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BLOCKCHAIN GOVERNANCE FOR INTEGRATED PROJECT DELIVERY 4.0

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Introduction

Construction projects are highly complex (Bertelsen, 2003). Traditional project delivery models that use a centralized organizational strategy often struggle to manage this complexity (Levitt, 2011). In response, the Lean Construction community has developed the project delivery model known as Lean Integrated Project Delivery (Lean IPD). Lean IPD uses a new organizational structure for more decentralized decision-making, a new operating system to improve handoffs and work commitments, and new commercial terms based on the principles of relational contracting (Mesa et al., 2016, 2019). The Lean IPD model has seen increased adoption across the industry (Hall & Scott, 2019).

However, the construction industry is now entering an era of Industry 4.0 and the emergence of new technologies, such as Digital Twins (see Chapter 2 and 14), Internet-of-Things (Chapter 2), artificial intelligence (see Chapter 5, 8, and 14), and virtual reality (see Chapter 11), offers new opportunities. To date, these technologies focus on improving the operational system to better manage production flow and eliminate 'waste'. In this chapter, we suggest that Industry 4.0 also simultaneously provides the opportunity to rethink the organizational structure and commercial terms of project delivery. In other words, how might project delivery models transform in an era of Industry 4.0?

We suggest that future project delivery models can take the approach of decentralized organizational structures and relational contracting found in Lean IPD and extend it further. For example, future project delivery models could embrace approaches like hive or swarm behavior that have been found to be highly effective in the management of complex production systems (Helbing et al., 2006). Guided self-organization, increased participant flexibility, and well-coordinated system dynamics can lead to better outcomes for complex systems (Helbing & Lämmer, 2008).

In this chapter, we propose that blockchain technologies can act as the technological foundation for this new model of project delivery. Blockchain and other distributed ledger technologies provides a distributed peer-to-peer system for value transactions without requiring a central intermediary. Blockchain is more than cryptocurrency transactions; it has inherent affordances that can also be useful to design new crypto-economic incentive systems. Through smart contracts and tokenization, new forms of micro-economic

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coordination can challenge existing assumptions around value and the nature of commercial terms.

We call our future vision Integrated Project Delivery 4.0 (IPD 4.0). IPD 4.0 is a project delivery system coordinated through blockchain technologies. While it should be noted that our thinking around IPD 4.0 remains early and underdeveloped, we attempt with this chapter to provide a conceptual and theoretical foundation for how IPD 4.0 might develop. To do so, we first review the limitations of the organizational structure, operational system, and commercial terms of the traditional project delivery system. We explain the problem of complexity, and how Lean IPD has made the first steps toward decentralization. Next, we introduce the fundamentals of blockchain technologies and describe how the use of smart contracts and tokens can increase automation, transparency, and alignment towards overall project success.

We then describe the key conceptual building blocks of IPD 4.0. This includes our vision for a collective organizational model based upon the crypto commons, an operating system built upon a value-based theory of production, and a commercial system that emphasizes micro-exchanges. We summarize the key differences between traditional project delivery systems, Lean IPD, and the proposed IPD 4.0. Next, we identify early research efforts and implementations that give tangible examples of how these ideas can be applied. Finally, we conclude with a discussion of the benefits and implications of the proposed IPD 4.0 model and the directions for future research.

Theoretical Underpinning

A project delivery system can be summarized by three distinguishing characteristics: the organizational structure, the operational system, and the commercial terms (Thomsen et al., 2009). The organizational structure defines the roles and relationships between the participants. The operational system describes the timing and sequence of events and practices and techniques of management. The commercial terms define the legal responsibilities for defining, designing and constructing a project (Mesa et al., 2016, 2019).

Traditional Project Delivery Systems

Traditional project delivery systems use a ‘command-and-control’ organizational structure, an activity-based operational system, and a series of transactional contracts (Alarcon et al., 2013). Command-and-control organization assumes that planners can develop detailed plans and performance targets that are feasible to implement and will remain valid for the entire execution of the project (Levitt, 2011). However, the nature of complex construction projects is such that change is inevitable; one or more key assumptions in the plan are likely to become invalid over time. When this occurs, the ‘validity of the baseline plan – even if it was developed by experts with a great deal of execution experience – immediately begins to erode’ (Levitt, 2011). A detailed plan that is constantly changing becomes ‘a virtual ball and chain around the legs of people trying to get the project completed’ (Levitt, 2011).

Traditional project delivery systems use an operating system that comes from a transformation view of production. The transformation view of production has dominated construction for a major part of the 20th century (Koskela, 2000). In the transformation view, production is viewed as a transformation of inputs to outputs. Production management requires decomposing the overall transformation into smaller transformations and tasks, and then carrying out these tasks as efficiently as possible (Bertelsen & Koskela, 2002). This is typically achieved using the critical path method (CPM) – regarded as the most important innovation in construction management in the 20th century (Koskela et al., 2014). However, the CPM can struggle to deal with the complexity and ever-changing nature of modern construction projects (Dallasega et al., 2020).

Traditional project delivery systems use transactional commercial terms. Transactional contracts emphasize 'one-off' exchanges between two parties. In practice, this is achieved through the process of a low-bid tender process. Contracts are written with the assumption of a singular exchange and that can clearly define the entire scope of work (Henisz et al., 2012). However, there are several challenges to transaction contracting for the delivery of complex projects. At each stage in the project life cycle (e.g., design, construction, and operations), multiple stakeholders can have different sub goals (Henisz et al., 2012). For example, designers have little incentive to reduce the life cycle costs of facility management and facility managers have a relatively weak voice during the design phase. Transaction cost economics suggests that the cost of writing general contracts and pursuing third-party intervention (e.g., arbitration, litigation) for contractual disputes can be prohibitive due to the nature of infrequent and highly idiosyncratic transactions (Williamson, 1979). This is especially true for construction projects because they involve shifting counterparties sequenced over multiple phases (Henisz et al., 2012).

The Problem of Complexity

While traditional project delivery methods can be adequate for simple and repetitive projects, the traditional approach struggles to deal with the problem of complexity.

Bertelsen first suggested that construction projects can be understood as complex systems due to the presence of autonomous agents, undefined values, and non-linearity (Bertelsen, 2003; Son et al., 2015). Construction projects are characterized by many mutually interacting parts (Corrado, 2019). Complexity arises when dependencies among the subsystem behaviors become important to the objective or function of the system (Miller & Page, 2009). Complex systems have very different characteristics from other systems, such as emergence, nonlinearity, decentralization, and adaptation (Son et al., 2015). System-level characteristics cannot be understood as a simple sum of subsystem behaviors. Instead, the emergent properties of the system are influenced by the interactions and behaviors that occur between the sub-elements (Bar-Yam, 2004).

The governance and management of such complex systems is difficult. Complex systems do not behave linearly. The system does not always do what is desired. The proportional effect of a single change in production or management is difficult to predict as it propagates across the system. Small subsystem interventions might cause a large-scale change in system behavior, while greater intervention efforts might remain useless (Helbing & Lämmer, 2008). In such settings, classic managerial strategies such as the structured hierarchical control used by traditional project delivery are likely to fail. Highly centralized and controlled systems can become unstable in the face of complexity, and skilled, well-informed and well-intentioned system managers can lose control (Helbing, 2013).

Lean Integrated Project Delivery

Lean IPD has emerged over the past 20 years as an alternative to traditional forms of contracting, design and supply chain management (Hall & Scott, 2019; Mesa et al., 2019). The

Lean approach has long emphasized decentralization as part of its approach to deal with the challenge of complexity in construction projects (Bertelsen & Koskela, 2004).

A full description of Lean IPD goes beyond the scope of this chapter (readers are referred to Mesa et al. (2019) for a more detailed description). Instead, a short summary is provided to describe how Lean IPD departs from traditional project delivery systems with regard to organizational structure, operating system, and commercial terms. Lean IPD uses a decentralized organizational structure composed of interorganizational teams-of-teams (Bygballe et al., 2014). Projects can create an inter-firm project board composed of whom the project firms collectively feel are the most important people (Hall et al., 2018). The organizational structure emphasizes joint project control to encourage collaborative decision-making, team buy-in and shared responsibility for innovation decisions (Hall et al., 2018) and this is reinforced by a co-located, shared workspace (Kokkonen & Vaagaasar, 2018). Lean IPD also uses early involvement of key participants allowing contractors to contribute construction knowledge and experience to design (Bygballe et al., 2014; Papadonikolaki, 2018).

Lean IPD uses an operating system based upon principles of Lean Production. Specifically, Lean IPD emphasizes a flow-based theory of production as opposed to the transformation theory of production (Koskela, 2000; Mesa et al., 2019). Pull techniques govern the flow of materials and information through networks of collaborating trade contractors and specialists. Optimization efforts do not focus on improving productivity, but instead making workflow more reliable and eliminating bottlenecks from the production system. Feedback loops enable learning and rapid system adjustment and decisions about planning are intended to be bottom-up from the so-called Last Planner (Ballard, 2000). Overall, the operating system emphasizes clear handoffs and workflow leveling.

Lean IPD uses commercial terms based on relational contracts instead of transactional contracts. Relational contracts are long-term agreements based on substantial mutual commitment, extensive cooperation, and trusted communication (Williamson, 1979). Relational contracting is well-suited for construction (Henisz et al., 2012) because highly interdependent but diverse counterparties engage in multiple sequential and complex transactions (Argyres & Liebeskind, 1999). Using this approach, construction managers pursue modified cost-minimization approach that balances the governance of an individual transaction with that of transaction's contractual hazards (Henisz et al., 2012). In practice, this is done using multi-party, incentivized contracts such as the Integrated Form of Agreement (IFOA) (Lichtig, 2010). Without a contractual hierarchy, IPD uses 'pluralistic coordination to align decisions and actions towards an established direction' (Tillmann et al., 2014). Project clients, contractors, and planners collaborate with one another on equal standing and a shared destiny dependent on the overall success of the project. Put in another way, the Lean IPD model creates a shared financial resource pool, shared decision rights, and shared risk and reward for the project outcomes. The project begins to resemble a common-pool resource scenario (Hall & Bonanomi, 2021) with a pooled project budget available to all signatory parties (Thomsen et al., 2009).

Blockchain Technology

Historically, transactions of value have been facilitated by trusted private or institutional intermediaries. The recent emergence of blockchain technology removes the need for these intermediaries while still allowing for secure and direct value transactions between actors in a network.

To do this, a copy of transactions (called a ledger) is distributed across many networked computers. The ledger is fully transparent, so everyone can always check and compare different versions for potentially malicious transactions. This is possible because the transactions are stored in a sequential chain of timestamped and cryptographically connected blocks (hence the name blockchain). As soon as new transactions are appended, it is not possible to change past transactions without causing a change in the signature of newer transactions.

The encoded consensus rules of the blockchain define how users agree and add new transactions. These consensus mechanisms are the main innovation of blockchain technology. A well-designed incentive system ensures that it is more profitable to secure the chain rather than to attack it. The most famous consensus mechanism comes from the first ever blockchain Bitcoin (Nakamoto, 2008) and is called proof-of work (Gervais et al., 2016). For further details, readers are referred to various taxonomies of the distributed ledger technology (DLT) landscape (Ballandies et al., 2021; Tasca & Tessone, 2019). Furthermore, Hunhevicz and Hall (2020) provide information on how these technical characteristics of blockchain enable various use cases in a construction industry context.

Since the creation of Bitcoin, many new blockchains have been developed to extend use cases beyond transacting cryptocurrency. The Ethereum blockchain (Buterin, 2014) made it possible for the first time that Turing-complete code pieces termed 'smart contracts' could be executed on a blockchain. Smart contracts allow for the coding of interaction rules with blockchain transactions. This enables transaction workflows and custom containers of value (i.e., tokens). Tokens can then be transferred easily among users of a blockchain. Subsequently, the second big wave of innovation was triggered in the blockchain space predominantly with countless decentralized finance applications (Schär, 2020).

However, the long-term promise of blockchain lies in new economic organization and governance, potentially disrupting or substituting existing forms of coordination (Davidson et al., 2018; Miscione et al., 2019). Blockchain creates ecosystems where the benefits from network effects and shared digital infrastructure do not come at the cost of increased market power and data access by platform operators (Catalini & Gans, 2020). On the one hand, smart contracts can encode coordination rules for digital workflows to coordinate global economic activity of actors in a decentralized way. On the other hand, tokens can incentivize actors within the created economic system towards intended behavior at the individual level.

For the coordination of complex construction projects, there is a strong fit between the nature of blockchain and the problems arising from complex systems and misaligned incentives. Construction research has started to investigate blockchain for suited application areas. The most prominent use cases include tracking and securing data in construction processes and the supply chain, as well as improving the financial processes with more transparent and automatized payment logic (Hunhevicz & Hall, 2020; Li et al., 2019; Li & Kassem, 2021; Perera et al., 2020; Scott et al., 2021). But while many of these use cases apply blockchain to improve existing construction processes, there is a bigger opportunity to leverage blockchain for novel forms of economic coordination in construction (Hunhevicz, Dounas et al., 2022).

Hunhevicz, Dounas et al. (2022) outline these new possibilities of collaboration within and across the built asset life cycle phases by describing the connection of blockchain governance with characteristics of the architecture, engineering, and construction sector. Blockchain-based governance for construction can enable novel decentralized incentive and market structures towards decentralized coordination. Individuals and communities of practice can contribute to value creation in the built environment without formal affiliation to a centralized project organization or firm. There is potential for blockchain as an inherently decentralized technology to embrace the loosely coupled characteristics of the construction industry (Hunhevicz, Dounas et al., 2022).

Towards Integrated Project Delivery 4.0

In this section, we propose how blockchain technologies can act as the foundation for a new project delivery system called Integrated Project Delivery 4.0 (IPD 4.0). Although existing studies have replicated and extended the collective risk/reward sharing mechanisms of integrated project delivery systems (Elghaish et al., 2020; Rahimian et al., 2021), we suggest this can be extended further to a fundamental rethinking of project delivery systems. In the spirit of a radical rethinking for the possible governance, we propose three conceptual principles to act as the foundation of IPD 4.0: a collective organizational structure, a value-based operating system, and micro-contractual commercial terms.

Collective Organization: The Crypto Commons

The proposed IPD 4.0 begins with a novel organizational structure known as a decentralized autonomous organization (DAO). A DAO is a blockchain-powered organization that can run on its own without any central authority (Wang et al., 2019). The management and operational rules of a DAO are solely governed by the rules embedded using smart contracts (Hassan & De Filippi, 2021). Participants in a DAO are responsible to define governance mechanisms using smart contracts. In this way, the DAO can self-operate, self-govern, and self-evolve (Wang et al., 2019).

Basic implementation of a DAO requires that stakeholders organize and develop rules around a treasury, which is then controlled by stakeholders. IPD 4.0 will use this concept for construction project funds. The project begins with an escrow fund controlled by a project DAO. Such escrow funds could come from a lump sum provided by a single owner, or collective funds from a community of interested stakeholders. The rules by which participants can withdraw funds from this escrow would be determined by the governance rules, including blockchain-based tokens to enforce voting rights. In IPD 4.0, the participants in the DAO collaborate and coordinate for the delivery of the final project according to the scope, time and budget constraints. Like the shared risk and reward terms of Lean IPD, the DAO governance rules can be encoded to allocate project rewards proportional to the overall success of the project.

The project escrow governed by the DAO represents a common-pool fund. The project resources become contractually available for free use by any token holders. The project participants must develop collective governance structures to deal with allocation of these resources throughout the project. Therefore, it will be the job of project participants to self-organize their own effective governance structures to help protect the project escrow from becoming ‘overdrawn’.

To do this, governance structures should be based on the principles for governance of common pool resources first proposed by Nobel-Prize winner Elinor Ostrom (2015). To be specific, IPD 4.0 teams will need to create principles that:

1. Define clear boundaries for project participants.
2. Match rules governing the use of project funds to the local project needs and conditions.
3. Ensure that those participating in the DAO can participate in modifying the rules.

4 Make sure that rule-making rights of community members are respected by outside authorities.
5 Develop a system for monitoring the project members behavior.
6 Use graduated sanctions for those who break the rules or do not perform.
7 Provide accessible, low-cost means for dispute resolution.
8 Build responsibility for governing the project in nested tiers, from the lowest levels up to the entire interconnected system (Ostrom, 2015).

Scholars suggest that blockchain is a key enabling technology to scale real-world commons (Bollier, 2015; Fritsch et al., 2021). The Ostrom principles act as guidelines to build such applications of real-world commons by encoding the respective governance rules with smart contracts (Hunhevicz, Brasey et al., 2022; Rozas et al., 2021). This connection was established because blockchains themselves can be described as a digital common pool resource. Actors in the network are motivated to contribute to the system through a bottom-up incentive system grounded in digital tokens that have perceived values to users, enabling peer-production of blockchains without any centralized coordinator (Red, 2019).

Therefore, Ostrom's design principles act as a theoretical starting point to conceptualize the governance structures of IPD 4.0 on the crypto commons. Following these principles, project participants can program specific governance structures and practices of the project delivery system on the blockchain (Hunhevicz, Brasey et al., 2022). The adoption of blockchain-based transparent decision-making procedures and decentralized incentive systems for community governance in commons could help avoid the *tragedy of the commons* (Bollier, 2015), or in this case the *tragedy of the project* where project participants overdraw resources from the common pool (Hall & Bonanomi, 2021). Blockchain can help create networked project governance to scale project delivery commons, similar to how the stock market enabled corporations to scale (Maples, 2018).

Operating System: A Value-Based Theory of Production

IPD 4.0 uses an operating system that emphasizes a value-based theory of production. Koskela (2000) first argued for the value-based concept of construction production alongside the theories of transformation and flow. Value-based production differs from the traditional transformation theory of production because:

- Value generation model considers all activities taking place inside the supplier, while transformation considers just the physical production.
- Value generation considers the customer, while transformation abstracts this away.
- Value generation inputs are based solely on customer dependent information and outputs are fulfillment of customer needs, while transformation considers all possible inputs, and the output consists of the products or services.
- Value generation is not a hierarchical model and not all activities are similar (Koskela, 2000).

Because blockchain can enable self-organizing and interconnected supply chains, the IPD 4.0 operating system can be based on guided self-organization to maximize value for each individual task, product or service. Lean-based approaches such as the Last Planner can still be used, with the addition that each activity can be assigned a token representing the perceived value in the current system. So how can a token represent the value of an activity?

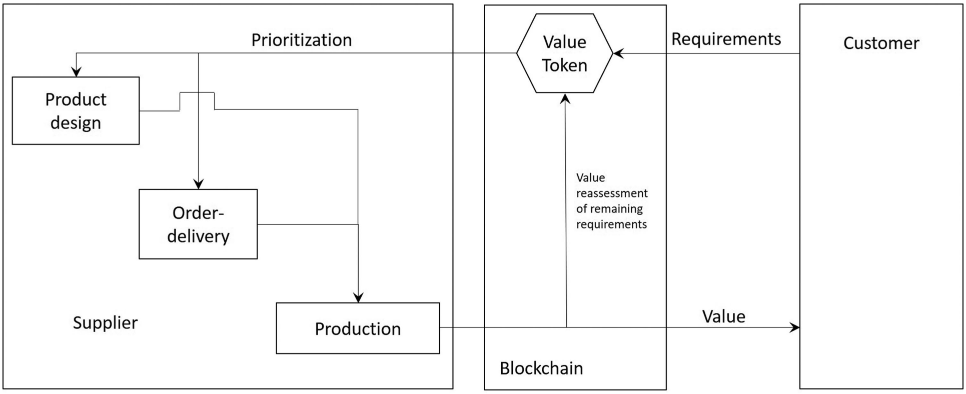

Figure 18.1 Revisiting the black box of value generation (adapted from Koskela, 2000)

Koskela (2000) began this in his exploration of the black box of value generation (see Figure 18.1). In Koskela's conceptualization of production value, the customer formulates measurable or quantifiable value of the products or services and passes them to the supplier to deliver this value. For construction activities, Koskela (1992) suggests that there are two types of customers, the subsequent activities and the final customer. Therefore, for most construction activities, the supplier is the previous activity in the production system and the customer the next activity. This means that value of an activity is not absolute. Instead, an activity's value is relative to the needs of future project activities, is time dependent, and ever changing based on the current status of the project. Therefore, participants of subsequent production steps or the final customer could assign tokenized value for project activities relative to their perceived value at a given time step.

As a simple example, consider a hypothetical trade-off between the delivery of prefabricated concrete columns and the delivery of a pump system, when there is only laydown space for one of the deliveries. How should the project team decide which activity will be postponed? In an IPD 4.0 operating system, each delivery could be ascribed value tokens on the blockchain by affected project participants. In case the delivery of the prefabricated concrete columns would provide a higher value than the pump system, this activity will be done.

In the simple example above, such a decision is obvious, but the power comes when the value of each activity is tokenized across the project. A value-based production system will incentivize the production of certain activities based on their relative value to all future activities in the project. Once value is clear, the participants in the system should in theory self-optimize to maximize their own rewards. Instead of the requirement of top-down controlling agents (e.g., managers), self-organizing agents (e.g., workers) can perform tasks with increased flexibility following simple rules. These decentralized interactions will appear closer to collective or swarm intelligence than a well-structured production approach. However, the system can also be designed for guided self-organization keeping project-level objectives in mind while allowing the system to self-optimize around individual agents.

The challenge is that setting up these rules towards guided self-organization requires a good understanding of the complex system. Only a slight modification of the interaction rules of a complex system can have favorable or undesirable results towards the overall system state (Helbing, 2014). Nevertheless, decentralized and non-hierarchical management approaches using principles of guided self-organization can be successfully implemented if several conditions are fulfilled (Helbing, 2014). For example, the use of self-organizing signal control adapting to local traffic demand performs better than pre-determined traffic light schedules that attempt to enforce prescribed controls (Kesting et al., 2008). Decentralized control of material flows for continuous conveyer systems that optimize local traffic flows performs better at the system level then centralized controlled systems (Gue et al., 2014; Mayer & Furmans, 2010). In general, guided self-organization inspired by biological approaches is seen as very promising in logistics and supply networks to cope with nonlinearity and complexity.

Commercial Terms: Micro-Exchanges

The commercial terms of IPD 4.0 will be based on smart contracts that enable micro-exchanges. From a micro-economic perspective, blockchain enables a fundamental shift in the distribution of rewards within an organization and the structure of that organization's transaction costs (Jacobo-Romero & Freitas, 2021). Smart contracts and new forms of reward distribution can therefore promote a bottom-up model of economic organization (Jacobo-Romero & Freitas, 2021).

Project firms no longer will need to sign a single contract intended to cover the entire scope and duration of the project. Instead, commercial terms will be characterized by repeated and frequent micro-exchanges. These micro-exchanges can be transactional or relational in nature.

Transactional micro-exchanges will transact funds from the DAO escrow for project tasks, such as design activities, production activities, or information sharing. The value of each transaction has already been tokenized, so the smart contract exchange simply confirms the completion of the activity and transfers the appropriate value. By focusing commercial terms on single exchanges with high asset specificity, projects can avoid the uncertainty costs priced into the delivery of complex projects.

To use an example, let us consider the design of a structural steel system. In traditional project delivery systems, the structural engineering firm would receive a contract to complete the overall system design, to complete detailing for each of the structural steel connections, and to approve the shop drawings of the beams proposed for production. In a micro-exchange environment, a series of smart contracts could be encoded to reward value for the design, detailing, and approval of the structural steel system. First, the contract could reward a systems-level design that ensures optimization of the whole system and not just the parts. Next, the work is parsed into specific, smaller tasks (e.g., detailing of the connections). A micro-exchange rewards the successful completion of each design and approval activity as they occur. As deadlines near, the relative value of completing certain tasks increases. Therefore, project participants are incentivized to "swarm" their time and attention on the most valuable tasks in order to maximize rewards. When these tasks are confirmed as complete, it triggers automated micro-payment from the DAO escrow.

Micro-exchanges can also work on the level of relational contracting. Micro-relational exchanges can make sense if micro-transactional exchange is not possible. For example, if a task involves multiple actors and it is hard to define clearly the scope of actors and the value of each activity because there is high interdependence and reciprocity. Relational contracts could be formalized into smart contracts, creating shared sub-reward pools for parts of the project. There could be multiple sequential or parallel relational contracts within one construction project.

As another example, micro-relational contracts could self-adjust the risk/reward distribution based with token-based peer review mechanisms. For example, reputation tokens could be issued to stakeholders according to the value contributed and the alignment with the overall perception of value of the community (Pazaitis et al., 2017). The final distribution of the reward pool depends on the final relative share of reputation tokens of the contractual parties. The Covee protocol is an example that sets up such a peer-review mechanism to determine the final rewards of anonymous contributors of a project, but with a score and not reward tokens (Dietsch et al., 2018). In a similar manner, reward tokens could be distributed on a regular basis when intermediate work packages are delivered, adapting continuously the reward structure of the relational contracting parties according to the relative share of reward tokens.

Comparison of Project Delivery Systems and Support of Lean Principles

Table 18.1 Comparison of the three project delivery systems

	Traditional project management	*Lean IPD*	*IPD 4.0*
Organizational structure	Command-and-control (Hierarchy)	Decentralized (Teams-of-teams)	Collective(Commons)
Operating system	Emphasis on transformation	Emphasis on flow	Emphasis on value
Commercial terms	Transactional	Relational	Micro-exchanges (Transactional & relational)

Organizational Structure

Traditional project delivery organizational structures have overestimated the ability of centralized command and concentrated decision making to control complex projects. As the advanced technologies described in the other chapters of this book bring additional data and information systems to manage, the complexity of project systems will only increase. Complexity science suggests the need for a fundamental redesign of organizational structures that use decentralization and distribution to better deal with these situations.

Decentralization is the dispersion of organizational communication while distribution is the dispersion of decision-making (Vergne, 2020). Lean IPD can be considered a decentralized-concentrated organizational form. This organizational form emphasizes problem-solving teams, incentive pay, flexible job design, and information sharing among workers (Mookherjee, 2006). The project sub-teams are tasked with reaching consensus and recommending a course of action, which the project management team can, based on extant knowledge, either accept or reject (Vergne, 2020). However, Lean IPD only includes partial distribution of decision making; decision-making power and autonomy are assigned to sub teams to a certain point (Levitt, 2011), but still require consensus of the project management team or sometimes a senior management team to make final decisions (see Figure 18.2).

By contrast, the collective structure of IPD 4.0 on the crypto commons takes both a decentralized *and* distributed organizational form (Vergne, 2020). To be able to make decisions without formally assigning decision-making authority to higher-ranked members, IPD 4.0 must define a non-hierarchical protocol for its members to reach consensus, which we suggest should be based on the Ostrom principles. In this organizational form, trust is both distributed (i.e., any member can be a decision-maker) and decentralized (i.e., every member

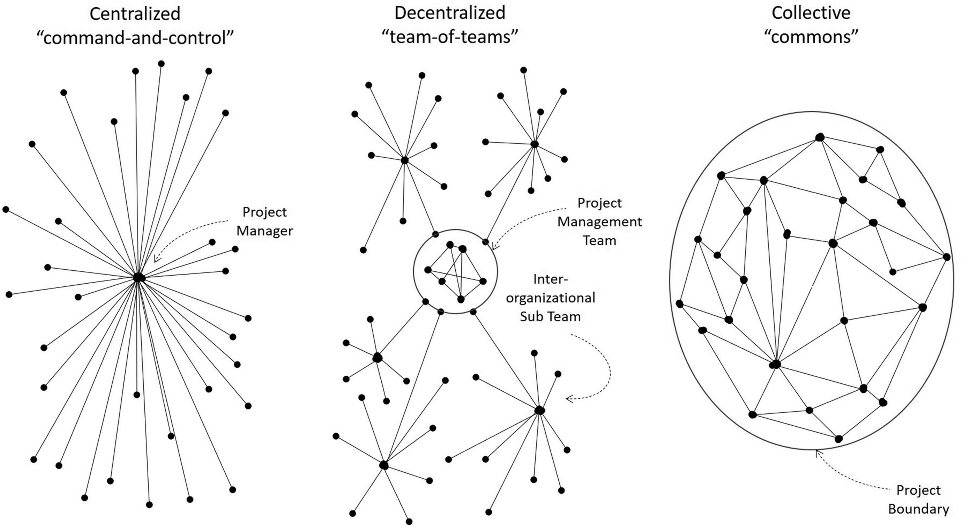

Figure 18.2 Organizational structure of the three project delivery models (from L to R: Traditional, Lean IPD, and IPD 4.0) (adapted from Baran, 1964)

has equal access to data and information) (Vergne, 2020). However, this organizational form comes with challenges. It can be difficult to ban specific members or censor transactions since no one entity holds the formal authority to do so.

Complexity theory suggests distributed networks, what we call the collective commons, offer an advantage over a concentrated teams-of-teams decision making approach. Distributed networks are more robust. There is redundancy in the network; if someone cannot deliver or decide, the mechanisms are in place so that someone else can immediately help. The project delivery team can be scaled across many individual actors and behave more like self-organizing hive structures than a collaboration of firms. In addition, project contributors could remain anonymous, conduct remote work, or only do small tasks for a short time.

Value-Based Operating System

When Koskela (1992) introduced three views of construction production, he argued that traditional project management was overly concerned with the transformation model of production. He conceptualized a new production philosophy for construction, based on two additional theories for production: flow and value.

The Lean Construction research community has made great advances in theory and in practice for flow-based production. The Lean Construction techniques that are most widely applied (e.g., Last Planner System) or that are rapidly emerging (e.g., Takt Planning) emphasize flow by reducing variability, reduce cycle times, and increase process transparency. The legacy of the past three decades of Lean Construction research has been an understanding of production flow on the construction site.

However, an argument can be made that the current approach *overemphasizes* the flow-based operating system. Concept and practices for value are present (e.g., Target Value Design) but these are applied in service of production flow. Discussions around value, such as reducing the share of non-value adding activities (Koskela, 1992), are done in order to improve the production flow. Other valuation practices such as Target Value Design are applied at a high level (e.g., the overall project cost), but little is known about the specific valuation of production activities.

The new operating system of IPD 4.0 returns to Koskela's assertion that concepts of transformation and flow work in service of value. A value-based production does not exist in isolation. Theories of production based on flow and transformation will still exist but will be re-focused on control of the transformation and the flow for the sake of the customer (Koskela, 2000). However, IPD 4.0 introduces a major shift through value tokens and smart contracts that will incentivize the behavior of the operating system to more closely resemble a guided self-optimizing system (e.g., a swarm or hive) instead of a production line (e.g., train or parade of trades). Because value is only created by fulfilling customer requirements, not as an inherent merit of conversion (Koskela, 1992) nor an inherent merit of maintaining steady workflow, the creation and management of value will receive new attention in IPD 4.0. Since blockchain is transparent, all actors can see the valuation of activities, as well as who contributed how much to value generation. This could lead to more open discussions about what is value to a project, how does value change over time, and how can value be maximized.

Commercial Terms

Traditional construction procurement using a transactional contract often fails because there is low asset specificity. At the time of tender, project documentation is often not complete, and it is hard to identify the 'unknown unknowns' facing the project team. Relational contracts create long-term agreements built upon mutual commitment, extensive cooperation, and trusted communication. However, from the perspective of market economics, relational contracts are not as efficient as purely transactional contracts with high asset specificity.

The proposed commercial terms of IPD 4.0 imagines a compromise between relational and transactional principles. Using smart contracts, transactions will only occur for specific activities (e.g., design this structural steel connection in exchange for this financial reward). However, not all transactions need to be monetary. The use of reputation tokens (e.g., for conducting a peer review of the structural connection) can help reward and recognize trusted participants and project leaders, potentially determining also the individual share of risk and reward defined in relational contracts.

How Do We Apply This?

Although the above is highly conceptual and theoretical, it should be noted that several research efforts are already underway that align with our vision for IPD 4.0.

For collective organizational structures, Hunhevicz, Brasey et al. (2022) outline opportunities of blockchain governance mechanisms for IPD based on the Ostrom principles. The research identifies 14 potential blockchain mechanisms to support the concept of a crypto commons of project delivery, and 22 specific ways to apply these to a blockchain-based digital governance of IPDs. Together they can help to create blockchain governance building blocks to manage IPD construction projects in a decentralized way on the 'crypto commons'.

For example, blockchain can be used to define boundaries within IPDs through access-rights for the users and resources with blockchain addresses and tokens. Since blockchain is inherently transparent, actions can be easily monitored. The system can be designed to incentive trusted behavior in line with the community defined goals. The project participants can develop decentralized proposal and voting platforms to ensure scalable and inclusive decision making about the project's rules and values. These rules and values can be then formalized with smart contracts and incentivized through new token-based systems, either representing financial rewards or reputation rewards. In addition, blockchain can facilitate the use of graduated sanctions or decentralized jurisdiction systems to collectively resolve conflicts fast and locally.

There are other efforts to create DAOs in the built environment. For example, Dounas et al. (2020) have prototyped a DAO for decentralized architectural design in consideration of blockchain mechanisms and the design processes.

For value-based operating systems, Kifokeris and Koch (2021) developed a proof-of-concept blockchain application for construction logistics. Elghaish et al. (2020) created an automated financial system with a methodology to enhance financial transaction management and risk/reward sharing practices in IPD. Yang et al. (2020) developed a blockchain application framework for business processes and information integration among multiple stakeholders for two cases: the design of an external cladding system and the engineering, procurement, and construction management of a large distillation tower. Hunhevicz et al. (2020) prototyped a crypto-economic incentive system for data sets that included a value for providing data and a value for checking that the data is correct. Tezel et al. (2021) have explored project bank accounts for payments, reverse auction-based tendering for bidding, and asset tokenization for project financing. The Construction Blockchain Consortium is currently working to create several white papers that consider how value, blockchain, and construction technology can work together (e.g., Campbell-Turner et al., 2020).

For commercial terms, there are several emerging examples of smart contracts that transact based on the specific completion of small pieces of work. Lee et al. (2021) integrated smart contracts with a digital twin of robotic fabrication. The robotic placement of each block, once verified by the digital twin to be correctly placed, triggers a micro-payment. Hunhevicz et al. (2022) developed a performance-based smart energy contract that took sensor measurements from a digital twin every 15 minutes. If the temperature measurements matched the target performance, incentive payments were made to the contractor and facility manager. Hamledari and Fischer (2021) developed a smart contract-based progress payment system using drones for automated production progress monitoring.

However, these efforts are all very early and much more research will be required before IPD 4.0 will be possible.

Implications, Limitations, and Conclusion

While there are numerous implications of the IPD 4.0 approach, only three are mentioned here for the sake of brevity.

The collective commons, or project delivery as a DAO, has implications for project managers and other decision makers. In the era of Lean IPD, it was argued that a new kind of project manager was needed (Seed, 2014). This 'project manager 2.0' was an agile leader who could empower other participants, collaborate across firm boundaries, and make decisions from multiple sources of information (Levitt, 2011). However, in the IPD 4.0 DAO, there is no prescribed hierarchy of decision making. Therefore, future research should identify the skills and competencies required of an IPD 4.0 project manager toinspire collective action for the overall good of the project without relying on formal hierarchy.

Lean IPD incentivizes rewards at the firm level. However, the micro-commercial terms of IPD 4.0 are designed to incentivize participants at the individual level. Blockchain can steer the individual human actors in the project delivery system through simple incentives towards valued contributions. Incentives in a swarm system motivate everyone to maximize their own rewards while also ensuring these rewards align with the overall health of the global outcome (Helbing et al., 2006; Peters et al., 2008). Blockchain-based governance processes can support data-driven bottom-up and collective decision-making through crypto-economic incentive systems. These systems guide individual actors toward behavior that optimizes the overall project (Hunhevicz, Dounas et al., 2022). Here there are major implications regarding professional liability, human resources, incentive design, gig economy, and the long-term future of the firm that require more investigation. Additional research is also needed to understand how to ensure how guided self-optimization retains control on the complete process to optimize the whole system and not just the parts.

Finally, blockchain does not discriminate between human and machine participation. Participants only need to own a recognized address on the blockchain. Therefore, each participant in the project could be a machine, another DAO, or a human decision-makers. Therefore, IPD 4.0 ultimately allow for human-machine interaction on equal standing for project coordination. For example, the IPD 4.0 project can open a design competition that accepts submissions from both humans and machine-learning algorithms. Such implications show how the future of artificial intelligence may be both self-organizing and self-assembling (Risi, 2021). Future research could study how this approach could provide incentives for algorithmic approaches for single functions (e.g., to design a floor plan or automate the creation of a weekly work plan) to be formalized as their own DAO or distributed application and scale across a network of IPD 4.0 projects.

To summarize, this chapter is intended as a high-level conceptualization to propose how blockchain technologies can act as the foundation for IPD 4.0. The work is limited in that many of the proposed ideas around IPD 4.0 remain conceptual and therefore somewhat vague. In particular, the ideas for a collective commons organizational structure, a value-based operating system, and micro-exchange commercial terms are meant to provoke discussion. Further research is needed to implement and prototype such systems, in order to refine or overturn the ideas proposed here. The ongoing blockchain research in construction cited above can act as a starting point to build an IPD 4.0 delivery system, and much more research will be needed. Nevertheless, the suggested theoretical and conceptual implications of blockchain on project delivery models can act as a starting point for the future of construction in an era of Industry 4.0.

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