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ÍNDICE DE COMUNICACIONES Y PONENCIAS

1. FORMACIÓN E INVESTIGACIÓN EN BIM

2 DISEÑO Y CONSTRUCCIÓN CON BIM

3. EXPERIENCIAS REALES CON BIM

Blockchain implementation in AEC sector: issues and opportunities

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Abstract
This paper aims to analyse in detail the national and international Blockchain level of implementation, focusing in particular on its adoption in the AEC sector. Due to the variety of disciplines involved, the construction sector has always suffered from lack of trust, incomplete sharing and transparency of information flow throughout the process execution. In this context, the progressive introduction of BIM has enabled the generation and management of project 3D models, encouraging the complete information sharing and the collaboration among project participants. However, this methodology raises a number of relevant issues such as the property and the incorruptibility of the model information, making the information reliability matter fundamental. In this context, the Blockchain implementation can provide a trustworthy infrastructure for information management during the design, tender and construction phases. This research intends to investigate the execution of public procurement through the integration and the use of Blockchain technology. The main objectives are the analysis of every single phase of the construction process, the identification of the primary problems in terms of information sharing and consequent loss of time and costs and finally the demonstration of how the use of the Blockchain methodology allows to contain and solve all these issues..

Keywords: *Blockchain, Smart Contracts, public tender, BIM, information trust, information immutability.*

Resumen
El objetivo de este documento es analizar en detalle el nivel de implementación nacional e internacional de la Blockchain, centrándose en su adopción en el sector AEC. Debido a la variedad de disciplinas, el sector de la construcción siempre ha sufrido de falta de confianza y transparencia en el flujo de información durante el proceso. La progresiva introducción de BIM ha permitido la generación y gestión de modelos 3D de proyectos, fomentando el intercambio de información y la colaboración entre los participantes. Esta metodología plantea cuestiones relevantes como la propiedad y la incorruptibilidad de la información del modelo, por lo que la fiabilidad de información es fundamental. En este contexto, la implementación de Blockchain puede proporcionar una infraestructura fiable para la gestión de información durante las fases de diseño, licitación y construcción. Esta investigación considera la ejecución de contratación pública a través de la integración y el uso de la tecnología Blockchain. Los objetivos principales son el análisis de las fases del proceso de construcción, la identificación de problemas principales en términos de compartir información y la consecuente pérdida de tiempo y costes y la demostración de cómo el uso de la metodología Blockchain permite contener y resolver todos estos problemas.

Palabras clave: *Blockchain, Smart Contracts, licitación publica, BIM, confianza de información, inalterabilidad de información*

Introduction

Thanks to its ability to revolutionize international markets, Blockchain can be considered as the main technology characterizing the digital transition currently observed within the most advanced world economies. Blockchain is a methodology capable of managing contracts and transactions through which assets are organized and guarded, social actions are governed and relations between nations, institutions and individuals are guided (Shen and Pena-Mora 2018). The performance of a good construction process requires trust among the operators, the implementation of BIM models has fostered the project information exchange and collaboration, however the reliability and the transparency of each transiction aren't always guaranteed. Despite the innovative digital approach to the process, in a complex and growing construction sector the maintenance of trust among stakeholders is difficult, the links are too complex hindering the information sharing with consequent waste of time and process costs (Institution of Civil Engineers 2018). In this dynamic context, Blockchain stands as a solution ensuring a transparent information distribution among the participants of the network by diverting the control of information by a single subject.

1. Blockchain technology

The Blockchain as a Distributed Ledger Technology (DLT) is a distributed data logging and maintenance system that depends on and is ensured by the *consensus mechanism* implemented by the agents. The autonomy and updating of the information contained in the blocks are in fact subject to verification and authorization by all participants (Garzik and Donnelly 2018).

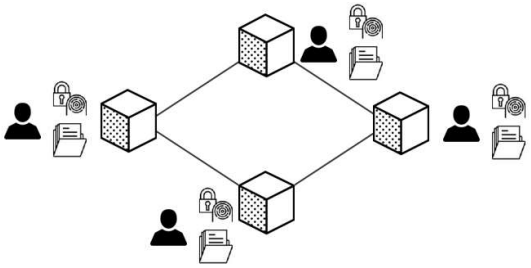

Fig. 1 DLT organization

1.1. Structure and main features

To better understand how Blockchain applications work, it is useful to outline their structure, consisting of a chain of blocks that develops within a distributed database - public ledger - on which are recorded series of operations encrypted in time sequence. Each block represents a link in the chain, initially completed and validated with information on the operations received and then closed and characterized by its own identification code, thus being unchangeable. Each new block is located at the top of the chain and contains the identifier of the previous block, thus creating a database of all operations in chronological order. The Blockchain can be defined as a system that allows the acquisition of a certain data in computer format, making it true and unchangeable without the control of a third authority. The information recorded on the Blockchain is therefore verified, controlled and validated by the entire network, and not by a third-party through the *consensus mechanism*. The distributed database prevents the structure alteration and the content violation because the same information entered and validated in the chain are distributed, then stored in all nodes that compose it. The decentralized system based on *consensus mechanisms* gives participants the autonomy to evaluate and approve the data entered in the chain, thus making unnecessary the presence of a third figure to verify the data value (Kshetri 2017).

Given the recent spread of technology, its correct implementation is achieved identifying the areas in which the application of the Blockchain is convenient. The main benefits offered by the use of technology can be summarized in:

- Intermediaries elimination;
- Information inalterability;
- Information traceability.

Despite the advantages that the use of Blockchain technology offers, it is worth considering that its youth will lead in the coming years to conflicting debates about the its real applicability and usefulness. The challenges and obstacles in the Blockchain implementation that can be detected today are not only of a technical nature but involve several areas, including man as a subject who decides to adopt this new technology, the national economy that must support the digital transition and the institutions that must regulate the transition itself. Identifying in advance the limitations allows to study possible countermeasures before the actual use of the technology. The main limitations that influence the use of technology can be identified in:

- Innovative technology;
- Digitalized asset;
- Operators education.

Fig. 2 Blockchain benefits and limitations

While Blockchain could solve some of the issue that arise with the use of BIM, one of its protocols has the potential to revolutionise the relationship between construction projects and to establish longstanding contractual procedures. The Blockchain as a DLT technology supports different digital transition protocols: thanks to its programmable nature it allows the proper use of Smart Contract, i.e. contracts written in code capable of executing the clauses established and shared by the contracting parties automatically and independently. This technology highlights the traditional contract system revolution where the parties draft the essential terms of the agreement through a descriptive language. The implementation of Smart Contract instead promotes the representation of clauses in the form of structured data executable by means of computer protocols with a high degree of accuracy compared to those defined by traditional language. Smart Contract protocol allows the legislative, IT and financial fields to be combined in an original way, modelling the traditional idea of contract law (Giancaspro 2017).

Fig. 3 Smart Contract based on Blockchain main features

2. Actual Blockchain implementation

Despite the various obstacles that the adoption of technology must consider, thanks to its nature Blockchain supports lean processes, i.e. the respect of time, cost and quality, the reliability of data and the streamlining of activities. The distributed validation mechanism and the sharing of reliable information encourages participants to be more accountable for their work (Kshetri, 2018). Thanks to the features offered by Blockchain recent surveys have focused on assessing the impact caused by the adoption of technology within different industries (Carson et al. 2018).

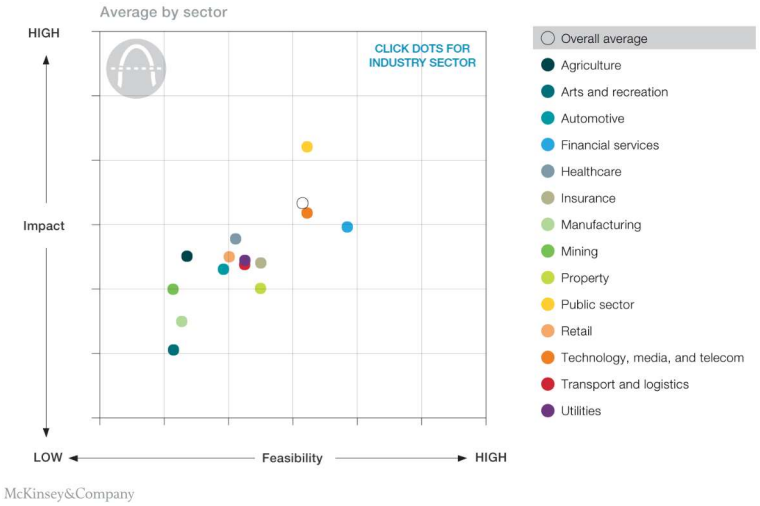

Fig. 4 Blockchain opportunities by industrial sector. Source: McKinsey, (2018)

Together with private industrial sectors, many public administrations are taking an interest in the technology implementation within their own processes in order to improve the way they manage urban contexts. Many cities and nations around the world are supporting Blockchain initiatives, setting goals and pursuing approaches that keep up with technology. Althuogh various sectors are now exploring and testing Blockchain applications in their processes, its investigation in the construction sector is still meager and at a conceptual level (Mason 2017).

2.1. AEC sector

Given the increasing construction projects complexity – sets of processes, products and materials – both the change in project management technologies and the creation of an information sharing environment are necessary to support activities. Traditional information sharing methods can in fact hinder the sector evolution as they negatively influence three fundamental aspects of the process:

- Trust among participants:
- Supply chain control;
- Asset management.

Considering the process nature and the critical trend that has characterized the construction sector in recent years, a research carried out within the Italian context has identified the main factors that currently hinder proper management of the process and consequently the results that can be obtained (European Commission 2017). These critical aspects can be summarized in:

- Productivity decrease;
- Demand reduction;
- Time and cost excess;
- Contract fragmentation and variation.

The multidisciplinary and the number of participants in the construction process makes it difficult to manage and resolve the above limitations. Communication among the various work areas and their operators, due to different interests and approaches, can be overshadowed to the detriment of compliance with the overall process objectives. A collaborative approach to the construction process allows a positive departure from the usual procedures with consequent limitations containment or overcoming. In this context, it is legitimate to believe that fair communication between operators can favor the implementation of the contract activities and the consequent compliance with the clauses predefined in it (Hsiao 2016).

The digital transition that has recently influenced the construction sector procedures has allowed to modify and evolve the communication methods between the project participants. While in the past the contractor was the main custodian of the documentation, the current BIM approach to the project guarantees the digital

information exchange, offering a single database containing all the data created and shared by the operators during all phases of the construction process.

3. BIM implementation

The digital transition involving the construction sector is characterized by the implementation of different tools and modeling software that support an efficient drafting of the project and an interactive documents and construction phases control. As mentioned in the previous paragraph, the most significant innovation is represented by Building Information Modelling, which acts both as a guarantor of integrated processes between participants and as a database containing all the digital information of every aspect of the building. Most of the planning and design activities are now fully digitized and the information associated with them is structured through the BIM technology which in this way induces a significant change in both the approach to the construction process and to the execution of each activity (Di Giuda and Villa 2016).

3.1.Structure and main features

Considering what has just been said, BIM is much more than an asset digital model because it defines the modalities with which the model is integrated in the general construction system, the procedures through which information is added or extracted from the same and the creation, use and management criteria of the informative model.

Despite the fact that in the last ten years there has been a significant spread of BIM methodology use, the actual potential offered by it has yet to be reached. The information quantity and level of detail present in the model vary according to the project type and the construction sector in which it operates. The model levels are in fact distinguished by the assignment of dimensions associated with the model itself; currently five dimensions are identified starting from the 3D dimension that gives the model geometric information, up to the 7D dimension that assigns data relative to the building state of performance for monitoring the entire life cycle efficiency (Institution of Civil Engineers 2018).

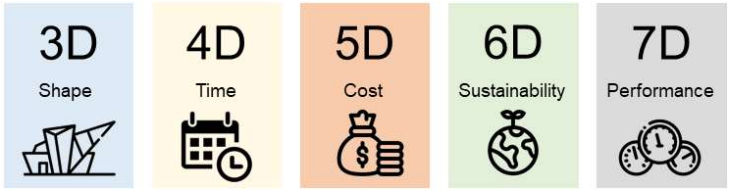

Fig. 5 BIM dimensions

Thanks to the above characteristics it is possible to understand the divergence between the digital and the traditional approach. In the last, project information – technical and legal nature – is collected in sheets signed directly by the authors, while in a BIM process all the information is contained in the model composed of all the elements associated with parameters related to the geometric, physical and maintenance characteristics. The creation of such a digital database facilitates the information sharing among participants who can refer to a single source of information, identify and consult the desired documents and check the work progress at any time. The BIM methodology implementation and the development of its dimensions allows to manage in a transparent way all the project significant information and avoid the frequent disputes and contentious emergence in the construction processes often caused by a partial sharing of information.

Despite the above advantages, recent research has questioned the actual effectiveness of the technology, highlighting some limitations to be taken into account when implementing a BIM process (Turk and Klinc 2017). Some of the problems consist in the impossibility to define:

- Model properties;
- Right of modification;

- Error responsibility;
- Intellectual property of information.

Although the progressive use of the BIM methodology and related supporting technologies has significantly renewed and improved the usual procedures pursued in the construction sector, the issues not yet resolved make it legitimate to assume an integration between the BIM and Blockchain in order to overcome the limitations previously identified.

4. Integration between BIM and Blockchain

Considering BIM methodology as a shared database among the project participants aimed at exchanging information on each process phase, it is fair to assume the activities of sharing, managing and recording data by means of an information model supported by the Blockchain (Turk and Klinc 2017).The sharing information digital register offered by the technology ensures the data reliability, integrity and transparency by fostering loyal cooperation and trust between operators. The Blockchain implementation within the construction process is able to solve and overcome the potential limitations encountered during the execution of a BIM process.

Since both the BIM approach and the Blockchain technology are based on the creation and management of a single source of information related to the process, it is legitimate to assume and investigate how to integrate them during the execution of the construction process, from the design to the building lifecycle. Due to the comparison and coordination of multiple disciplines, construction projects are often characterized by a large amount of data that can be stored in the BIM model and ensured from the point of view of reliability and transparency if stored in the shared register offered by Blockchain. The combination of the information model and the distributed digital database makes it possible to create a single effective shared source of information relating to the project, considered therefore as the only source of truth that guarantees the reliability of the data, the congruence of the sources of information and the identity of the subjects responsible for the activities.

In this innovative context, the project BIM model is therefore the only source of information accessible and consultable by all participants. The information in it is reliable and unchangeable, in a similar process execution the use of Blockchain technology further strengthens the development of the BIM model, ensuring a feeling of trust between operators. Since any information stored in the Blockchain database is traceable and unchangeable, time wasted and redundant verification of shared data due to frequent lack of trust among project participants are eliminated.

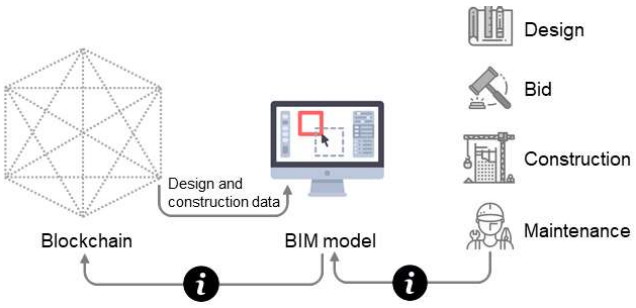

Fig. 6 BIM+Blockchain coordination

4.1.Benefits in construction process

The potential offered by the use of Blockchain allows to remove the limitations that have recently discouraged the creation of the BIM model such as reliability, traceability, disintermediation, recording of changes and data ownership. It is therefore possible to highlight the main benefits that can be obtained through the joint use of BIM and Blockchain.

4.1.1. Collaborative environment creation

Coordination between the BIM model and the distributed database containing all process information such as design decisions, verification, procurement and information sharing during construction operations ensures the creation of a single, reliable and unchangeable register. This construction process source of information establishes a collaborative environment among all participants and defines transparently the responsibilities and duties of each, reducing or eliminating the emergence of any misunderstandings and subsequent conflicts between the parties.Undoubtedly, the implementation of Blockchain technology within a construction process pursued through a BIM approach introduces a feeling of trust inherent in the system: the archiving and traceability of every decision and every project change allows to create a cooperative environment.

4.1.2. Intellectual properties preservation

In addition to supporting the creation of a collaborative environment, the distributed database allows to store and trace the information intellectual property contained in it and entered by each party of the process. Thanks to the collaboration created, it is possible that the research and work activities lead to the creation of new products or services, which are often limited for fear of not being able to associate the rights related to their designer. This happens to the ideas and information included in the BIM models where the integration of Blockchain can act positively as a register in which the copyrights of any innovative contribution or project modification are stored, stimulating operators to disseminate such ideas in other projects.

4.1.3. Smart Contract execution

If the two benefits illustrated above are mainly attributable to the design phase, the implementation of Smart Contract associated with the evolution of the BIM model is also relevant during the construction phase. The simultaneous progress between the BIM model and the execution of Smart Contract makes it possible to automate all the delivery phases. By its nature Smart Contract allows for economic transition when the predefined criteria are met, i.e. when the requirements of the contracting parties are met.

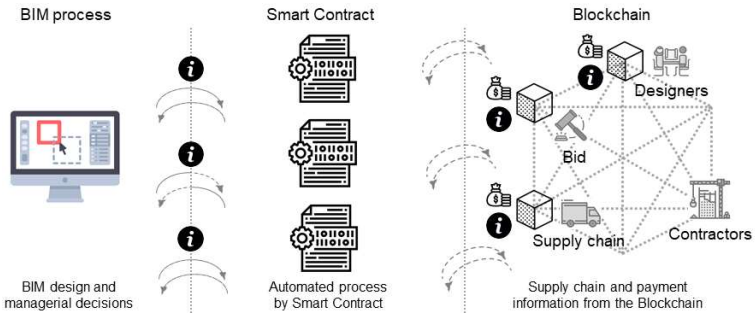

Fig. 7 BIM enables Blockchain technology

The relationship among the parties involved in the whole process is often characterized by the presence of asymmetrical information during the design, tender, construction and management phase, generating conflicts and mistrust with consequent impediments to the contract execution. For these reasons, the integration between the BIM model and the Blockchain illustrated so far is useful in making the activities carried out during the process explicit and visible, highlighting the honesty of those who act. Considering the benefits, various public administrations, including the italian one, are committed to understand the potential uses of the Blockchain in order to eliminate and manage in an optimal way the traditional criticalities.

4.2.Implementation in contract execution

The BIM model development based on a distributed digital register, updated and modified with the contract execution progress, allows to archive all the transitions made by drawing up a non-modifiable chronology of all the construction process stages. The Blockchain properties, guaranteeing the unchangeability of the data and the presence of a widespread control of every single step of the procedure, are therefore well disposed to face the waste of time and cost due to the lack of trust and the absence of a transparent sharing of information between the participants in the different process stages.

The possible uses and therefore the advantages that can be obtained through the BIM model development to support all the contract execution phases - design, commissioning, construction and management of the asset - based on the distributed database Blockchain are highlighted below.

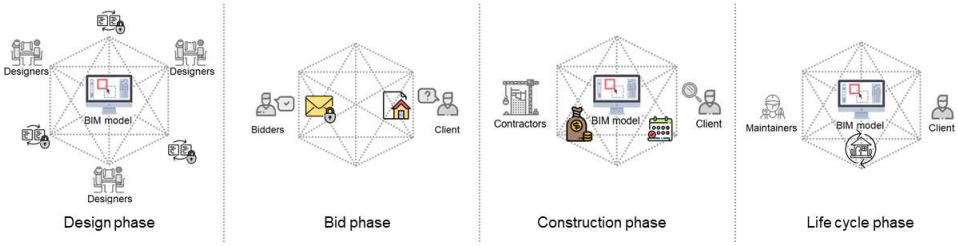

Fig. 8 BIM+Blockchain in contract execution phases

4.2.1. Design

The design levels preparation based on BIM methods allows to share and exchange all the project information through a single digital platform. The integration of these digital methods with the shared Blockchain database allows to create a truly collaborative process that limits the gap between digital information modeling and the management of project information - administrative, financial, insurance - typically expressed in sheets. The possibility of associating automatic payments to the data present in the model through the use of Smart Contract guarantees an exhaustive implementation of the engineering and architecture service contracts and therefore the respect of the requests expressed by each person involved. In this regard, the usual BIM model is no longer considered as a central data sharing environment based on a cloud platform governed by a third party, but rather as a peer-to-peer data exchange environment in which each participant can define and control the ownership of information in an immutable way.

4.2.2. Bid

Due to the frequent ambiguities that arise during tender procedures, the presence of a distributed ledger in which all information is stored in a transparent, permanent and accessible manner helps to contain any doubts. The digital tools implementation provided by the distributed platform, characteristic of the Blockchain technology, would make it possible to store in an immutable way all the main tender documents: that is, the information models presented both by the client and by the bidders.

The procedure described above guarantees the immutability and transparency of the tender documents published by the client. The procedures and criteria for evaluating the bids are accessible to all participants, making the reasons for the award explicit and eliminating any possible operational ambiguity. In the same way, the tenderers bids are also deposited in an unchangeable way on the distributed register, the client can access them only at the end of the reception phase, thus ensuring effective competition and giving all participants the opportunity to observe all the bids and to analyze them compared to the predefined award criteria.

4.2.3. Construction

The 4D and 5D dimensions model development allows to update and monitor the construction phase progress, the BIM model representing the site allows to understand the actual works state and the

continuous progress information storage allows to understand the causes and trace those responsible in case of delays or budget excess. In this way, the client can control the actual activities progress and the sharing of information relating to the construction site is immediate and transparent.

The Blockchain use during the construction activity is also useful in controlling the supply chain: materials that arrive at the site are traced along the entire route and therefore in case of defects or delays you can consult each stage of processing that was recorded on the Blockchain database and then connected to it internally to the BIM model (Kouhizadeh and Sarkis 2018).

Finally, the record of both supplies and work status information allows the Smart Contract to be performed correctly. The connection between the information model, i.e. the activities progress, and the computational contract allows automatic payments to be issued whenever the milestone set by the work program is reached.

4.2.4. Life cycle

Once the endeavour is completed, it is possible to create the as-built model of the building containing all the information relating to each component actually built. Through the entire asset life cycle, the BIM model implementation based on Blockchain facilitates the satisfaction of the circular economy principles (Marzouk, Azab, and Metawie 2018). Some building component data collected during the construction phase and stored in the distributed registry can support future maintenance, replacement and dismission activities during the operational phase. The constant components conservation and maintenance state updating makes it possible to use the BIM model as a database of materials and therefore to facilitate a considerable reduction in waste.

In addition, in the presence of plant terminals equipped with smart interfaces, it is possible to envisage the execution of Smart Contract for maintenance work on plant devices in the building. Once the intervention has been carried out, in fact, the maintenance technician can insert the activity carried out into the machine, which confirms the fulfillment of Smart Contract clauses, releasing automatically the payment.

Considering this preliminary analysis of the integration of the BIM approach and Blockchain technology in the development of procurement process, it has been realized that one of the most encouraging prospects offered by technologies is the reduction of information asymmetry between all contracting parties. The data definition, updating and validation by the participants allow them to access and consult, throughout the entire process, complete and truthful information thus increasing mutual trust. Such a technological enhancement would ensure that operators have a transparent understanding of the procedures for the award of contracts and that the client has a reliable check of the data relating to competitors, their offers and commitment.

5. Conclusion

The topics discussed in this paper demonstrate how the integration of the BIM model and Blockchain technology can offer benefits and add value to the main stages of contract execution. The BIM model can either incorporate information from Blockchain distributed ledger, such as material properties, supply documents or status, or send to Blockchain information about model changes that need to be updated and used later in the execution of Smart Contract, for the automatic release of payments or the definition of new supply orders (Carson et al. 2018). The construction sector has always been characterized by aspects that, due to ambiguity or incompleteness, often generate conflicts during the contract execution. The absence of a truthful and complete information exchange among the participants, the lack of responsibility, origin and tracking of information, the sporadic recording of changes and the difficult disciplines interoperability facilitate the emergence of misunderstandings, discussions and disputes among participants influencing in a negative way the progress and the results in terms of time and cost compliance.

Faced with these criticalities, the potentials offered by the Blockchain and BIM model development allow to address and govern positively the aforementioned problems thanks to applications that allow to streamline and improve the contract management, ensuring transparency in the information sharing and traceability.

Unlike some industries, the construction sector has not yet developed an effective digital ecosystem and investments in new technologies. In the presence of a constant increase in project complexity, the promising integration between Blockchain technology and BIM is a key step in the sector progress. Blockchain technology is here and although it is at an early stage of development with many challenges it presents a relevant opportunity for all companies in the construction industry to emerge as more effective, transparent and sustainable entities (Institution of Civil Engineers 2018).

6. Future developments

Thanks to the topics covered, it has been demonstrated that the adoption of new technologies is able to revolutionize the contract execution practices. The Blockchain technology can in fact guide a lean construction process, by reducing the industry fragmentation and complexity, making it a single trusted entity. The integration of the BIM model and Blockchain technology creates a single source of true information about all aspects of the process, giving the digital project model the only reliable tool to support the development and management of all phases of the construction process - from the design phase to the operation along the whole lifecycle (Wang et al. 2017).

Given the innovative nature of the technologies presented, it is not possible to think that professionals linked to tradition can rely with simplicity to a digital system that, based on protocols and codes, is able to manage and execute independently the contractual clauses. What is evident, is that construction industry stakeholders need to think about these issues and together develop the best possibile tools and procedures to address them. In order to facilitate the adoption and integration of these technologies the change of mentality and training are necessary since the intellectual and technological leap required is significant and may not be shared and approved initially by the community. The construction sector is one of the largest industrial sectors in the world and its structure is the foundation for economic growth and productivity. It is therefore essential to support and facilitate the digital transformation of processes in order to adapt and prepare the practices of the sector for further and possible future digital challenges.

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