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The Development of Ilima: An African Platform for Smallholder Supply Chain Integration

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Abstract: Emerging farmers in resource-constrained environments often face significant challenges that hinder their commercial success, including issues related to productivity, market access, consumer trust, and other well-documented factors. The Ilima platform takes a supply chain perspective on emerging farmer performance, and supports supply chain functioning from farm to fork. Its blockchain backbone facilitates traceability, certification and other functions that require trust in information integrity, while the platform generates information that can be used by the stakeholder ecosystem to support supply chain development. The development of Ilima follows a design science approach, with iterations of which the outcomes affect the evolution of the platform. This development process is summarised in this paper, and learning and recommendations for the development of 4IR solutions in developing contexts are shared.

Keywords: small scale agriculture; supply chain integration; blockchain; innovation ecosystem; farm-to-fork solutions.

1. Introduction

Emerging smallholder farmers (small-scale producers; SSPs) in resource-constrained contexts are challenged by obstacles along the entire supply chain, from production to market. These include access to quality inputs, production capability and skills, access to affordable transport, compliance with food safety and other regulations, and access to markets [1]. Technology provides the opportunity to address some of these challenges [2], but needs to be deployed into a resource-constrained context where connectivity, device recency, skills, and others could be limited.

The challenges and constraints of emerging farmers are well-researched, and ranges from financial and input constraints to market access [3]. In spite of numerous small-scale producer development programs, their overall success remains limited (e.g., [4]). While some interventions focus on farm-to-fork development approaches, challenges of SSP within value chains, and in the context of their enabling environments, have not been addressed systemically (e.g., [5]).

Multiple fragmented development approaches and interventions remain a reality in South Africa, with programmes focusing separately on access to land, access to input materials, farmer productivity, market access, and others. In practice, SSPs experience a number of systemic or chain-related challenges, such as the inability to prove compliance with food safety and environmental requirements, the inability to produce sufficient and consistent product of appropriate quality to attract either financing or commercial attention, and the inability to engender consumer trust by providing assurances of the use of responsible and safe practices along the supply chain. Further, logistics costs are disproportionately high due to poor load consolidation and the inherent challenges of the rural and last-mile reach of supply chain.

Ilima is a blockchain-based technology platform that is under development to address some of the challenges of small-scale producers, while also generating data and information to be used by actors who aim to support the development of the sector. The pilot platform has been completed and tested for the emerging poultry sector. In addition to addressing contextual challenges, the development of 4IR solutions poses challenges related to design for context, access to development skills, and others.

1.1 Objectives

This paper addresses a gap in the literature in that it describes comprehensively the application of a Design Science process to the development of a 4IR technology solution for deployment in under-resourced areas. While a limited number of blockchain platforms exist to support supply chains in under-resourced areas, these are not comprehensive in the integration of multiple support layers, and the Design Science-based development thereof has not been described.

The paper describes the development path of Ilima, with emphasis on the journey from concept to implementation, the challenges encountered, and the development direction that emerged from these. It outlines the approach (methodology), describes the concept and development path, summarises learning and recommendations, and outlines the direction for future research.

2. Concept

Within the context described in the Introduction, the long-term aims of the Ilima platform, as illustrated in *Figure 1*,

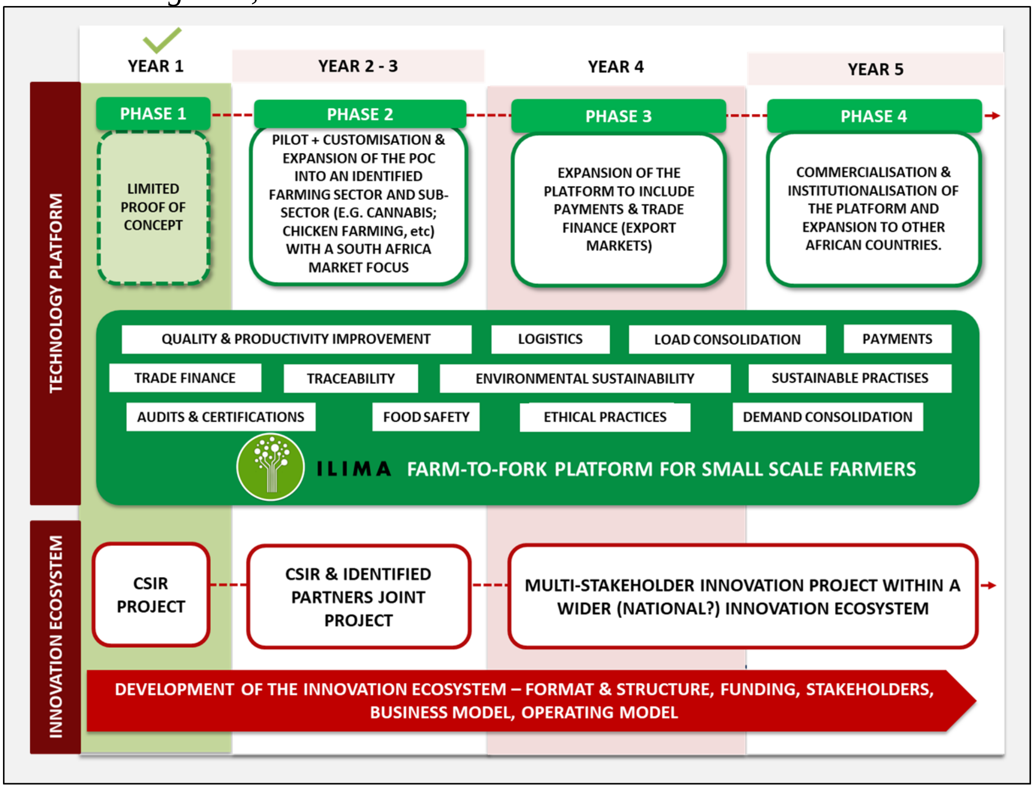

Figure 1: Ilima Farm-to-Fork Phases

are to:

- Create a **multi-stakeholder innovation ecosystem**, which focuses on using 4IR approaches to support emerging farmers and small agro-processors from multiple perspectives (technology, business models, governance and policy, and skills development);

- Provide a **technology platform** within which supply chain technologies can be tested for broader implementation in multiple agricultural sectors; and
- Enhance emerging farmer and small processor development through a holistic perspective on the implementation of emerging technologies in developing environments.

For this project, a **4IR innovation ecosystem** is defined as a multi-disciplinary, focused collaboration between role players in an industry sector to apply 4IR technology, business innovation, and process innovation as catalyst for sector transformation in South Africa. Innovation is a key driver of economic growth and development. In addition to leading to greater efficiencies and productivity, it can change how individuals benefit from products and processes. Innovation ecosystems stimulate new solution development and successfully taking those solutions to market.

*Expected outcomes for the **technology platform** are:* (1) improved trust in SSP products from selected geographies and, hence, (2) integration of farmers into local and/or commercial food supply networks, leading to improved market access; (3) provision of safe food to local communities; (4) enhanced household income from farming activities; and (5) growth and expansion of SSP farming activities and outputs.

Impacts include enhanced food safety, food security, and improved household economic gain from farming.

*Expected outcomes for the **innovation ecosystem** are:* (1) evidence-informed innovations (e.g., alternative financing models) and (2) evidence-informed deployment of context-specific advanced technologies in SSP supply chains (e.g., predictive tools customised for a specific geography and for technology readiness of users in the area).

Impacts include (1) enhanced sophistication of SSP supply chains and (2) graduation of chains to trusted participants in local, national, or international food supply chains.

3. Methodology

The development of the Ilima platform comprises the application of blockchain technology in a resource-constrained context. To mitigate the uncertainties associated with adoption, and to ensure agility and responsiveness, a Design Science development approach was adopted. The model, as defined by Peffers et al. [6] serves to illustrate the iterative approach (see *Figure 2*).

Adoption of this approach allowed for iterative development of insights into the deployment of 4IR technologies within the context, and iterative adjustment of both the functional (user and ecosystem) and the technical concepts underlying the platform design. Phases 1 and 2 have been completed, with Phase 3 under negotiation at the time of writing.

The activities within each phase varied depending on maturity of the concepts. In Phase 1, the focus was on *design and development* of a minimum viable product (MVP), as well as *demonstration*, with a more informal approach to *evaluation*. In Phase 2, all three phases were done more rigorously, with consideration of the learning from Phase 1. Based on the results of Phase 2, sufficient tools will be available in subsequent phases (3..n) to allow for minor sector-specific adjustments of the basic architecture (if any); sector-specific *development* of the user interface; rapid progression to in-field *demonstration*; and rigorous *evaluation* followed by operational implementation.

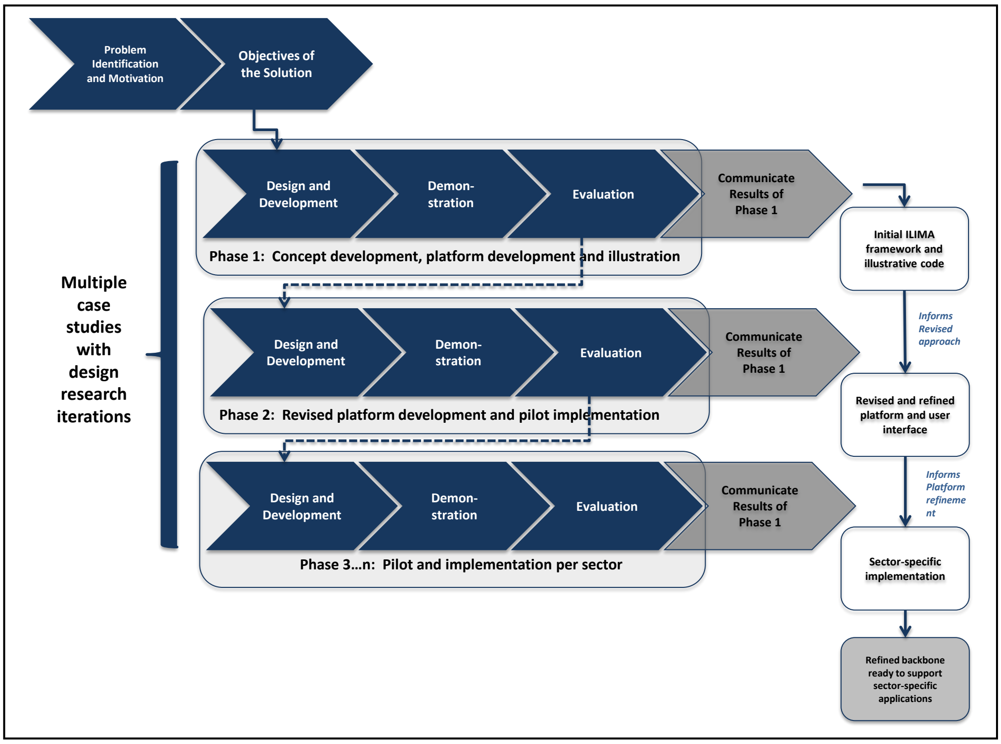

Figure 2: Design Science development approach [6]

4. Ilima: A platform for integration and growth

Ilima has been conceptualised as an end-to-end supply chain platform that supports best production practise and links emerging farmers to markets. With supply chain enablement as a first focus, the foundations are laid to provide additional services across the chain. These include, but are not limited to, access to raw material; product visibility and traceability (including visibility of origin, certifications, and others); support for production processes (efficiency; disease management); pooling of production equipment (e.g., tractors); collective access to transport; measuring and management of environmental impacts; access to markets; and others (see Figure 3).

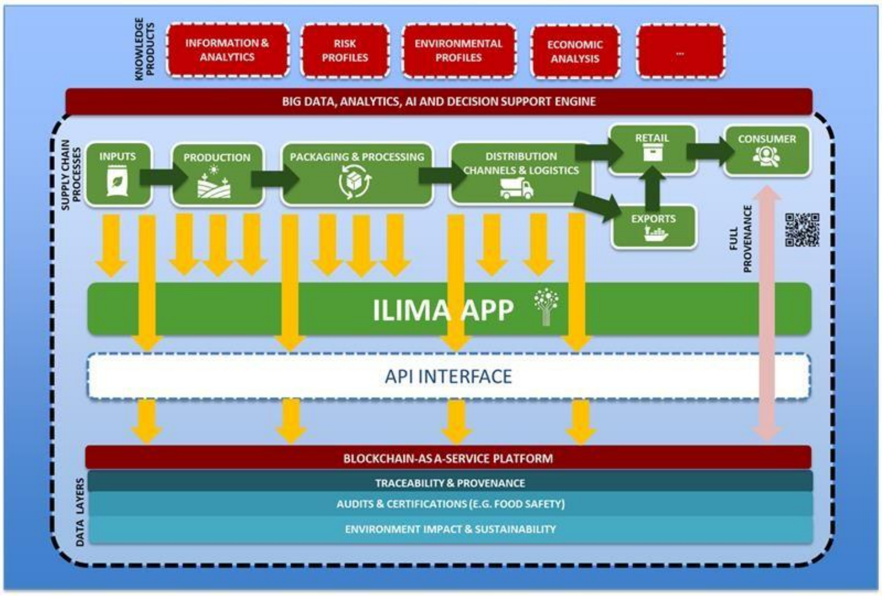

Figure 3: Ilima conceptual framework

While supporting supply chain functions, the platform generates an information layer that informs a variety of perspectives on the channel, such as risk profiles (for access to finance), disease risks, vulnerabilities, and others. This provides a powerful basis from which supply chain improvements can be undertaken.

The information layer provides a basis from which an ecosystem of stakeholders could engage with the platform and support the ongoing development of participating farmers. In addition, farmers and supporting service providers (e.g., transporters) in a specific region or sector will form an ecosystem of collaborators who will engage to facilitate supply chain functioning in the local context.

It is foreseen that Ilima will be rolled out across sectors and regions, with each of these comprising its own ecosystem of collaboration as described above. Eventually, Ilima will comprise a network that is supported by an overarching ecosystem of stakeholders, based on insights gathered from the various information layers generated by the platform.

5. Development path

In the initial stages of the Ilima project, the team contracted with an Australian blockchain provider known for successfully implementing agricultural blockchain supply chain management solutions in Australia and China. This provider collaborated with a South African services company to tailor the MVP for the Ilima project, focusing on a Moringa supply chain use case. However, as development progressed, it became apparent that the solution presented significant limitations.

Specifically, it was not well-adapted to the socio-economic and operational context of South African small-scale farming where there is a lack of technical skills and ICT literacy. Users were too exposed to the blockchain aspects of the solution, with these concepts and terminology at the forefront of the user experience. In addition, the high costs associated with the Australian platform beyond the MVP, presented additional barriers. Examples of the challenging user interface developed is provided in *Figure 4*. Because the development was done using a blockchain interface on an existing platform, it was not possible to customize the user experience to the extent required.

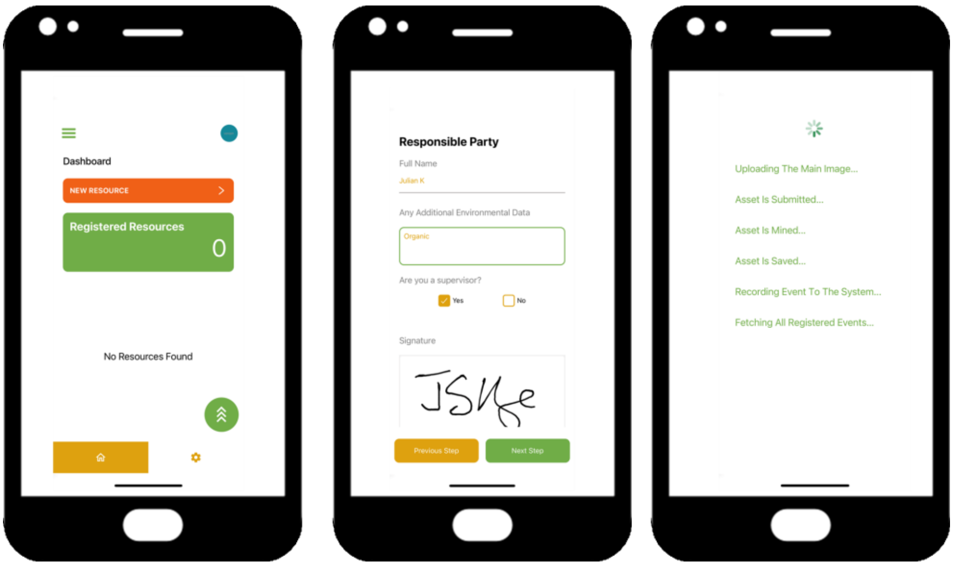

Figure 4: Blockchain-based user interface

Recognizing these challenges, the Ilima team re-evaluated its approach. This led to a decision to collaborate with a local South African mobile development company with deep familiarity with the regional agricultural environment. Using standard mobile development tools and methodologies, the team successfully decoupled the blockchain components from the application layer. This resulted in exactly what was required – a user-friendly app that embedded good practice into the production process, as shown in *Figure 5* below.

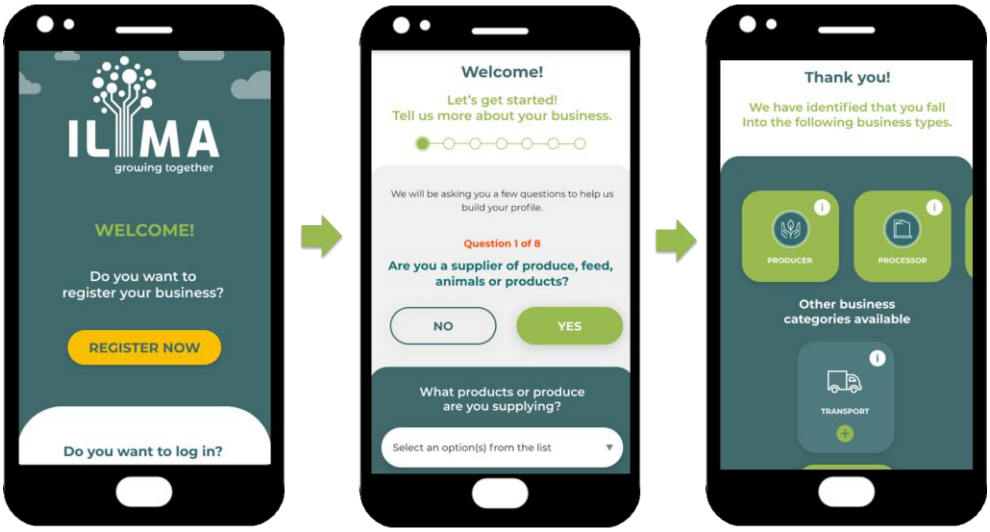

Figure 5: Mobile-app based user interface, with blockchain-based features hidden in the back-end

This shift allowed for a more flexible blockchain-as-a-service architecture, which enabled a selective approach to data storage on the blockchain, focusing only on critical information. This context-sensitive restructuring ultimately proved to be a breakthrough in aligning the platform's technical framework with the unique needs of South Africa's emerging agricultural sector. It also led to a new product, a "Blockchain-as-a-Service" (BaaS) platform that could be applied to many other use cases, since it responded to the gap in blockchain development skills and the cost of developing and maintaining blockchain solutions and infrastructure.

6. Related platforms

At the time of conceptualisation of the platform, a brief review of related platforms was conducted to differentiate Ilima and assess its competitive positioning.

A key focus area of comparable platforms is traceability. The two diagrams in Figure 5 summarise the positioning of Ilima relative to traceability and farm scale, as well as traceability and market access.

Figure 6: Positioning of Ilima relative to comparable platforms

As per the above description, Ilima focuses on emerging farmer scale (i.e., larger than subsistence farming but not yet commercial farming). This aligns with its developmental intent of migrating farmers of promising scale towards an improved economic position. Further aligned with this intent is the relatively high focus of Ilima on market access. In terms of traceability, its focus is comparable with a large number of platforms (that are normally initiated with this goal in mind). A key differentiator of Ilima relative to other platforms is the intended integration of multiple layers of functionality in addition to traceability (see Figure 1).

7. Learning and Recommendations

The process of developing the Ilima platform offered insights into how advanced and emerging technologies can be effectively implemented in resource-constrained environments. Several key lessons emerged:

- **Local context sensitivity.** The initial reliance on an Australian blockchain provider highlighted the importance of solutions tailored to the socio-economic and technical realities of South Africa. Decoupling blockchain complexity from the application layer facilitates improved user adoption and platform usability.
- **Iterative Development.** The Design Science approach enables phased testing and refinement, ensuring that feedback from pilots directly inform subsequent platform improvements.
- **Affordability and Accessibility.** Cost barriers to technology adoption are reduced by focusing on a BaaS architecture and leveraging mobile-friendly development tools.
- **Data as a catalyst.** The platform's information layer (e.g., traceability data, compliance reports) is positioned as a potentially valuable tool for risk assessment, market linkage, and decision-making.

Based on execution of Phases 1 and 2 of the Design Science process, and with broad but sector-specific future uptake in mind, the following two aspects are among the recommendations to inform future development:

- **Focus on adoptability.** Continue focusing on reducing user complexity by refining the user interface and incorporating digital literacy and operational skills training in system rollouts; and
- **Enable Scalability.** Adopt a modular deployment strategy that allows for customisation across agricultural sectors and geographies. Keep platform components standardised to accelerate onboarding of new sectors or regions.

The latter two recommendations are formulated to address implementation and scaling challenges. The former are expected to relate to the resource-constrained context of deployment, including literacy and ICT skills. Other implementation challenges include limited connectivity and sophistication of devices. Scaling is expected to be limited by the low-volume nature of supply chains, which could limit the successful commercial enablement thereof.

Based on execution of Phases 1 and 2 of the Design Science process, and with broad but sector-specific future uptake in mind, the following two aspects are among the recommendations to inform future development:

8. Conclusion

The adoption of 4IR technologies in multiple contexts is seen as a means to accelerate progress, facilitate growth and position for future enterprise development [2]. When used in resource-constrained contexts, it is essential that agile, adjustable approaches are adopted to ensure best fit of technology to the readiness of the context [7]. Intentional adoption of a Design Science approach allowed for planned iterative development and learning from one implementation to the next. While the first iteration delivered less than ideal results, it paved the way for diversification of the original intent into the development of a BaaS offering. This enabled the development of an affordable solution with the potential to be replicated across contexts.

The development journey of Ilima emphasizes the value of the use of local solutions for local contexts. It provides pointers to practitioners for the development of 4IR solutions in resource-constrained contexts. Future work will focus on the deployment of the platform across sectors, while focusing on the development of the supporting ecosystem both within and across sectors. Refinement of the BaaS concept will be a focal point for future work.

9. Future work

The initial phases of the Design Science process, as described here, provided the project team with the opportunity to develop and test a limited version of the blockchain platform, but with the future vision in mind. The latter assumes scaling of the initiative through per-sector deployment of the platform, resulting in a number of local, sector-specific networks that adopt and use the technology. Based on the learning and vision, the following priorities are set for future development.

Simplify Technology Adoption

Expand implementation in a perp-sector manner, and deploy the functionality in a modular fashion. This implies that deployment focuses on the weak points in a specific sector (e.g., production efficiency, supply chain visibility, and others).

Develop and refine the technology backbone

Refine the BaaS concept and implementation, and develop the information layer and analytical capabilities of the platform. Integrate across sectors to strengthen the data layer. Connectivity needs to be assessed per deployment, and enhanced where appropriate.

Develop the stakeholder ecosystem

Expand partnerships with development entities, including special economic zone, SEZs NGOs, local government, and international development agencies. Include financial institutions in the ecosystem to develop innovative financial models based on platform metrics (e.g., compliance and productivity information). Develop community and farmer networks as local ecosystem to facilitate local interactions and benefit from economies of scale.

Monitor impact

Track metrics such as farmer income growth, market access improvement and environmental benefits (carbon footprint reduction) and provide dashboards for impact reporting to stakeholders. Use iterative feedback loops from pilot projects to refine platform features and strategies. Benchmark Ilima's outcomes against other supply chain solutions for continuous improvement and stakeholder benefit.

Policy and institutional integration

Position Ilima with public and private institutions, providing access to data for policy making, market development and planning.

Develop the business model

Development of business models appropriate for the different classes of users. These include business models for farming supply chain services, verification services, and the use of knowledge products (through the information layer) to improve performance

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Declaration of use of content generated by Artificial Intelligence (AI) (including but not limited to Generative-AI) in the paper

The authors confirm that there has been no use of content generated by Artificial Intelligence (AI) (including but not limited to text, figures, images, and code) in the paper entitled "The development of Ilima: an African platform for smallholder supply chain farmer integration".

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