Open Platform Concept for Blockchain-Enabled Crowdsourcing of Technology Development and Supply Chains

[1]Jens Ducrée, [2]Max Gravitt, [3]Ray Walshe, [4]Sönke Bartling, [5]Martin Etzrodt, [6]Tomás Harrington

[1]School of Physical Sciences, Faculty of Science & Health, Glasnevin, Dublin 9, Ireland
[2]Digital Scarcity, digitalscarcity.io, USA
[3]School of Computing, Dublin City University, Glasnevin, Dublin 9, Ireland
[4]Blockchain for Science, Berlin Germany
[5]Akasha Foundation, Zug, Switzerland
[6]Innovation, Technology & Operations Management Group, Norwich Business School, Faculty of Social Sciences, University of East Anglia, United Kingdom

Abstract

We outline the concept of an open technology platform which builds upon a publicly accessible library of fluidic designs, manufacturing processes and experimental characterisation, as well as virtualisation by a 'digital twin' based on modelling, simulation and cloud computing. Backed by the rapidly emerging Web3 technology "Blockchain", we significantly extend traditional approaches to effectively incentivise broader participation by an interdisciplinary 'value network' of diverse players. Ranging from skilled individuals (the 'citizen scientist', the 'garage entrepreneur') and more established research institutions to companies with their infrastructures, equipment and services, the novel platform approach enables all stakeholders to jointly contribute to value creation along more decentralised supply chain designs including research and technology development (RTD).

Blockchain-enabled "Wisdom of the Crowds" and "Skin in the game" mechanisms secure "trust" and transparency between participants. Prediction markets are created for guiding decision making, planning and allocation of funding; competitive parallelisation of work and its validation from independent participants substantially enhances quality, credibility and speed of project outcomes in the real world along the entire path from RTD, fabrication and testing to eventual commercialisation. This novel, Blockchain-backed open platform concept can be led by a corporation, academic entity, a loosely organised group, or even "chieflessly" within a smart-contract encoded Decentralised Autonomous Organisation (DAO).

The proposed strategy is particularly attractive for highly interdisciplinary fields like Lab-on-a-Chip systems in the context of manifold applications in the Life Sciences. As an exemplar, we outline the centrifugal microfluidic "Lab-on-a-Disc" technology. Rather than engaging in all sub-disciplines themselves, many smaller, highly innovative actors can focus on strengthening the product component distinguishing their unique selling point (USP), e.g., a particular bioassay, detection scheme or application scenario. In this effort, system integrators access underlying commons like fluidic design, manufacture, instrumentation and software from a more resilient and diversified supply chain, e.g., based on a verified pool of community-endorsed or certified providers.

Introduction

It is now widely recognised that manufacturing "value chains" including initial design, testing and optimisation stages, to production ramp-up and in-use activities are critical in transforming new technologies and ideas into marketable products. However, how best to manage critical network resources in the design and setup of enabling (yet often) ‘nascent’ supply chains is poorly understood and executed. Forming and growing a ‘resilient’ supply chain should be a critical component in the design of a platform-based business model.

In such platform-based strategies that have been widely adopted by mature industries like automotive since the later 1970s [1], a wide range of products are derived from a joint, modular architecture so components, processes and services can be shared internally and / or with suppliers. Such platform approaches accelerate, de-risk and reduce costs for research & technology development (RTD) and subsequent manufacture and configurability of new products; related formal or internal standards also allow forging comprehensive RTD capabilities and supply chains composed of specialist players as a hallmark of modern, task-sharing economies. The availability of a critical market size and diversity of its members constitutes a key prerequisite for such platform strategies; otherwise, the set up cost for such a generalised approach would be excessive, the risk high and, hence, the overall incentive for (independent) parties to embark rather low.

The Distributed Ledger Technology (DLT) “Blockchain” [2, 3] has already proven to afford a high level of trust and transparency to financial transactions for fuelling collaboration in the digital world; its “smart contracts” are mostly executed on the (nearly [4]) Turing-complete “Ethereum Virtual Machine” (EVM) [5] without the need for a middleman. Beyond such decentralised finance (“DeFi”), our new approach expands the concept of Blockchain-endowed trust to the real world of product development for crowdsourcing of work, expertise, infrastructure and services along the entire pipeline from idea generation, funding, RTD and production and marketing.

By competitive parallelisation of work and their validation, our novel concept resorts to “Wisdom of the Crowds” [6-8] or “Collective intelligence” [9] principles including Blockchain, typically Ethereum-enabled bounty networks [10] and prediction markets [11] for finding best possible “truth” as a foundation of governance and decision making, as well as assessment of technical progress and future, technological or commercial prospects, e.g., return-on-investment. This comprehensive crowdsourcing strongly relies on well established “Skin in the game” mechanisms like proof-of-work, proof-of-stake, formalised reputation [12], staking, governance and arbitration [13, 14] schemes. Funding can be leveraged through blockchain-based seigniorage [15] as well as recently proposed crowdfunding [16, 17], initial coin / token offerings (ICOs / ITOs), curation markets [18, 19] and token bonding curves [20].

Amongst the wide scope of applications, this paper exemplifies the implementation and benefits of the novel, blockchain-backed open platform concept for “Lab-on-a-Chip” systems. The primary commercial use cases of these microfluidic devices are biomedical in-vitro diagnostics (IVD) at the point-of-care (PoC), tools for life-science (research), and monitoring industrial processes, infrastructures and the environment. The present global market for such microfluidic devices and products is valued well above 10 billion USD [21].

Conventional platform concepts [22] and standards [23-27] have already been suggested for such Lab-on-a-Chip systems. However, the vast majority of these microfluidics-based products still addresses comparatively small niche markets for which it is extremely hard to recover upfront investment, e.g., for RTD and production; nevertheless, companies are still quite hesitant to share their technology portfolio outside their own contract suppliers.

This paper first outlines the basics of open platform models for the representative case of the modular, centrifugal microfluidic “Lab-on-a-Disc” (LoaD) platform. It then elaborates present bottlenecks for wider-scale commercial success of this special variant of Lab-on-a-

Chip technology. Next, “Wisdom of the Crowds” mechanisms in connection with their blockchain-based implementation and reward schemes are elaborated. After the final summarise, we discuss further synergies, opportunity and challenges.

Platforms

Technology platforms create a variety of applications, e.g., to address different market segments, from a common set of design rules, materials, processes, components and development tools. Prominent examples are car platforms (e.g., Volkswagen Group, Toyota, GM, Fiat, Mitsubishi, Ford, Mazda, Chrysler, Hyundai-Kia) defining essential architecture such as floorplan, wheelbase, steering mechanism, suspensions and wheelbase [28]. Economy-of-scale effects markedly reduce cost (per unit) of RTD for the product and production technologies, and lower the number of parts in the inventory, promote quality, enhance reliability, enable customisation and facilitate logistics. Computing platforms provide an environment for executing programmes; there are different levels, such as browsers, programme suites, operating systems, software, hardware, and combinations thereof [29, 30].

In strictly proprietary platforms, these core elements are sourced internally, or from designated contract suppliers who are bound to confidentiality and / or exclusivity. This restrictive policy can be lifted by publishing standards, e.g., for component interfaces or test methods, to attract more players and thus to create choice for buyers and to relax the dependence of specialised suppliers from a single organisation; yet, certain key enabling intellectual property (IP) including know-how may remain confidential, e.g., kept as a trade secret by in internal group or filed as patent, to shield the product against competition. In any case, the formation of such platforms vitally requires the involvement of a critical mass of participants and a matching market demand. Therefore, it is much easier for established, large-scale industries and their conglomerates to organise a “closed” supply chain.

Open platforms release information needed to participate in the RTD and supply chain to stimulate the engagement of multiple parties, thus inducing crucial economy-of-scale effects for seminally augmenting quality, speed and cost. Especially smaller, highly innovative system integrators can thus efficiently outsource essential elements, such as materials, manufacture and specialised services, to a commercial network while leaving sufficient room to distinguish their own value proposition and USPs, e.g., their distinctive methods or application spaces. The benefits of such open platform approaches are likely to significantly outweigh drawbacks such as potential loss of IP on common aspects of the product that may be shared with competitors.

Example: Lab-on-a-Disc

Technology

In the wide arena of microfluidic systems, platform concepts [22] and related standards [23-27] have been propagated for quite a while. To further illustrate the extended, open platform concept presented in this paper, we consider the specific use case of centrifugal microfluidic systems which have been developed by many commercially [31-35] and academically [36-46] driven initiatives since the 1990s. On these “Lab-on-a-Disc” (LoaD) systems (Figure 1), liquid samples and reagents are pumped and conditioned by the a centrifugal field which is modulated by the spin rate of the rotor. While a variety of geometrical formats of microfluidic chips which displays a network of miniaturised chambers and interconnecting channels have been utilised, a disc of similar size as optical storage media (e.g., CD, DVD or Blu-Ray) is still a common shape. Its exceptional capability of larger-scale (functional) integration (LSI) on the LoaD enables comprehensive sample-to-answer automation and parallelisation for "point-of-use" scenarios as a critical USP with major markets in bioanalytical point-of-care diagnostics, tools for life-science research and the biopharmaceutical industry. A 'White Paper' type document [47] is currently issued as a foundational element to encourage and enable broad participation of RTD communities and supply chains. In particular "digital twin" concepts [48] in connection with widely available cloud computing will shift the emphasis from experimental to *in silico* design optimisation, and thus massively open up participation in crowdsourcing of RTD.

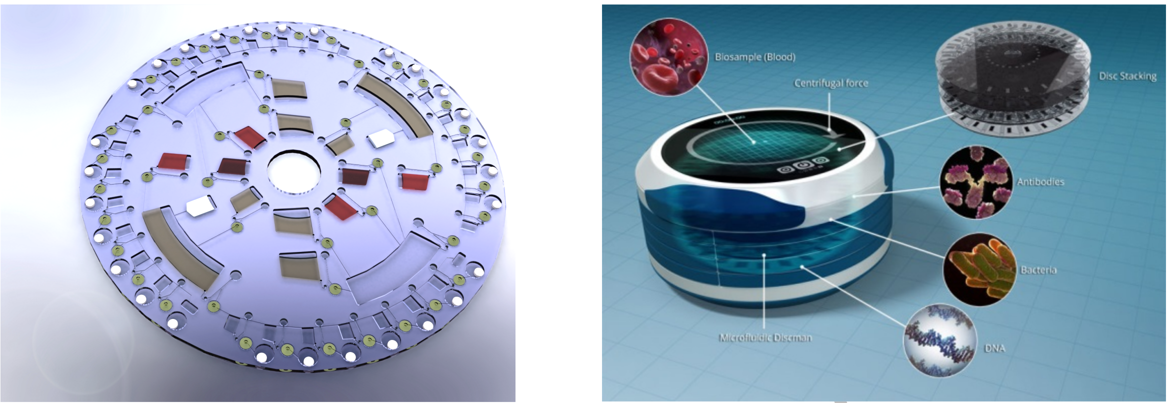

Figure 1 Lab-on-a-Disc (LoaD) systems feature a modular setup of a single-use, polymer chip, often of similar geometry as common optical storage media like CD, DVD or Blu-ray, which features a netwerk of chambers for batch-wise conditioning os (bio-)samples and reagents. These chambers represent Laboratory Units Operations (LUOs) such as metering, mixing, aliquoting, purification, concentration and particle separation which are sequentially processed in a abtch-wise fashion along a conventional laboratory protocol through normally-closed valves placed at their interconnecting channels.

Modularity, whether by hardware or design, constitutes a key enabler for platform strategies. On a component level, the LoaD features an instrument which is essentially assembled from a simple spindle motor, electronic control and (mostly optical) detection units; this "player" receives a typically single-use (polymer) cartridge which fully contains the sample and reagents, while safely retaining potentially (bio-)hazardous waste; the contact-free, field-induced pressurisation of the chip-based liquids supersedes the need for maintenance-prone fluidic or pneumatic interfaces to the player. The variant of the LoaD platforms considered here [49-63] also allows a second level of modularisation where assay protocols are run in a batch-wise "stop-and-go" fashion along a sequence of Laboratory Unit Operations (LUOs), such as metering, mixing and particle filtering, each of which is independently controlled by a rotationally actuated, normally-closed valve at its interconnecting outlet.

Similar to common lumped-element models for electronic circuitry, a layout can be well represented by a network of parallel or serially connected fluidic equivalents of resistors, capacitors, inductances, diodes, relays and routers which are powered by voltage or current sources. By virtue of their functionally modular architecture, LoaD systems can hence be described and simulated by lumped-element models where LUOs and valves are characterised by reduced-dimension transfer functions. Importantly, the availability of accurate modelling of liquid handling on the LoaD allows to directly derive component performance and reliability from geometrical tolerances related to device manufacture to rapidly raise Technology Readiness Levels (TRLs) [64].

The modular setup and predictability of fluidic function from basic manufacturing tolerances creates a sound basis for crowdsourcing of RTD. In addition, and similar to mature industries such as electronics and Micro Electro Mechanical Systems (MEMS), capable supply chains can be built around foundries to significantly accelerate, de-risk and economise the development of new applications.

Supply Chain

With modularity of its foundational technologies and scope applications, LoaD systems are particularly amenable to the platform concept. However, in line with other emerging industry-type examples, e.g., 'plastic electronics', that are often characterised by new and innovative manufacturing processes driven by individual actors and new enterprises [65], single-handed development is still prevalent amongst start-up companies in the arena of microfluidics.

Given the specialist nature and a limited pool of suppliers in terms of, e.g., specialised manufacture, the current *modus operandi* is to carry out contract work under strict confidentiality or exclusivity arrangements. As well as failing to take advantage of technological synergies and economies-of-scale, the underlying risk is that one becomes merely 'reactive' in response to competitor strategies [66, 67]. In the absence of widely accepted standards, a platform-based mechanism paired with blockchain-enabled incentivisation schemes presented here can boost market driving strategies where an actor or enterprise may proactively influence the competitive landscape and industry standards [68, 69].

Apart from somewhat valid concerns on sharing IP and trade secrets, this legacy corporate culture is also rooted in the huge variety of underlying microfluidic concepts, often requiring development from scratch for most of their technological constituents. Actors and small emerging firms then focus their efforts on resolving associated technical issues and developing prototypes while early 'non-technical' requirements are often overlooked.

As a result, research in the area of emerging industries has typically concentrated on the technology side, coupled with particular technology-specific commercialisation challenges. However, the 'industrial ecosystem' is much more complex, and cannot be readily described by a single viewpoint [70]. For example, it is argued that emergence is largely dependent on the parallel development of a 'new' supply chain or network to flank such commercialisation activities [71]. Yet, the design, setup and operation of enabling supply chains, in the context of emerging industries, is poorly understood. One key challenge is the lack of a defined strategy that a firm can follow due to the uncertainty which often forces entrepreneurs to experiment with multiple choices for supply chain designs [72].

For example, supplier identification has both a long- and short-term impact on supplier selection and the performance of entire supply chains [73]. This selection process can be very time consuming – leading to increased time-to-market and making it difficult to maintain (or achieve) critical 'first mover advantage' [72]. As a result, identification and compilation of an appropriate pool of trusted suppliers has become an integral part of the supplier selection process [74].

The proposed open platform concept can contribute to improve management of critical network resources in the setup of enabling 'nascent' supply chains, and allow system integrators to access shared assets (e.g., fluidic design, manufacture, instrumentation and software) from more resilient supply chain setups (a verified pool of certified suppliers enabled by an open platform concept).

Even though there have been significant success stories in the world of microfluidic technologies, a large number of projects are smothered by often completely underestimated costs of bespoke facilities for (manufacturing) scale-up; it is typically only realised in retrospect that greater numbers of microfluidic devices, ideally produced by the eventual mass fabrication scheme, are required well before eventual market entry to optimise and properly validate functional reliability with sound statistics and assay performance towards passing internal quality checks and regulatory compliance [75].

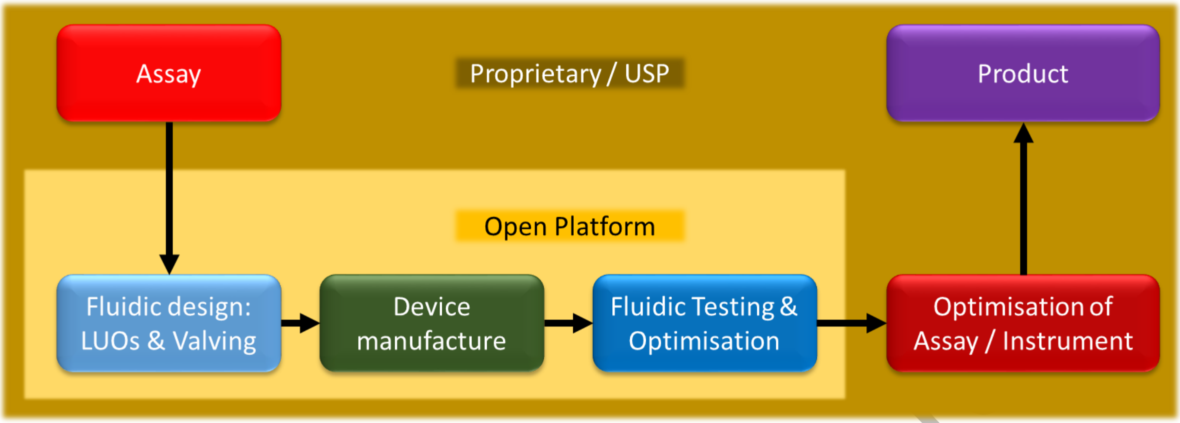

Figure 2 Exemplary pipeline from idea to a unique microfluidic, e.g., "Lab-on-a-Disc" product. The proprietary part underpinning the Unique Selling Points (USPs) comprises of the original idea of an assay protocol, its reagents or application including specific optimisation cost, performance, productisation and marketing; the embedded, shared part comprises of a library of fluidic designs, testing and manufacturing methods which sourced from a common, multi-player RTD and supply chain, e.g., following foundry-type business models which are, for instance, well-proven in the electronics / MEMS [76, 77] or photonics [78] industries.

Figure 2 depicts a possible concept how an open platform can distribute the development and scale-up fabrication of LoaD technologies based on a supply chain for providing commons like fluidic design, manufacture and testing. Similar to successful business structures in big industries such as electronics, this model is likely to stimulate the formation of foundries [76] which provide digital-twin supported design-for-manufacture (DfM) for delivering highly predictable functionality of components and devices. The responsibility for such "commons" is thus taken from the shoulders of innovative system integrators who can align their resources on progressing their ring-fenced competitive edge, e.g., on behalf of their distinctive know-how on bioassays, or their applications and market access.

"Wisdom of the Crowds"

The idea that collective intelligence tends to supersede the quality of individual assessment was pushed since the early 2000s [6]. This section reviews instances where "Wisdom of the Crowds" principles have been successfully applied in the social Web2.0 and science to pave the way for its implementation for crowdsourcing of work, expertise, infrastructure and services for RTD projects in the next section on related blockchain technologies.

Social Web

Already in the social Web 2.0, "wisdom of the crowds" has been extensively implemented, e.g., in social media (e.g., "likes", "followers") and online shopping (e.g., ratings and comments by buyers and sellers), which, as a positive knock-on effect, also boost customer engagement [79, 80]. Especially in dearth of other objective sources, information obtained from the crowd can be very useful, and many portals have managed to widely suppress manipulation. For instance, tapping into the crowd has also proven to be very useful for aggregating information on the "state of the world", e.g., real-time updates on transport networks or footfall in local shops; even emerging pandemics such as Covid-19 have been identified and reported at a very early stage [81-83].

Finding "Truth" in Science and RTD

The need for decision making in absence of "absolute truth" particularly applies to the realm of projects in science and RTD which coarsely follow a sequence of conception, planning, evaluation, implementation and exploitation. In principle, all these phases are susceptible to subjectivism, misjudgement, undeliberate error and even deceit, whether from the originators or their assessors. Here, we briefly survey truth finding schemes for projects in the commercial and academic domains, which will then be ported to Blockchain in the subsequent section.

In the corporate world, RTD is often carried out within a closed circle of workers, managers and assessors (Figure 3). The technological idea or application case is based on an (assumed) understanding of a functional principle or market context. With the funding raised, staff is hired and resources for product development and its commercial exploitation procured, which is monitored by the stakeholders and boards appointed by them. Truth finding at the root of decision making is thus based by "skin in the game" of investors, management and employees, e.g., in terms of assets, stock options, career opportunities or salaries.

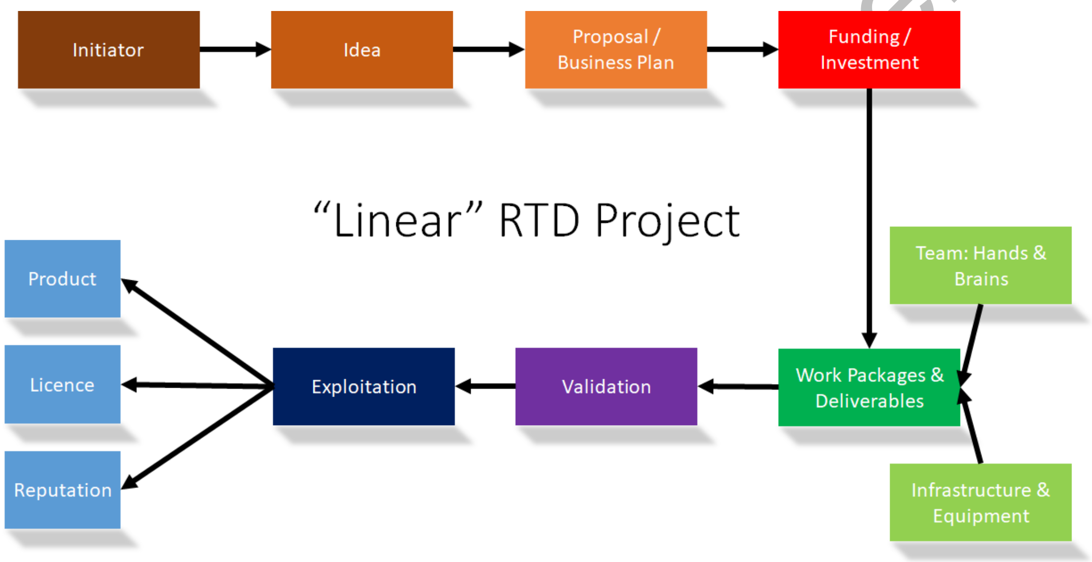

Figure 3 Projects are traditionally organised in a linear fashion from starting with idea creation, advancement into a business plan, attracting funding. Teams and infrastructure are set up to execute work packages (WPs) which it (self-)validates. The results the then exploited through various avenues, e.g., by direct sales of a product, licencing or, in particular in academia, by publishing for building up reputation in the community.

In science, a panel of uninvolved peers evaluates of the proposal, its implementation plan and the appropriateness of requested funding. Upon their positive review, a designated group of (internal) researchers, e.g., recruited from a closed research group or consortium, runs the project, and disseminates its outcomes within the scientific community.

Transparent documentation of materials, methods and results is at the heart of finding "truth" in academic publishing [84], where a 2-stage process is usually enacted: upon submission, journal editors appoint independent experts to assess the quality and originality of the manuscript. Post acceptance, the entire scientific community is invited to validate the paper, so flawed or fabricated results are quickly disguised, especially on topics of wider-ranging relevance. Other than in the commercial world, errors mainly affect scholarly reputation rather than financial penalties, so that legal sanctions are mostly enforced for gross misconduct or deliberate fraud. Compared to the commercial RTD path displayed in Figure 2, primarily the validation stage is crowdsourced in academia.

Blockchain Toolbox

Having its origin in the first popular cryptocurrency Bitcoin launched by the famous white paper authored in 2009 by the pseudonym "Satoshi Nakamoto" [3], blockchain technology has already impressively succeeded to implement financial transactions on its cryptographically safeguarded distributed ledger technology (DLT). Boosted by release of Ethereum's virtual machine (EVM) which can execute smart contracts a few years later [5], a plethora of projects continues to break new grounds in decentralised finance ("DeFi") [85]. Opinions of investors on the solidity and prospects of "crypto" tend to largely diverge [86].

A broad range of commercial projects on advancing blockchain technologies are driven by companies and foundations [87-90]; even more, projects pursuing goals that are shared by communities, referred to as "Commons", are carried out by a diverse range of loosely organised groups of volunteers. Management and governance are enacted by blockchain-backed tools for stake-based decision making, governance and arbitration [13]. The blockchain community also seeks to extend the trust without middleman community to encode entire Decentralised Autonomous Organisations in smart contracts. These "DAOs" [13, 91-93] bear great promise to (self-)organise conception, fundraising, selection, management, monitoring and governance.

As a key advantage, Blockchain supports project funding of projects by seigniorage [94], or the privilege to issue new money, typically in the form of project-specific initial coin offerings (ICO) which issue tokens [95] that may be traded against other crypto- or fiat currencies at various exchanges. Yet, there are still some regulatory issues to be addressed [96].

In the realm of science and RTD, several blockchain portals support scientific publishing [97, 98], research and technology development [99, 100]. Blockchain tools have been developed for aggregating and exchanging data on the state of the world, e.g., obtained from simulation, historical records and "Internet of Things (IoT)" sensor netwoartifrks [101, 102]. Also non-fungible tokens (NFTs) [103, 104] which might be applied to protect intellectual ownership, e.g., of microfluidic design elements.

Establishing trust at the heart of blockchains themselves relies on crowd-based "skin in the game" mechanisms referred to as proof-of-work and (delegated) proof-of-stake, respectively. In the meantime, the blockchain community has created an ample ecosystem reaching beyond the social Web2.0 encompassing formalised reputation and staking schemes [12], idea promotion [105], bounties [16], token bonding curves [20, 106] and curation markets [18]. They incentivise objective vetting of experts via their immutable track record on reputation and community-based validation of technological concepts.

Crowdsourcing

Project Structure

We now outline how the previously introduced "Wisdom of the Crowds" and Blockchain technologies can be combined to organise projects on open technology platforms with the example of Lab-on-a-Disc. As opposed to a linear project in Figure 2, such an RTD project, as represented in Figure 4, the smart-contract and skin-in-the-game backed open platform allows to tap into the crowd for all stages along value creation.

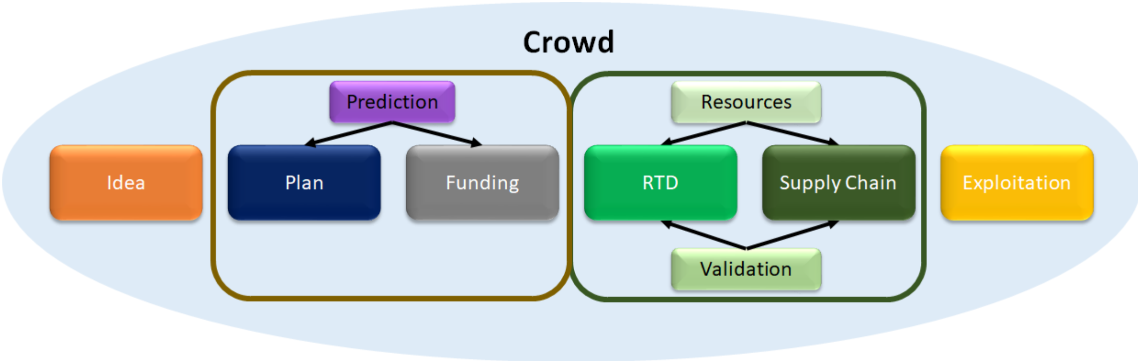

Figure 4 Involvement of the "Crowd" along the entire value creation from idea to delivery and exploitation. Prediction markets for planning are backed by collective intelligence while for work and validation on RTD and supply chain are crowdsourced through competitive parallelisation as outlined in in green-framed box and further illustrated in Figure 5.

Similar to architectural competitions, initial idea generation, e.g., an internal team, can be boosted by inputs from a vast pool of clever brains. Blockchain provides time-stamping such IP on its unforgeable ledger, and smart contracts can establish clear-cut participation, e.g., on shares of future revenues or licence royalties. Skin in the game schemes such as reputation and staking of assets invigorated by prediction markets can then support sound planning including the required investment, which might also be raised by crowdfunding mechanisms, seigniorage and token economies.

Competitive Parallelisation

For the following RTD phase and the supply chain, much of the work, expertise, infrastructure and services, at least the parts which are uncritical for the USP of the eventual product, should be crowdsourced on the basis of an open platform model. While trust in accompanying financial transaction is assured by "programmable money" in the form of smart contracts on the (e.g., Ethereum) blockchain, best possible "truth" on outcomes in the physical world is found through competitive parallelisation of deliverables and their validation (Figure 5).

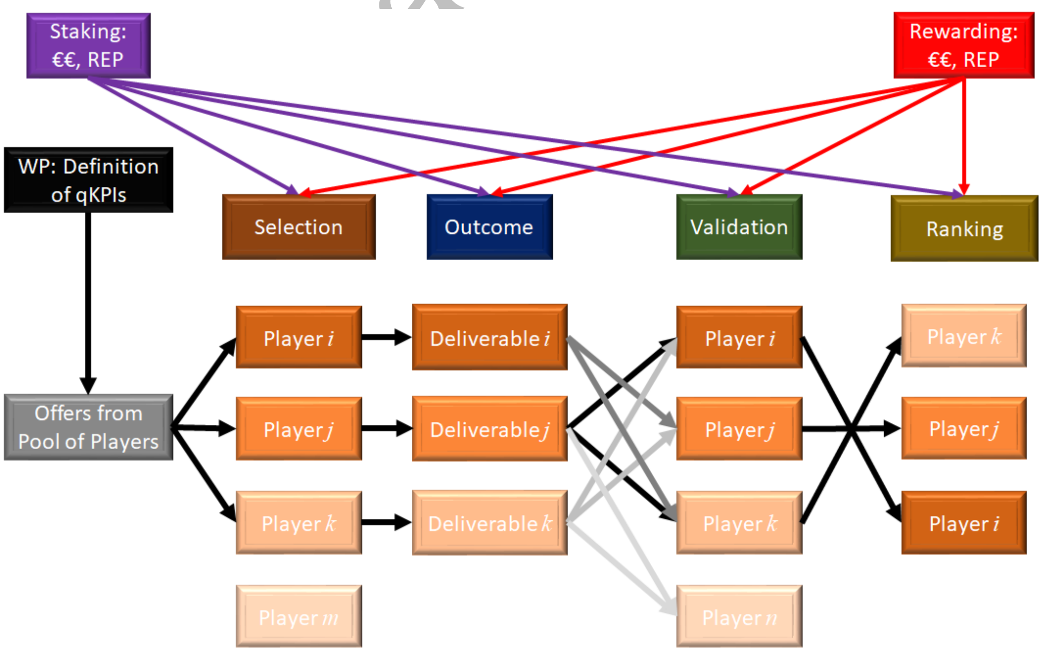

Figure 5 Competitive parallelisation. A system integrator or buyer crowdsources the work, e.g., on RTD or manufacture from independent players. The buyer selects a subgroup of players according to their offers. The

outcomes are ranked, as much as possible, by a validation panel according to quantitative Key Performance Indicators. Bidders can increase their chance of acceptance by staking while quality work is rewarded by assets and reputation.

In more detail, the deliverable of a work package (WP) should be described, as much as possible, by objectively assessable criteria such as quantitative Key Performance Indicators (KPIs) and associated methods of their characterisation. These descriptors are posted with the reward scheme or bounty to attract offers from (independent) players. Buyers then select a subset of these proposals for concurrent execution. Their deliverables are then evaluated and ranked, e.g., by a panel, and then remunerated with assets and reputation according to a pre-defined, transparent scheme that is immutably recorded on the blockchain.

Buyers, workers and validators can complement their requests or bids by blockchain enabled staking and reward schemes, e.g., in form of fiat-convertible assets and quantified reputation which are formally managed by smart contracts on the tamper-free and transparent DLT. Decision making for conflict resolution may be implemented by blockchain-backed arbitration mechanisms [13, 107]. Overall, such competitive parallelisation thus extends the peer-review process known from academic publishing by crowdsourcing of WPs to enrich intellectual contributions, the skill set, infrastructure, equipment, bandwidth and flexibility of the human resources and infrastructure.

At first glance, the parallelised approach in Figure 5 seems to be more costly than the linear scheme in Figure 3. This would certainly hold assuming equal work efficiencies amongst both approaches. However, experience tells that running a highly diverse interdisciplinary project with an internal team often leads to significant gaps in competences and delays on deliverables, especially in the technologies that reside outside the main technological or commercial enablers. To give a simplified example, crowdsourcing competence leaders at triple rate of an internal resource significantly enhances quality and speeds of delivery by a factor of 10, so charging three expert players in parallel for a given work package is likely to deliver at roughly the same overall cost, while substantially improving quality, credibility and speed of delivery.

Bestowed with the “trust” and “truth” through the blockchain and streamlining by the open platform concept, participation in RTD and supply chains is not restricted to full-fledged organisations, but reaches out to talent, knowledge and workforce of non-institutionalised individuals, e.g., through “hackathons” [108] or “citizen science” [109]. Fast emerging trends like Fab Labs [110] for making “things”, e.g., by 3D printing, cloud-based access to software, supercomputing, artificial intelligence (AI) and Big Data solutions [111, 112] are likely to further globalise and somewhat democratise value creation.

Trends & Challenges

Platform Strategies for Supply Chain Resilience, Responsiveness and Reconfigurability

The blockchain-backed open platform concept follows strong trends in globalisation and regulation, in addition to advances in digitalisation and data analytics, which are generating business opportunities in terms of novel value creation [113]. These drivers have formed an environment in which many firms are encountering new challenges and opportunities in traditional supply chain practices, for instance, in enhancing its supply chain resilience, responsiveness, and reconfigurability. A common thread recently emphasised by leading international multinational corporations (e.g., Cisco, Coca-Cola, Jaguar Land Rover) is the need to connect, network and collaborate across supply chains – in developing a ‘cleverer together’ operating philosophy; in designing supply chains to be more agile and customer-focused; exploiting the potential of digitalisation (e.g., blockchain for governance) and addressing the environmental impact of existing supply chain designs [114]. This is now further impacted by the complexities of the 'new normal', as such firms struggle to assess and rebuild their global supply chains after COVID-19 [115].

One area of focus is to develop open platform strategies for (re-)distributed manufacturing (RDM), i.e., 'the ability to personalize product manufacturing and deployment at multiple scales and locations, be it at the point of consumption, sale, or within production sites' [116] to promote supply chain resilience, responsiveness, and reconfigurability. RDM can also have a democratising effect on participation at a socio-economic level [117]. Here, new 'Circular Economy 4.0' operating principles have been developed that capture the interplay between digital technologies and circular supply chain designs based on centralised – semi-centralised – decentralised configurations [118]. In promoting open access to, e.g., 'asset libraries' of manufacturing processes and simulation methods, these configurations and operating principles lend themselves to open technology platforms for the crowdsourcing of supply chain including RTD, through Blockchain.

This is in line with moves towards interdisciplinary approaches involving 'innovation ecosystems' of diverse actors - ranging from skilled individuals (the 'citizen scientist'; the 'garage entrepreneur') to more emerging small and medium enterprises (SMEs) and well-established firms. Economic activity does not necessarily translate to direct support of 'micro-innovators', for example, in do-it-yourself (DIY) biotechnology-type RTD contexts [119]. Hence, open platform strategies can advance the emergence of a network of entrepreneur archetypes to collectively solve intractable challenges, by drawing on the philosophies of 'open science' [120] and 'collective intelligence' [121].

Our blockchain-backed open platform concept features important aspects of both RDM and the 'innovation ecosystem', such as providing access to local resources, exemplified by enhanced user participation across technology development, fabrication and supply. These mechanisms are typically enabled by digitalisation, virtualisation and new production (and analytical) technologies. We extend RDM by crowdsourcing upfront RTD and inclusion of non-corporate entities, e.g., empowering citizen science communities to avail of a resilient supply chain network of assets.

Challenges & Solutions

There are still various bottlenecks that stymie a seminal breakthrough of blockchain technologies. In the public eye, the volatility of cryptocurrencies represents a critical downside; meanwhile, a number of stablecoins has been issued which are hard- or soft-pegged to fiat currencies [122-126]. Also solutions to increase scalability, transaction throughput [127-131] and interconnectivity [101, 132] and compliance with financial regulators [133] have been developed.

Scamming, exploits, and poor governance constitute major setbacks for any project. Blockchain has already suffered, e.g., through the notorious hack of "The DAO" (Đ), the biggest crowdfunded project at its time having raised over $150 million from its more than 10,000 supporters [93, 134] in 2016. Since then, smart contract security and other mitigation techniques for DAOs have been massively improved, and even larger projects raising several billion dollars have been launched [135, 136].

Similarly, the "code is law" paradigm propagated by some hardcore blockchain communities might clash with legislation, and may undermine contingency plans usually required to mitigate the fall-out of unintended events, for instance, related to program bugs and abuse.

More recent technologies and networks, such as Telos [137], utilise readily upgradable smart contracts, and token holders appoint arbitrators [107, 138].

Most USPs of blockchain application are difficult to convey to the wider public, and participation often goes through user interfaces, such as decentralised applications (“DApps”) [139, 140], which may only be handled by possessing a certain level of technological understanding. This limits the creation of a critically sized user base for which the operation of blockchain concepts make sense [141]. For similar reasons, it is difficult to provide test beds including larger number of players which sufficiently represent all facets of the real-world user base [142, 143]. There is good progress on simulation tools [144].

Furthermore, institutional anchoring and compliance with existing legal frameworks, e.g., on corporate structure, equity and taxation, are, for the most part, not solved in a satisfactory fashion, yet [96]. Still, there are various governments evaluating their benefits and options for their legal embedding [91, 145, 146].

With the growing awareness for protecting the global ecosphere, there is somewhat valid public concern regarding the sizeable power consumption underpinning the protection of first-generation blockchains by “Proof of Work”; alternative “Proof-of-Authority” [98], “Proof of Stake” or more sophisticated “Delegated Proof of Stake” [147] decisively reduce the environmental impact.

Summary, Conclusions & Outlook

This paper synergistically combines blockchain-endowed incentivisation mechanisms and concepts for finding trust and truth rooted in skin-in-the-game, collective intelligence, prediction markets and competitive parallelisation mechanisms with an open platform strategy. The novel approach for value creation and supply chain formation is exemplified by the Lab-on-a-Disc platform where it harmonises technology development for efficient crowdsourcing of ideas, RTD, validation, infrastructure, equipment, processes and services from a wide range of participants including corporations, institutions and individuals. The strategy is particularly suited for accelerating and de-risking commercialisation of highly interdisciplinary applications by smaller players requiring early investment and fast innovation for rapid market entry.

In addition to companies or research organisations, such RTD and product projects may also be managed in the form of a Decentralised Autonomous Organisation (DAO) that are entirely run by a crowd of stakeholders through blockchain-enabled tools for governance and crowdfunding. Apart from commercial objectives, such DAOs have also been suggested for grass-roots driven non-for-profit initiatives on global Commons [148], e.g., in the context of disaster prevention like pandemics or “Saving the Planet” [149]. They also well align with trends such as new models of collaboration and re-distributed manufacturing (RDM), globalisation / democratisation / decentralisation of value creation, data ownership, access and exploitation, and the future or work.

With all prospects, the advancement, validation and convergence of its underlying technologies, packaging the resulting potential benefits into a compelling message to the general, presently widely apathetic public is urgently required. Also tapping into decisive economies-of-scale effects still represents major bottleneck challenge to the breakthrough of blockchain beyond decentralised finance (DeFi).

Conflict of Interest Statements

I, author Martin Etzrodt, was employed at Akasha Foundation. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

I, author Sönke Bartling, am the sole proprietor and owner of Blockchain for Science GmbH. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

I, author Max Gravitt, am the sole proprietor and owner of Digital Scarcity LLC. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Muffatto, M., *Introducing a platform strategy in product development.* International Journal of Production Economics, 1999. **60-61**: p. 145-153.
2. Yaga, D., et al. *Blockchain technology overview*. 2018; Available from: https://nvlpubs.nist.gov/nistpubs/ir/2018/NIST.IR.8202.pdf.
3. Nakamoto, S., *Bitcoin: A Peer-to-Peer Electronic Cash System.* Cryptography Mailing list at https://metzdowd.com, 2009.
4. Miller, A. *Ethereum Isn't Turing Complete and it Doesn't Matter Anyway*. 2016; Available from: https://media.consensys.net/ethereum-isnt-turing-complete-and-it-doesn-t-matter-anyway-625061294d3c.
5. Buterin, V. *White Paper· ethereum/wiki Wiki · GitHub*. 2014; 11 January 2014:[Available from: https://github.com/ethereum/wiki/wiki/White-Paper.
6. Surowiecki, J., *The wisdom of crowds: Why the many are smarter than the few and how collective wisdom shapes business, economies, societies, and nations.* 2004: Doubleday Books.
7. Becker, H., *Collective wisdom.* Lab on a Chip, 2010. **10**(11): p. 1351-1354.
8. Hill, S. and N. Ready-Campbell. *Expert Stock Picker: The Wisdom of (Experts in) Crowds*. 2011; Available from: http://repository.upenn.edu/oid_papers/72?utm_source=repository.upenn.edu%2Foid_papers%2F72&utm_medium=PDF&utm_campaign=PDFCoverPages.
9. *Collective intelligence*. Available from: https://en.wikipedia.org/wiki/Collective_intelligence.
10. *The Bounties Network - Changing the Way Communities Collaborate*. Available from: https://www.bounties.network/.
11. *Prediction Market*. Available from: https://www.investopedia.com/terms/p/prediction-market.asp.
12. *Augur - Put your skills to the test and WIN!* ; Available from: https://www.augur.net/.
13. *Organizations of the future run on Aragon*. Aragon empowers you to freely organize and collaborate without borders or intermediaries. Create global, bureaucracy-free organizations, companies, and communities.]. Available from: https://aragon.org/.
14. *COLONY.io - Organizations, for the Internet*. Available from: https://colony.io/.
15. *Seigniorage*. Available from: https://en.wikipedia.org/wiki/Seigniorage.
16. *Gitcoin - Crowdfunding and Freelance Developers for Open Source Software Projects*. Available from: https://gitcoin.co/.
17. Edmondson, B. *How Bitcoin and Blockchain Are Changing Crowdfunding*. 2020; Available from: https://www.thebalance.com/how-bitcoin-and-blockchain-is-changing-crowdfunding-4173837.

18. de la Rouviere, S. *Introducing Curation Markets: Trade Popularity of Memes & Information (with code)!* 2017; Available from: https://medium.com/@simondlr/introducing-curation-markets-trade-popularity-of-memes-information-with-code-70bf6fed9881.
19. Rouviere, S.d.l. *A Practical Example of Curation Markets: An #ethtrader token for Curating Good Market Analysis*. 2017; Available from: https://media.consensys.net/a-practical-example-of-curation-markets-an-ethtrader-token-for-curating-good-market-analysis-6f6f340c6916.
20. Goro, J. *Token bonding curves explained*. 2018; Available from: https://medium.com/coinmonks/token-bonding-curves-explained-7a9332198e0e.
21. *Status of the Microfluidics Industry 2019*. 2019; Diversification of microfluidic technologies has led to burgeoning new applications and market growth, driving players' interest and M&A.].
22. Jens Ducrée, J. and R. Zengerle, *FlowMap - Microfluidics Roadmap for the Life Sciences*. 2004, Norderstedt, Germany: Books on Demand GmbH.
23. Reyes, D.R., et al., *Accelerating Innovation and Commercialization Through Standardization of Microfluidic-Based Medical Devices*. 2020.
24. Tantra, R., H. van Heeren, and J. Jarman, *Role of standard documents in advancing the standardization of microfluidics connectors.* Journal of Micro/Nanolithography, MEMS, and MOEMS, 2016. **15**(2).
25. Klapperich, C.M., *Microfluidic diagnostics: time for industry standards.* Expert Rev Med Devices, 2009. **6**(3): p. 211-3.
26. van Heeren, H., *Standards for connecting microfluidic devices?* Lab Chip, 2012. **12**(6): p. 1022-5.
27. Stavis, S.M., *A glowing future for lab on a chip testing standards.* Lab Chip, 2012. **12**(17): p. 3008-11.
28. *Car platform*. Available from: https://en.wikipedia.org/wiki/Car_platform.
29. Bottcher, E. *What I Talk About When I Talk About Platforms*. 2018; Available from: https://martinfowler.com/articles/talk-about-platforms.html.
30. *Computing platform*. Available from: https://en.wikipedia.org/wiki/Car_platform.
31. *Abaxis*. Available from: https://www.abaxis.com/.
32. *Gyros Protein Technologies*. Available from: https://www.gyrosproteintechnologies.com/.
33. *Biosurfit SA*. biosurfit is a Portuguese diagnostics company focused on the development and manufacture of IVD tests at the Point-of-Care with highly innovative proprietary technology. biosurfit developed the spinit® technology, the first and only, diagnostics system capable of performing the major PoC blood test modalities (haematology, immunoassays and clinical chemistry) on the same instrument.]. Available from: https://www.biosurfit.com/.
34. *Blusense Diagnostics*. BluSense. Driven by visionaries, powered by scientists]. Available from: https://blusense-diagnostics.com/.
35. *LaMotte Chemical Products Co*. Available from: https://www.lamotte.com.
36. Schembri, C.T., et al., *Centrifugation and Capillarity Integrated into a Multiple Analyte Whole-Blood Analyzer.* Journal of Automatic Chemistry, 1995. **17**(3): p. 99-104.
37. Schembri, C.T., et al., *Portable Simultaneous Multiple Analyte Whole-Blood Analyzer for Point-of-Care Testing.* Clinical Chemistry, 1992. **38**(9): p. 1665-1670.
38. Johnson, R.D., et al., *Development of a fully integrated analysis system for ions based on ion-selective optodes and centrifugal microfluidics.* Analytical Chemistry, 2001. **73**(16): p. 3940-3946.
39. Madou, M.J. and G.J. Kellogg, *The LabCD (TM): A centrifuge-based microfluidic platform for diagnostics.* Systems and Technologies for Clinical Diagnostics and Drug Discovery, Proceedings Of, 1998. **3259**: p. 80-93.
40. Andersson, P., et al., *Parallel nanoliter microfluidic analysis system.* Analytical Chemistry, 2007. **79**(11): p. 4022-4030.

41. Honda, N., et al., *Simultaneous multiple immunoassays in a compact disc-shaped microfluidic device based on centrifugal force.* Clinical Chemistry, 2005. **51**(10): p. 1955-1961.
42. Clime, L., et al., *Active pumping and control of flows in centrifugal microfluidics.* Microfluidics and Nanofluidics, 2019. **23**(3).
43. Malic, L., et al., *Polymer-based microfluidic chip for rapid and efficient immunomagnetic capture and release of Listeria monocytogenes.* Lab on a Chip, 2015. **15**(20): p. 3994-4007.
44. Clime, L., et al., *Active pneumatic control of centrifugal microfluidic flows for lab-on-a-chip applications.* Lab on a Chip, 2015. **15**(11): p. 2400-2411.
45. Krauss, S.T., et al., *Centrifugal microfluidic devices using low-volume reagent storage and inward fluid displacement for presumptive drug detection.* Sensors and Actuators B: Chemical, 2019. **284**: p. 704-710.
46. Thompson, B.L., et al., *A centrifugal microfluidic device with integrated gold leaf electrodes for the electrophoretic separation of DNA.* Lab Chip, 2016. **16**(23): p. 4569-4580.
47. Ducrée, J., *Towards Large-Scale Integration of Centrifugal Microfluidics - The bioCPU*. 2020.
48. Grieves M. and V. J., *Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems*, in *Transdisciplinary Perspectives on Complex Systems* 2017, Springer, Cham. p. 85-113.
49. Ducrée, J., et al., *The centrifugal microfluidic Bio-Disk platform.* Journal of Micromechanics and Microengineering, 2007. **17**(7): p. S103-S115.
50. Steigert, J., et al., *Rapid prototyping of microfluidic chips in COC.* Journal of Micromechanics and Microengineering, 2007. **17**(2): p. 333-341.
51. Boning, J., et al., *"Lab-on-a-Chip Foundry Service": A Systematic Approach to the Development of Centrifugal Microfluidic Technologies*, in *Actuator 08, Conference Proceedings*. 2008. p. 814-+.
52. Mark, D., et al., *Centrifugo-pneumatic valve for metering of highly wetting liquids on centrifugal microfluidic platforms.* Lab on a Chip, 2009. **9**(24): p. 3599-3603.
53. García-Cordero, J.L., et al., *Liquid recirculation in microfluidic channels by the interplay of capillary and centrifugal forces.* Microfluidics and Nanofluidics, 2010. **9**(4-5): p. 695-703.
54. Godino, N., et al., *Centrifugally Enhanced Paper Microfluidics*, in *2012 IEEE 25th International Conference on Micro Electro Mechanical Systems (MEMS)*. 2012.
55. Gorkin, R., 3rd, et al., *Centrifugo-pneumatic valving utilizing dissolvable films.* Lab Chip, 2012. **12**(16): p. 2894-902.
56. Dimov, N., et al., *Centrifugally Automated Solid-Phase Purification of RNA*, in *2014 IEEE 27th International Conference on Micro Electro Mechanical Systems (MEMS)*. 2014. p. 260-263.
57. Kinahan, D.J., et al., *Event-triggered logical flow control for comprehensive process integration of multi-step assays on centrifugal microfluidic platforms.* Lab Chip, 2014. **14**(13): p. 2249-58.
58. Burger, R., et al., *An integrated centrifugo-opto-microfluidic platform for arraying, analysis, identification and manipulation of individual cells.* Lab Chip, 2015. **15**(2): p. 378-81.
59. Kinahan, D.J., et al., *Baking-Powder Driven Centripetal Pumping Controlled by Event-Triggering of Functional Liquids*, in *2015 28th IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2015)*. 2015. p. 504-507.
60. Mishra, R., et al., *Lipophilic-Membrane Based Routing for Centrifugal Automation of Heterogeneous Immunoassays*, in *2015 28th IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2015)*. 2015. p. 523-526.
61. Kinahan, D.J., et al., *Xurography actuated valving for centrifugal flow control.* Lab on a Chip, 2016. **16**(18): p. 3454-3459.

62. Brennan, D., et al., *Development of an on-disc isothermal in vitro amplification and detection of bacterial RNA.* Sensors and Actuators B-Chemical, 2017. **239**: p. 235-242.
63. Delgado, S.M.T., et al., *Wirelessly powered and remotely controlled valve-array for highly multiplexed analytical assay automation on a centrifugal microfluidic platform.* Biosensors & Bioelectronics, 2018. **109**: p. 214-223.
64. Ducrée, J., *Reliability analysis and optimization towards highly multiplexed lab-on-a-disc systems*. 2020: Jounal of Microelectromechanical Systems.
65. Harrington, T. and J. Singh Srai, *Understanding stages of supply network emergence in technology commercialisation.* International Journal of Manufacturing Technology and Management, 2016. **1**(1).
66. Hills, S.B. and S. Sarin, *From Market Driven to Market Driving: An Alternate Paradigm for Marketing in High Technology Industries.* Journal of Marketing Theory and Practice, 2015. **11**(3): p. 13-24.
67. Santos, F.M. and K.M. Eisenhardt, *Constructing Markets and Shaping Boundaries: Entrepreneurial Power in Nascent Fields.* JSTOR, 2009. **52**(4): p. 643-671.
68. Kumar, N., L. Scheer, and P. Kotler, *From market driven to market driving.* 2000. **18**(2): p. 129-142.
69. Jaworski, B., A.K. Kohli, and A. Sahay, *Market-Driven Versus Driving Markets.* Journal of the Academy of Marketing Science, 2000. **28**(1): p. 45-54.
70. Harrington, T. and Y. Zhang, *Supply network evolution in emerging industries.* International Journal of Manufacturing Technology and Management, 2017. **31**(1-3): p. 1-3.
71. Sebastiao, H.J. and S. Golicic, *Supply Chain Strategy for Nascent Firms in Emerging Technology Markets.* Journal of Business Logistics, 2008. **29**(1): p. 75-91.
72. Sarasvathy, S.D., *Causation and Effectuation: Toward a Theoretical Shift from Economic Inevitability to Entrepreneurial Contingency.* The Academy of Management Review, 2001. **26**(2).
73. Lasch, R., H. Kopfer, and C.G. Janker, *Supplier selection and controlling using multivariate analysis.* International Journal of Physical Distribution & Logistics Management, 2005. **35**(6): p. 409-425.
74. Govindan, K., M. Shankar, and D. Kannan, *Supplier selection based on corporate social responsibility practices.* International Journal of Production Economics, 2018. **200**: p. 353-379.
75. Ducrée, J., *Efficient development of integrated Lab-On-A-Chip systems featuring operational robustness and nanufacturability.* Micromachines (Basel), 2019. **10**: p. 12.
76. Ersland, P. and S. Somisetty, *Reliability validation of compound semiconductor foundry processes.* Microelectronics Reliability, 2012. **52**(9-10): p. 2210-2214.
77. *List of MEMS foundries*. Available from: https://en.wikipedia.org/wiki/List_of_MEMS_foundries.
78. Khan, M.U., et al., *Photonic Integrated Circuit Design in a Foundry+Fabless Ecosystem.* IEEE Journal of Selected Topics in Quantum Electronics, 2019. **25**(5): p. 1-14.
79. Tan, B.J., M. Brown, and N. Pope, *The role of respect in the effects of perceived ad interactivity and intrusiveness on brand and site.* Journal of Marketing Communications, 2017. **25**(3): p. 288-306.
80. Yoon, D. and S. Youn, *Brand Experience on the Website: Its Mediating Role Between Perceived Interactivity and Relationship Quality.* Journal of Interactive Advertising, 2016. **16**(1): p. 1-15.
81. *How ProMED Crowdsourced the Arrival of Covid-19 and SARS*. 2020; The low-tech site run by health experts collects reports of new diseases in real time. They've got a shoestring budget—and a stunning track record.]. Available from: https://www.wired.com/story/how-promed-crowdsourced-the-arrival-of-covid-19-and-sars/.

82. *HealthMap*. Available from: http://www.diseasedaily.org/about.
83. Brownstein, J.S. and C.C. Freifeld, *HealthMap: the development of automated real-time internet surveillance for epidemic intelligence.* Euro Surveill, 2007. **12**(11): p. E071129 5.
84. Baldwin, M., *Scientific Autonomy, Public Accountability, and the Rise of "Peer Review" in the Cold War United States.* Isis, 2018. **109**(3): p. 538-558.
85. Leonhard, R., *Decentralized Finance on the Ethereum Blockchain.* SSRN Electronic Journal, 2019.
86. Suberg, W. *Billionaire Investor Tim Draper Quit Stocks for Bitcoin 6 Months Ago*. 2020; Available from: https://cointelegraph.com/news/billionaire-investor-tim-draper-quit-stocks-for-bitcoin-6-months-ago.
87. *IBM Blockchain's Hyperledger Fabric: the flexible blockchain framework that's changing the business world*. Available from: https://www.ibm.com/blockchain/hyperledger.
88. *Hyperledger*. Advancing business blockchain adoption through global open source collaboration. Hyperledger is an open source community focused on developing a suite of stable frameworks, tools and libraries for enterprise-grade blockchain deployments.]. Available from: https://www.hyperledger.org/.
89. *R3's Corda*. Available from: http://www.r3.com.
90. *AKASHA RELOADED*. Available from: https://akasha.world/.
91. *New GBA Governance Working Group on DAOs*. Available from: https://www.gbaglobal.org/governance.
92. *Moloch DAO explained: Using self-interest to Ethereum's advantage*. What the heck is all this talk is about Moloch DAO? Well for starters, this is a moloch:]. Available from: https://concourseopen.com/blog/moloch-dao-explained/.
93. Vigna, P. *Chiefless Company Rakes In More Than $100 Million - Group called DAO is running itself via computer code*. The Wall Street Journal 2016 16 May 2016; Available from: https://www.wsj.com/articles/chiefless-company-rakes-in-more-than-100-million-1463399393.
94. Craig, B.R. and J. Kachovec, *Bitcoin's Decentralized Decision Structure.* Economic Commentary (Federal Reserve Bank of Cleveland), 2019: p. 1-5.
95. *ERC-20 Tokens, Explained*. Available from: https://cointelegraph.com/explained/erc-20-tokens-explained.
96. *SEC Issues Investigative Report Concluding DAO Tokens, a Digital Asset, Were Securities*. 2017; Available from: https://www.sec.gov/news/press-release/2017-131.
97. *ARTiFACTS - Researcher recognition. Accelerated*. Available from: https://artifacts.ai/.
98. *Bloxberg: Blockchain Infrastructure for Scientific Research*. Available from: https://bloxberg.org/.
99. *DEIP.world - Open Innovation Network*. Available from: https://deip.world/.
100. Bartling, S. *Blockchain for Science*. 2016; Available from: https://www.blockchainforscience.com/.
101. *CHAINLINK - Your smart contracts connected to real world data, events and payments.*; Available from: https://chain.link/.
102. *IOTA Foundation - Redifining trust, value and ownership*. Available from: https://www.iota.org/.
103. *Non-fungible token*. Available from: https://en.wikipedia.org/wiki/Non-fungible_token.
104. Montoya, T. *Nonfungible Tokens Could Change the Way We Own Things*. 2020; Available from: https://cointelegraph.com/news/nonfungible-tokens-could-change-the-way-we-own-things.
105. *Ideamarket.io*. Ideamarket is a decentralized marketplace for establishing credibility without relying on media corporations.]. Available from: https://ideamarket.io/.
106. *Molecule.to - The next evolution of drug development*. Available from: https://molecule.to/.

107. *Telos Blockchain Network Arbitration Rules and Procedures*. Available from: https://resources.telosfoundation.io/governance_documents/TBNARP_Adopted_2018-10-26.pdf.
108. *Hackathon*. Available from: https://en.wikipedia.org/wiki/Hackathon.
109. *Foldit is a revolutionary crowdsourcing computer game enabling you to contribute to important scientific research.*; Available from: https://fold.it/.
110. *Fab Labs*. A Fab Lab, or digital fabrication laboratory, is a place to play, to create, to mentor and to invent: a place for learning and innovation. Fab Labs provide access to the environment, the skills, the materials and the advanced technology to allow anyone anywhere to make (almost) anything.]. Available from: https://www.fablabs.io/.
111. *AWS - Amazon Web Services*. Available from: https://aws.amazon.com/.
112. *Google Cloud*. Available from: https://cloud.google.com/.
113. *The 'New' Digital Economy and Development*. 2017, UNCTAD - United Nations Conference on Trade and Development.
114. Harrington, T., *Connecting the unconnected: new thinking on next-generation supply chains.* IfM Review, University of Cambridge, 2015(4).
115. Betti, F. and J. Ni. *How China can rebuild global supply chain resilience after COVID-19*. 2020; Available from: https://www.weforum.org/agenda/2020/03/coronavirus-and-global-supply-chains/.
116. Srai, J.S., et al., *Distributed manufacturing: scope, challenges and opportunities.* International Journal of Production Research, 2016. **54**(23): p. 6917-6935.
117. Srai, J.S., T.S. Harrington, and M.K. Tiwari, *Characteristics of redistributed manufacturing systems: a comparative study of emerging industry supply networks.* International Journal of Production Research, 2016. **54**(23): p. 6936-6955.
118. N, T., H. TS, and S. JS, *'Digital Supply Network Design: A Circular Economy 4.0 Decision-making System for Real-World Challenges.* Production Planning and Control, 2020.
119. *DITOS Consortium and WeObserve Consortium: Making Citizen Science work: Innovation Management for Citizen Science*, in *DITOS Policy Brief 6*. 2019.
120. Smart, P., et al., *Open Science and Open Innovation in a socio-political context: knowledge production for societal impact in an age of post-truth populism.* R&D Management, 2019. **49**(3): p. 279-297.
121. Malone, T. and M. Bernstein, *Handbook of collective intelligence*. 2015, Cambridge, MA, USA: MIT Press.
122. *Tether*. Digital money for a digital age]. Available from: https://tether.to/.
123. *USD Coin*. A stablecoin brought to you by Circle and Coinbase]. Available from: https://www.centre.io/usdc.
124. *Anchor is a stablecoin offering users long-term price stability and protection from inflation, while hedging against daily market volatility.*; Available from: https://theanchor.io/.
125. *The Maker Protocol: MakerDAO's Multi-Collateral Dai (MCD) System*. Available from: https://makerdao.com/en/whitepaper.
126. *Can Stablecoins Promote the Mass Adoption of Cryptocurrencies?* 2020 13 January 2020; Available from: https://www.etoro.com/news-and-analysis/market-insights/what-role-will-stablecoins-play-in-crypto-mass-adoption/.
127. *TRON - Decentralize the web*. TRON is one of the largest blockchain-based operating systems in the world.]. Available from: https://tron.network/.
128. *Lightning Network - Scalable, Instant Bitcoin/Blockchain Transactions*. Available from: https://lightning.network/.
129. Mearian, L. *Sharding: What it is and why many blockchain protocols rely on it*. Available from: https://www.computerworld.com/article/3336187/sharding-what-it-is-and-why-so-many-blockchain-protocols-rely-on-it.html.

130. *Bitcoin Cash - Peer-to-Peer Electronic Cash*. Enabling new economies with low fee micro-transactions, large business transactions, and permissionless spending.]. Available from: https://www.bitcoincash.org/.
131. *Bitcoin SV*. Bitcoin SV is the original Bitcoin]. Available from: https://bitcoinsv.io/.
132. *What Are Atomic Swaps?* ; Atomic swaps are a peer-to-peer, trustless method of exchanging coins on different blockchains. In essence, atomic swaps allow you to exchange, for example, bitcoin with litecoin, while avoiding the need to trust an exchange or any other third party.]. Available from: https://bitcoinmagazine.com/guides/what-are-atomic-swaps.
133. Hussey, M. *What is Tokenomics?* ; Available from: https://decrypt.co/resources/tokenomics.
134. Siegel, D. *Understanding The DAO Attack*. 2016 27 June 2017; Available from: https://www.coindesk.com/understanding-dao-hack-journalists.
135. *Block.one is a leader in providing high-performance blockchain solutions.*; Available from: https://block.one/.
136. *A blockchain start-up just raised $4 billion without a live product*. 2018; Available from: https://www.cnbc.com/2018/05/31/a-blockchain-start-up-just-raised-4-billion-without-a-live-product.html.
137. *Telos is a networked ecosystem enabling visionary leaders and communities to work together to build a new global economy.*; Available from: https://www.telosfoundation.io/.
138. *Telos User's Guide: Understanding Telos Resolve*. Available from: https://medium.com/telos-foundation/telos-user-guide-understanding-telos-arbitration-111e2397244b.
139. *Decentralized application*. Available from: https://en.wikipedia.org/wiki/Decentralized_application.
140. *Dapp.com*. Available from: https://www.dapp.com/search/Marketplace.
141. Zhu, F. and M. Iansiti. *Why Some Platforms Thrive and Others Don't*. 2019; Available from: https://hbr.org/2019/01/why-some-platforms-thrive-and-others-dont.
142. Harrington, T.S., N.R. Joglekar, and J.S. Srai, *Digitalisation of Development and Supply Networks: Sequential and Platform-Driven Innovations*. 2018: SSRN Working paper.
143. Skowronski, K. and W.C. Benton, *The Influence of Intellectual Property Rights on Poaching in Manufacturing Outsourcing.* Production and Operations Management, 2018. **27**(3): p. 531-552.
144. *BlockScience - Complex Systems Engineering*. Available from: https://block.science/.
145. *Bundesblock*. BLOCKCHAIN BUNDESVERBAND - Association Promoting Blockchain Technology in Germany]. Available from: https://bundesblock.de/.
146. *Government Blockchain Association (GBA) promotes blockchain technologies by empowering individuals and organizations to connect, communicate, and collaborate to solve public sector challenges around the world*. Available from: https://www.gbaglobal.org/.
147. *DPoS - Delegated Proof of Stake*. Available from: https://en.bitcoinwiki.org/wiki/DPoS.
148. *SEEDS - A payment platform and financial ecosystem to empower humanity and heal our planet*. Available from: https://joinseeds.com/.
149. Ducrée, J., et al., *Blockchain for Organising Effective Grass-Roots Actions on a Global Commons: Saving The Planet.* Frontiers in Blockchain, 2020(The 2nd International Conference on Blockchain and Web3 for Science, Research and Knowledge Creation: New deals).