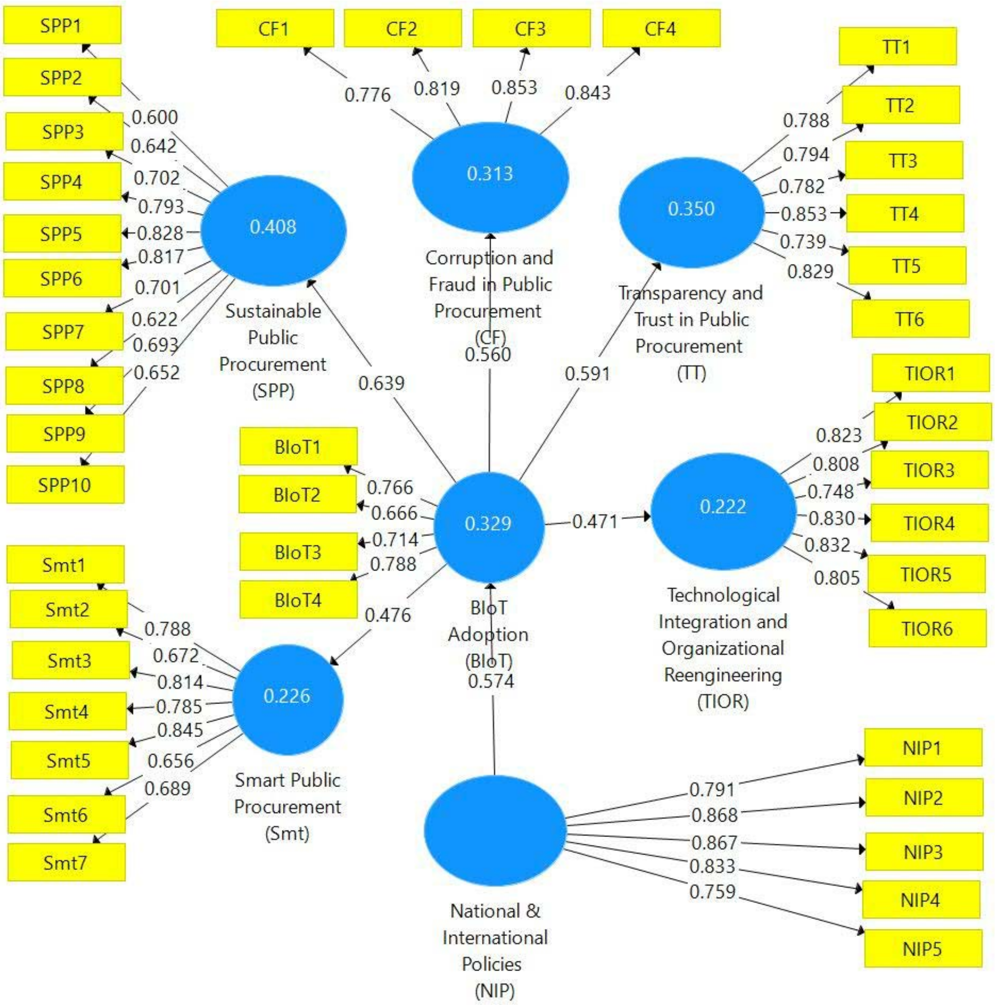

FIGURE 8. Outer model assessment.

1) COLLINEARITY ASSESSMENT

Before assessing the structural relations, we must also check the collinearity (the degree of correlation between the constructs). To assess collinearity, we typically use VIF values. Ideally, VIF values should be lower or close to 3, otherwise they generate collinearity issues [75]. After the execution of the algorithm, we found that the VIF values are lower than 3 and that there are no multicollinearity issues.

2) SIGNIFICANT OUTER WEIGHT

When P is lower than 0.05, then the relation between variables is significant, whereas when P-value is at least 0.05, the relation between the variables is non-significant [78]. Table 7 shows that all P-values are equal to zero, therefore the relationships between constructs are significant.

3) DETERMINATION COEFFICIENTS

A determination coefficient is used to measure the accuracy of the estimate. R^2 values of 0.75, 0.50 and 0.25 are typically considered substantial, moderate and weak, respectively [75], and are correlated with different disciplines. On the other hand, [80] suggests that for the branch of social and behavioural sciences, for instance, a determination coefficient $R^2 \geq 0.26$ is considered to have a strong effect. Nevertheless, based on recent theoretical considerations of [75], figure 8 captures the fact that the hypotheses on the BIoT impact on SPP ($R^2 = 0{,}408$), TT ($R^2 = 0{,}350$), CF ($R^2 = 0{,}313$) are statistically significant with effects that are considered moderate. On the other hand, the hypotheses on the BIoT impact on Smt ($R^2 = 0{,}226$) and TIOR ($R^2 = 0{,}222$) are suggestive of weaker effects. In regards of the impact of NIP on BIoT ($R^2 = 0{,}329$), it is statistically significant with moderate effects.

4) STRUCTURAL MODEL PATH COEFFICIENTS

By using a significance level of 0.05, a path coefficient is significant if T statistics is higher than 1.96 [81]. In regard of the path coefficients (O in table 7), the higher the absolute value is, the stronger becomes the predictive relation between the latent variables [72]. BIoT adoption has the highest

TABLE 7. Summary of testing the hypotheses in the model (subsamples 5000, significance level 0,05).

Hypothesis. Path	f^2	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values	Result
H4: BIoT Adoption (BIoT) -> Corruption and Fraud in Public Procurement (CF)	0.456	0.560	0.563	0.046	12.275	0.000	Confirm
H1: BIoT Adoption (BIoT) -> Smart Public Procurement (Smt)	0.292	0.476	0.486	0.084	5.636	0.000	Confirm
H2: BIoT Adoption (BIoT) -> Sustainable Public Procurement (SPP)	0.690	0.639	0.646	0.044	14.405	0.000	Confirm
H5: BIoT Adoption (BIoT) -> Technological Integration and Organizational Reengineering (TIOR)	0.286	0.471	0.479	0.061	7.707	0.000	Confirm
H3: BIoT Adoption (BIoT) -> Transparency and Trust in Public Procurement (TT)	0.538	0.591	0.596	0.047	12.573	0.000	Confirm
H6: National & International Policies (NIP) -> BIoT Adoption (BIoT)	0.490	0.574	0.578	0.045	12.793	0.000	Confirm

TABLE 8. Construct crossvalidated redundancy.

Construct	Q^2
BIoT	0.169
CF	0.205
Smt	0.124
SPP	0.198
TIOR	0.138
TT	0.214

effect (O=0.639) on the achievement of sustainable public procurement and the lowest effect on the challenges related to technological integration and organisational reengineering (O = 0.471). As it is shown in table 7, all T statistics are higher than 5, therefore we may conclude that the loadings of the outer model are significant.

5) SIZE OF THE EFFECT

When we assess the size of the effect, if f^2 is at least 0.35, 0.15 and, respectively, 0.02, then the effects indicated are high, average and low [82]. The conclusions emerging from table 7 are that there is a strong relation between BIoT and CF, SPP, TT, NIP (high effect), whereas the effect of the BIoT adoption on Smt and TIOR is average.

6) PREDICTIVE RELEVANCE

Q^2 coefficients may be calculated by using the Blindfolding method. According to [78], 0.02 is considered a value of low predictive relevance, 0.15 shows a moderate predictive relevance and 0.35 indicates a high predictive value. According to the values shown in table 8, we may say that for BIoT, CF, SPP, TT, predictive relevance is moderate, and that for Smt, TIOR, the predictive relevance of the model is lower compared to the latent variables.

In conclusion, by taking into account the analyses and the interpretation of the statistical results presented above, we find that the hypotheses that we proposed in the model are grounded.

E. DISCUSSIONS AND RECOMMENDATIONS

This study examines the impact of BIoT emerging technologies on public procurement. The transformation of the entire public procurement mechanism in a smart system, one of holonic nature and built on BIoT, is a critical step in moving to the stage of Industry 4.0. This aspect lends significance to the smart dimension in governance/administration, transport, healthcare, education, city life, life and the standard of living in general. Suffice is for this metamorphosis to occur once, within a national system, for its fractal propagation never to be stopped.

Although there is a small number of studies regarding the IoT use in public procurement, it is noteworthy that its increasing presence in other fields of activity creates the premises of analysing and adopting this technology in order to modernise the public procurement system. The adoption of BIoT has turned into one of the active fields of research aimed at overcoming the challenges regarding the storage capacity, scalability, as well as the security and confidentiality of the data within the information systems [83]. The positive experiences with the use of BIoT (including in the sphere of Logistics and Supply Chain Management) create the premises of equally expanding the use of the BIoT to the field of public procurement. On the other hand, we should consider not only the benefits offered by BIoT, but also the challenges/risks which are associated with these technologies, also highlighted in other studies, [84]–[86], as well as the costs of such solutions.

The analysis of the data collected in the survey conducted in Romania indicate the possibility of a significant link between BIoT and corruption/fraud, sustainability, transparency and trust, national and international public procurement policies and an openness to the modernisation of this system. The effect of the adoption of BIoT on carrying out smart procurement may reach an average level, as other technologies are likely to be necessary. Similarly, the impact of BIoT on the challenges related to integration and reengineering is not seen as a highly significant effect, one that should influence the modernising option in the public procurement system.

TABLE 9. Actions and recommendations in order to benefit from BIoT advantages.

Scope	Actions/Recommendations
Government	✓ defining and adopting a national public procurement strategy which promotes the use of the emerging technologies as a solution to the current challenges; ✓ development of a GPP national action plan; ✓ attracting dedicated funding for training the staff involved in public procurement; ✓ accessing funding for the projects aimed at increasing the national experience in using 4.0 technologies; ✓ creation of the instruments able to measure the performance in public procurement and to ensure free access to this data; ✓ ensuring free access to data on the whole procurement lifecycle for all stakeholders; ✓ creation of a legislative framework that would safeguard compliance with the principles of public procurement as well as the possibility to penalise the contracting authorities and the economic operators that violate these principles; ✓ harmonising the public procurement principles at international level.
Contracting authorities	✓ ensuring enough, well-trained, ethical and practically engaged staff; ✓ promotion of preferential policies in order to motivate the staff working in public procurement; ✓ reduction of redundant administrative flows and creation of efficient and transparent working procedures; ✓ ensuring an institutional policy that supports competitiveness, meritocracy, the promotion of employees and the protection against external (political) interventions;
Economic operators	✓ training for the related staff (knowledge on ICT, public procurement legislation, contract management); ✓ building private-public partnerships in order to attract funding and running projects that are beneficial to both parties (with direct consequences on the national public procurement policies); ✓ promotion of competitiveness and elimination of the practices that may generate corruption and fraud at different stages of the procurement processes.

Table 9 describes the changes that may represent as many elements that can ease the way to this transformation, aimed at adopting the BIoT as a support element for the achievement of a smart public procurement system.

VI. CONCLUSION, LIMITATIONS AND RESEARCH DIRECTIONS

Public procurement is a field of multiple challenges, one that shows increasingly more interest in research and development. Concurrently, the emerging technologies come with countless benefits as well as challenges, both requiring to be understood, analysed and applied in an adequate manner. The analysis of the model as well as the current research status indicate that BIoT adoption has a positive impact on the achievement of sustainable public procurement processes (H2 – the highest effect), on transparency and the trust in public procurement (H3), on reducing corruption and fraud in public procurement (H4). The adoption of BIoT is also a positive factor for the achievement of smart public procurement (H1) and generates challenges related to technological integration and organisational reengineering (H5 – the lowest effect), but such influences have a rather attenuated influence. In regard of national and international policies, they have a positive effect on BIoT adoption in public procurement (H6). The hypotheses proposed in the model are validated through reference to the literature as well as the PLS-SEM analysis that we carried out on the survey conducted with the main public procurement stakeholders in Romania. The resulting analysis showed that the effect of the impact is generally significant and might lead to beneficial changes in the field of public procurement.

The research study is the more so significant for Romania since the pool of the respondents included the main actors on the national public procurement stage – authorities that regulate and monitor the specific policies, important economic operators, representative contracting authorities, non-governmental organisations. The adoption and the implementation of emerging technologies in the specific mechanisms of public procurement call not only for the usual funding, but also for complementary actions, such as changing the legislation, (re)skilling the human resources, reengineering the business processes, rethinking the role of organisational culture, redefining the information architecture of the organisations etc. Similar to any other change process, it is all about a sum of actions that must be carried out convergently in order to attain a well-defined modernisation and development objective of a smart public procurement system.

The study represents both a national and international contribution with respect to the potential impact that the use of blockchain and IoT technologies may exert on addressing a series of current challenges/problems in the field of public procurement. At the same time, the research results may represent a valuable input for the approach of modernisation in other fields of activity.

On the other hand, moving to a superior technological level in a such a sensitive field of activity as public procurement may spotlight a series of vulnerabilities. Therefore, it is necessary to address with a lot of attention aspects such as data security, integrity, confidentiality and non-repudiation, as well as securing the quality of technological implementations and the compliance with the specific standards. To that end, one aspect worthwhile considering and analysing may focus on the environmental side of ensuring the specific back-up and recovery procedures in case of disaster, an element that, together with blockchain technology, requires large volumes of resources (data storage space – data centres, electrical power – conventional and, especially, non-conventional energy sources).

The research that we conducted is not exhaustive as it was limited only to the analysis of the impact of the two technologies on public procurement. Future research studies will also consider other technologies (e.g., artificial intelligence, robotic process automation, cloud/fog computing), as well as other economic, social, environmental and legal aspects that will be subject to review in order to improve the current system. We will also take into account conducting interviews with more of the stakeholders acting in the field of legislative/technical changes in order to identify other modernisation challenges and opportunities. Moreover, we will consider the possibility of using other specific instruments to analyse the research models. In addition to the research directions previously enumerated, it is worthwhile considering some practical examples in which the implementation of the emerging technologies may help developing the field of public procurement, as well as a tentative architecture that would combine the benefits that the spectrum of the reviewed emerging technologies has to offer in order to shift to a smart public procurement system.

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MARINELA MIRCEA was born in Videle, Teleorman County, Romania, in 1979. She received the degree in informatics in economy from the Bucharest University of Economic Studies, in 2003, the Ph.D. degree in economics (Ph.D. Thesis Title: Business Management in Digital Economy), in 2009, and the Habilitation degree in economic informatics (Habilitation Thesis Title: Agile Informatics Solutions for Services-Oriented Organizations Management), in 2016.

Since 2003, she has been teaching at the Informatics and Cybernetics Economy Department, Bucharest University of Economic Studies. In 2005–2012, she was an Employee of the Public Procurement Compartment within the Bucharest University of Economic Studies, where she was the Head of the Monitoring and Reporting Office and engaged directly with the procurement procedures conducted by the university. In that period, she has attended numerous nation-wide training and upgrading courses in the field of public procurement. The experience she gained in the seven years of direct activity in public procurement was later turned to good account through her participation as a public procurement expert in different internationally-funded projects (over five years). She has published over 50 articles in journals and magazines in fields, such as computer science, informatics, and business management. She has over 50 papers presented at international conferences and authored and coauthored 18 books. She was a member for over 15 research projects and a project manager for two national research projects. Her research interests include programming, information systems, business management, and business intelligence.

Prof. Mircea has been a member of the Association for the Promotion of Economic Informatics Education—INFOREC, since 2008, a Senior Member of the International Association of Computer Science and Information Technology—IACSIT, since 2010 (member no.: 80338836), and a member of the Association of North America Higher Education International, since 2015.

MARIAN STOICA was born in Bucharest, Romania, in 1974. He received the degree in informatics in economy from the Bucharest University of Economic Studies, in 1997, and the Ph.D. degree in economics, in 2002.

In 2010, he acquired the capacity of a scientific doctoral coordinator in the field of economics and economic informatics profile. Since 1998, he has been teaching at the Informatics and Cybernetics Economy Department, Bucharest University of Economic Studies. Since 1998, he has been a member of the research teams of over 30 research contracts with the Romanian National Education Ministry and a project manager in five national research projects. In 2004–2012, he was an Employee of the of the Public Procurement Compartment within the Bucharest University of Economic Studies, where he was of the Head of Compartment and engaged directly with the procurement procedures conducted by the university. In that period, he was involved in numerous modernization projects related to the specific public procurement procedures operating in the university. The experience he gained in the eight years of direct activity in public procurement was later turned to good account through his participation as a public procurement expert in different internationally-funded projects (over six years). In 1996, his research interests started and include many themes, which focus on management of information systems, computer programming, and information society paradigms. The main domains of his research interests include information society, E-activities, tele-working, information systems, and computer science. The outcome of this research interests to this day consist of over 100 articles published, 30 books, and over 50 scientific papers presented at national and international conferences.

Prof. Stoica has been a member of the Association for the Promotion of Economic Informatics Education—INFOREC, since 2000.

BOGDAN GHILIC-MICU was born in Bucharest, Romania, in 1960. He received the degree in informatics in economy from the Bucharest University of Economic Studies Bucharest, in 1984, and the Ph.D. degree in economics, in 1996.

In 2007, he acquired the capacity of a scientific doctoral coordinator for the economics, cybernetics, and statistics in economy specialty, and also economy informatics specialty, since 2010. In 1984–1990, he has worked as a Researcher at the Computer Technology Institute of Bucharest. Since 1990, he has been teaching at the Informatics and Cybernetics Economy Department, Bucharest University of Economic Studies. In 1984, his research interests started and include many themes, such as computer programming, software integration, and hardware testing. The main domain of his latest research interest is the new economy—digital economy in information and knowledge society. Since 1998, he has been managing over 25 research projects, such as system methodology of distance learning and permanent education, the change and modernization of the economy and society in Romania, E-Romania—an information society for all, and social and environmental impact of new forms of work and activities in information society. Throughout his 40-years of long research activity, he has participated as an ICT expert in numerous nationally and internationally-funded projects.

Prof. Ghilic-Micu has been a member of the Association for the Promotion of Economic Informatics Education—INFOREC, since 1995.