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THE CONDITIONS, METHODS AND MECHANISMS FOR RAPID EVOLUTION OF DIGITAL INFRASTRUCTURE PLATFORMS: THE CASE OF THE DIGIT PLATFORM

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ABSTRACT

Digital infrastructure platforms are increasingly being designed and deployed to address a range of complex challenges at the intersection of society, organisations, environment, and governments. Existing literature provides powerful insights into the inner workings of these systems and the capabilities and mechanisms that lead to their evolution. However, little attention has been given to the challenges of addressing complexity that organisations and managers of these systems are faced with and the conditions that impact the evolution of these platforms. Hence, this paper adopts a complexity lens for understanding digital infrastructure platforms and what causes their rapid evolution. It follows a case study method where it studies the DIGIT platform through participatory immersion, interviews with managers of the platform and through review of platform-related literature. This paper contributes to the literature on digital infrastructure platforms by proposing a conceptual framework that factors in the conditions, methods and mechanisms that lead to rapid evolution of digital infrastructure platforms. The framework this paper proposes looks at three aspects. First, it identifies the contextual conditions that have an impact on evolution outcomes. Second, it identifies the methods used for addressing complexity faced by organisations and managers in platform evolution. Third, it maps the evolution of the platform to three generative mechanisms of innovation, adoption, and scaling.

Keywords: Digital infrastructure platforms, digital transformation, platform evolution, emergence, generative mechanisms, complex systems, complexity theory, adoption, innovation, scaling, case study

INTRODUCTION

Over the past few decades, the role of information technology (IT) based systems has evolved from being tools used by individuals in their functional work to a core ingredient of work itself which is woven into every aspect of the organisational fabric that enables the organisation to connect internally as well as externally (Tanriverdi, Rai, and Venkatraman 2010). As organisations grow and evolve, newer IT capabilities and systems are added, each integrated with other systems, making the design, management, scaling, and evolution of these systems complex. Over time, these disparate systems find it hard to keep pace with the changing organisational structures and user needs (Bygstad and Hanseth 2019). Some researchers have argued that a new approach is required to understand the evolution of the multitude of these IT systems that is shaped by the complexity arising from the confluence of changing technologies, organisational structures and needs of various users of these systems (Bygstad and Hanseth 2019). A mode of enquiry of understanding this phenomenon is to treat these disparate but interconnected systems as infrastructures rather than as standalone systems (Henfridsson and Bygstad 2013).

These digital infrastructures and platforms can be thought of more than just technological artefacts. They operate within organisational and social constructs. The notion that IT-based information systems improve the effectiveness of managing an organisation is widely prevalent. There is also a growing recognition that the pervasiveness of disparate IT-based information systems within and across organisations, many of them introduced at different time periods for different purposes, is conditioned by the wider socio-technical ecosystem within which they operate (Henfridsson and Bygstad 2013). They are influenced by the unpredictability of human behaviour and the internal and external environments. The interconnectedness of digital infrastructures, human actions, social constructs, and the domain they operate within creates complexity that has a bearing on the design, evolution, and effectiveness of these digital infrastructures.

What then are the factors that lead to the evolution of these digital infrastructures? There is a need to explore this question beyond just the technological dimension. Digital infrastructures are characterised by complexity. This complexity has a role to play in the evolution of these digital infrastructures. From the review of literature, it emerges that there is a growing recognition of this complexity and of the significance of the human, social, environmental, and other external factors in the role played by digital infrastructures. However, there is a need to theorize the significance of this complexity and of the socio-economic environment that these systems inhabit in their evolution. While there are some studies that point to the factors that lead to the evolution of complex digital systems, there is little, if any, research that incorporates an understanding of the complexity, the conditions, and the causal structures in the evolution of digital infrastructure platforms. As complex systems like digital infrastructure platforms become more commonplace across sectors, an understanding of how they evolve will be important for organisations and managers faced with the complexity of managing them.

To understand this phenomenon, this paper looks at digital infrastructure platforms through the complexity lens. It tries to understand what the necessary conditions are, how complexity is addressed and what mechanisms lead to the evolution of these systems. It deals with the following research question – what conditions and mechanisms cause the rapid evolution of digital infrastructure platforms? In addressing this question, this paper follows the case study method and looks at the case of DIGIT, a digital infrastructure platform that is used in the delivery of civic services by different levels of government in India. Studying the evolution of the DIGIT platform is useful since it embodies much of the social, technological, and environmental complexities that digital infrastructure platforms are faced with. Additionally, it has scaled rapidly across different contexts providing the necessary variability that makes the study more generalisable.

This paper makes the following contributions while answering the research question: First, it applies the complexity lens to develop an understanding of digital infrastructure platforms and how this translates to develop an understanding of tackling complexity. Second, it looks at the inner workings of these systems and examines the key conditions that impact their evolution. Third, it leans on existing research and frameworks to understand the key mechanisms that lead to the evolution of these platforms. Finally, it proposes a framework that brings together the contextual conditions, methods of addressing complexity and generative mechanisms that impact the evolution of digital infrastructure platforms.

This paper is structured in chapters. Chapter 1 covers the background and theoretical foundation of digital systems, digital infrastructures, and platforms, and sets the unit of study for this paper. Chapter 2 looks at the nature of complexity. This chapter covers issues of identifying complexity, getting an understanding of complex systems, what makes them complex and the types of complex systems. It then looks at the key aspects of evolving complex systems and proposes a conceptual framework. Chapter 3 sets the methodology for the selected case study. Chapter 4 maps the case findings to the proposed conceptual framework which leads to a discussion in chapter 5 and a conclusion in chapter 6.

1 BACKGROUND AND THEORETICAL FOUNDATION

1.1 Digital Infrastructures

Tilson, Lyytinen and Sørensen (2010) in their paper on digital infrastructures, describe digital infrastructures as a new type of information technology artefact that shape products and services as the process of digitalisation expands to cover an increasing number of organisations and industries (Ibid.). Digital infrastructures provide the necessary computing, data storage, data exchange and networking resources needed for operationalising digital systems. They point to digital infrastructures as being a separate category of information technology artefacts that, owing to their pervasiveness and social embeddedness, need to be defined as sociotechnical systems rather than just as specific systems or application that are defined through a set of distinct functions or strict boundaries (Ibid.).

Digital infrastructures help organisations, industries, sectors and indeed countries, in their digital transformation journeys through processes of digitalisation (Tiwana 2014; Senyo, Effah, and Osabutey 2021; Choudary 2021; Constantinides, Henfridsson, and Parker 2018). More broadly, digital transformation has come to signify how digital technologies can transform organisations and sectors to be more relevant and succeed in a digitalised world (Nambisan, Wright, and Feldman 2019). So, while digitisation is a technical process of going from analogue to digital, digitalisation is a "sociotechnical process of applying these technologies to broader social and institutional contexts, rendering them infrastructural." (Tilson, Lyytinen, and Sørensen 2010). Bygstad and Hanseth (2019) define digital infrastructures as complex socio-technical systems that are developed, operated, and used by a heterogenous set of actors, where the use and evolution is not controlled by any one actor.

Digital infrastructures have emerged as a way of conceptualising interconnected system collectives across different contexts such as health, government, natural resource management, and different technologies such as standards and platforms that are leveraged together to produce an outcome (Henfridsson and Bygstad 2013). A wide variety of human and organisational actors use digital infrastructures differently, suited to their needs based on their specific contexts. Given the variety of contexts that digital infrastructures operate in, they often evolve into complex structures, for example the internet, which are beyond the control of any one stakeholder (Klievink, Bharosa, and Tan 2016). Digital infrastructures then need to cater to the requirements of global scalability while at the same time factor for flexibility of use in varied local contexts. Consequently, the idea of decentralised control and loosely coupled technical architecture have emerged as the key contextual conditions for the evolution of digital infrastructures (Henfridsson and Bygstad 2013).

Digital infrastructures do enable some fundamental purposes, like establishing connectivity or communication, but they are not designed to solve specific, narrow problems. Instead, digital infrastructures are designed to be leveraged to solve many different types of problems by a multitude of actors. Digital infrastructures also give rise to generativity, which is the ability of a system to generate new outputs, structures, or behaviours without being completely dependent on the originating system. Generativity leads to outcomes that are not always linear and predictable or foreseen based on the inputs (Nambisan, Wright, and Feldman 2019). Due to this generativity, digital infrastructures are "built on the notion that they are never fully complete, that they have many uses yet to be conceived of, and that the public can be trusted to invest and share the good ones" (Zittrain 2008). Generativity affords organisations and individuals to recombine the capabilities of digital infrastructures in newer ways, without being encumbered by existing, tightly interlocked, social, technical, and institutional boundaries. This has resulted in newer business and service models, cutting across sectoral and industry domains, and giving rise to a new social and organisational formations. Generativity is also what distinguishes digital infrastructures from the commonly understood definitions derived from other industrial-era infrastructures such as roads and electricity grids where the emphasis is on access and connectivity. While digital infrastructures do have these properties, they are different in that they are extremely scalable at minimal cost and with ease, are recursive in nature, exhibit flexibility that widens scope and reach of their applicability and are agnostic to what goes through or is built on them (Tilson, Lyytinen, and Sørensen 2010). When compared to traditional non-digital value chains, value in digital spaces is created through dynamic interactions of different actors in non-linear and distributed processes (Holmström 2018). Understanding these properties of digital infrastructures and their effects on actors and their interactions is crucial while developing an understanding of the design, scaling, and evolution of digital infrastructures.

Digital infrastructures have coevolved with newer forms of social and organisational order, making digital infrastructures inseparable from these new forms of social infrastructures and organisational configurations (Tilson, Lyytinen, and Sørensen 2010). In addition to the complexity that arises through the integration of multiple systems in digital infrastructures, they have some inherent tensions that have an impact on their evolution and scalability (Bygstad and Hanseth 2019) -

- Short-term decisions versus long-term growth
- Global interoperability versus local optimisation
- Planned versus emergent change

These tensions have a bearing on the design and evolution of digital infrastructures and hence, consideration of organisational configurations and social dimensions becomes crucial to fully understand the factors that drive the evolution of such systems.

1.2 Digital Platforms

In recent years, there has been a growing interest in digital platforms that generate value through enabling interactions between different actors within and across organisations, some with spectacular results such as Google's Android platform, Apple's iOS platform, AirBnB, Amazon, and Uber to name just a few (Constantinides, Henfridsson, and Parker 2018; Gawer and Cusumano 2014; Bygstad and Hanseth 2019; Tilson, Lyytinen, and Sørensen 2010; de Reuver, Sørensen, and Basole 2018; Tiwana 2014; Choudary 2021). Digital platforms themselves are created on top of underlying capabilities and resources of digital infrastructures (Constantinides, Henfridsson, and Parker 2018). In many ways, digital infrastructures afford digital platforms the possibility to operate across industries and sectors (Ibid.).

Gawer and Cusumano (2014) describe platforms as a set of assets including products, technologies or services that are organised in a structure that makes it efficient to produce derivative products or services. The term platform appears to be commonly used to describe an environment where "incremental innovation takes place around reusable components or technologies" (Ibid.). Common examples of these are from the durable goods industries, like auto or electronic industries, where organisations have used the platform approach to save production time and costs and efficiently developed a range of products by reusing a common set of assets (Ibid.). Gawer and Cusumano (2014) further classify platforms as internal platforms or external platforms, depending on the context in which they are used. While internal platforms allow an organisation to improve efficiency and incremental innovation by allowing reusability of assets and capabilities, external platforms or industry platforms afford the similar benefits to a larger industry by opening-up the platform to other organisations.

Industry platforms influence relationships and interactions between different participants of the platform, resulting in change in power dynamics between the participants and an increase in the degree of innovation at the ecosystem level (Gawer and Cusumano 2014; Choudary 2021). The term platform is also used to describe two-sided or multi-sided markets, where participants rely on the platform to mediate their transactions. While multi-sided markets have similarities with industry platforms in that they produce network effects, they are different in that all industry platforms facilitate innovation in the ecosystem while multi-sided markets don't always do (Gawer and Cusumano 2014; de Reuver, Sørensen, and Basole 2018; Choudary 2021).

Digital platforms, though similar in concept to the understanding of physical platforms mentioned above, differ in some respects. They differ from physical product platforms, like automotive platforms, in that they do not necessarily generate value by the sale of physical products but rather through the enabling of value-generating interactions between different actors in the innovation ecosystem, including, but not limited to, producers and consumers (Constantinides, Henfridsson, and Parker 2018; Choudary 2021).

The layered technological architecture of digital platforms enables their capabilities to be leveraged across industrial boundaries and contexts, which is different from physical platforms such as automotive platforms, where their utility is bounded by the industry they operate in (Constantinides, Henfridsson, and Parker 2018). This characteristic of digital platforms, where its enabling capabilities can be extended and applied to diverse use cases, opens potentially infinite possibilities of their applicability. By extending and increasing participation to multiple actors across boundaries, digital platforms create new value and innovation (Constantinides, Henfridsson, and Parker 2018; Yoo, Henfridsson, and Lyytinen 2010). The ability of the actors in the ecosystem to participate is guided by a design principle of openness, where the platform is open-enough for other actors to create and extend the capabilities of the platform thus serving as an incentive to innovate (Gawer and Cusumano 2014; Sandebrg, Holmstrom, and Lyytinen 2020). From a socio-technical perspective, digital platforms facilitate and increase interactions between different actors and provide the means to respond to a dynamic and changing environment (Senyo, Effah, and Osabutey 2021).

The concept of industry platforms has been extended to define the construct of open platforms as, "freely available, standard definitions of service outcomes, processes, or technology that encourage multiple users to converge on utility consumption of services based on these definitions – which in turn encourages suppliers to innovate around these commodities" (Fishenden & Thompson, 2013 referenced in Brown et. al., 2017). It is this definition of open platforms that resonates most closely to the definition of digital platforms and digital infrastructure platforms and the one that this paper builds on.

1.3 Digital Infrastructure Platforms

Digital platforms facilitate actors to create value by opening their organisational and technical boundaries, thus expanding their scope and reach. When digital platforms extend their scale and scope, they become more heterogenous and can be said to be performing an infrastructural function. This expansion of scope and reach of digital platforms can be viewed as infrastructuring of digital platforms which needs to be met with appropriate governance controls for them to evolve and scale (Constantinides, Henfridsson, and Parker 2018; de Reuver, Sørensen, and Basole 2018).

Just as digital platforms undergo a process of infrastructuring as they expand their scope and reach to operate across multiple industries, sectors and contexts, infrastructures can also undergo a process of platformisation that aides their evolution by opening-up their architectural and governance control points (Constantinides, Henfridsson, and Parker 2018). Some of the core logics of platforms, namely those of modularity, standardisation and of having a stable core and a loosely held set of peripheral components are useful in understanding platformisation of infrastructures (Bygstad and Hanseth 2019).

Digital components used in platforms and infrastructures can be recombined in ways which blurs the functional boundaries between them. For instance, digital infrastructures can provide the service layer for other infrastructures and even platforms, at the same time digital platforms can play an infrastructural function through a stable core for smaller third-party developers to build their services on (Constantinides, Henfridsson, and Parker 2018).

Platformisation of digital infrastructures and infrastructuring of digital platforms can be viewed along a continuum of control and innovation with implications on their scaling and evolution. While digital platforms enable innovation by opening-up and loosening their control and distributing it to actors at the periphery, digital infrastructures centralise control and push out innovation to the periphery. Digital platforms are designed to evolve based on demand-driven innovation while digital infrastructures evolve based on supply-driven innovation (Ibid.).

Platform theory offers a way to address some of these tensions, owing largely to how platforms are structured where they consist of a stable core and a loosely held periphery; modularity, standardisation, boundary resources that connect the different components (Bygstad and Hanseth 2019).

It is important to highlight the infrastructural characteristics of digital platforms not just from technological and architectural considerations but also because their evolution is determined by a complex set of organisational, social, and domain-specific considerations of multiple actors. In larger social and governance contexts, with existing systems, processes, routines, practices, policies and capabilities, digital platforms look less like the well-defined born-digital platforms like Apple and Airbnb and more like digital platforms with characteristics of legacy infrastructural systems they replace or complement (Ibid.).

It is this broader understanding of digital platforms that we discuss in this paper, where we refer to digital platforms as digital infrastructural platforms.

2 THE NATURE OF COMPLEXITY

Problems can be of different types. Simple problems have known, linear cause-and-effect relationships. The solutions to these problems are straightforward. Problems can also be complicated, where there are different stakeholders and many moving parts, which makes finding solutions to these problems more difficult. Solutions to these problems are complicated but it is possible to arrive at an optimal solution. Other types of problems, like societal challenges, have multiple stakeholders and each of those stakeholders have a diverse set of challenges. However, unlike complicated problems, societal challenges present themselves as complex problems, where the moving parts and stakeholders interact in non-linear ways, adapt and produce emergent behaviour, where finding an optimal solution is not feasible (Tanriverdi, Rai, and Venkatraman 2010; Ooms and Piepenbrink 2021). These types of problems are harder to address not just because of the degree of difficulty they pose, but because they are fundamentally different where conventional approaches of problem-solving become ineffective (Camillus 2008).

Some complex problems are "wicked problems". The term "wicked problem" was coined by design professor Horst Rittel, where he referred to problems in social systems that were ill-formulated, where there was no obvious solution, where there were many actors involved and each had conflicting views not only on possible solutions but on the nature of the problem itself and where some of the proposed solutions turn out to be worse than the problems themselves (Conklin 2001; Camillus 2008; Yawson 2013; Zhang and Kim 2016) . In a subsequent paper, Rittel and Webber identified ten distinctive properties of wicked problems (Rittel and Webber 1973 referred in Zhang and Kim 2016). The table in appendix 1 lists down the ten criteria that Rittel and Webber outlined. The caveat here is that these criteria are not to be used as a checklist to determine whether a problem is wicked or not, but rather as a guide that helps to ascertain wickedness in a problem (Camillus 2008). Wicked problems would reflect some or all these criteria.

In their mapping of the literature review to understand the meanings associated with the concept of wicked problems, authors Lönngren & Poeck (2021) surmised that there is no consensus on the theoretical underpinnings of wicked problems and that there is a high degree of variability in the meanings ascribed while referring to problems as wicked problems. They further elaborated that the meanings ascribed to wicked problems can be understood through co-articulation with alternative concepts that include the terms, “complex/complex challenges/complex problems”, “social/societal/socio”, “sustainability/ecology/environment”, and “policy” (Lönngren and van Poeck 2021). Hence, even though the concept of wicked problems was developed within the context of social policy, it has widely been used in sustainability, environmental and societal contexts (Ibid.).

The wickedness of problems captures the multi-dimensional nature of systems and helps to recognise that complex problems arise at the intersection of multiple systems. That is what makes these problems complex. Rittel and Webber recognised that a linear problem-solving approach would not work towards solving wicked problems (Yawson 2013). Robert Yawson (2013) puts forward a contention that organisations across sectors are confronted with wicked problems that cannot be solved by traditional linear approaches. Approaches to address complex societal challenges using an industrial revolution mindset where “data is gathered, analysed, solutions formulated and implemented” are rooted in a linear and mechanistic view of the world and will not help address these challenges effectively (Ibid.). For organisations to address wicked problems effectively, there is a need for organisational change; to learn, to adapt, and to collaborate across boundaries (Ibid).

2.1 Identifying Complexity or ‘Wickedness’

When dealing with wicked problems, where circumstances and the nature of the challenges are unfamiliar, comprehending the challenge is itself the initial problem (Camillus 2008). So how do we identify the challenges we are trying to solve as complex or wicked challenges? A pragmatic approach would be to see these problems on a spectrum of problem types (Ooms and Piepenbrink 2021). For this, we can lean into a sense-making framework that C. F. Kurtz and D. J. Snowden developed (Kurtz and Snowden 2003).

The Cynefin frame helps in decision-making under uncertainty when there are a wide range of unspecified problems (Kurtz and Snowden 2003). It recognises that systems are not the same and that there are in fact different types of systems. This is arrived at through our understanding of the relationships between the agents and their interactions. The Cynefin framework, has five domains – the known and knowable domains are ones where the interactions and the cause-and-effect relationships of those interactions are known or knowable. These are classified as ordered domains. The next two are unordered domains, where the cause-and-effect relationship is not clear – in the complex domain the interactions between the agents is emergent and becomes coherent retrospectively; in the domain of chaos the cause-and-effect relationships are not perceivable (Ibid.).

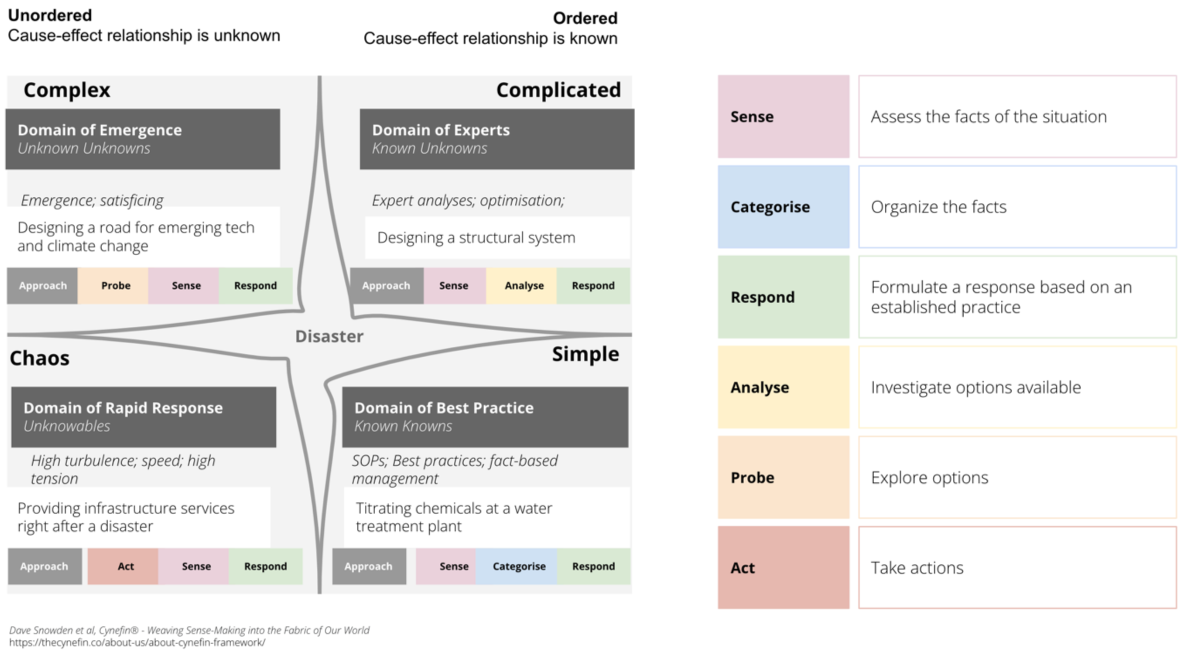

Figure 1: The Cynefin framework allows us to locate systems within different domains.

Source: (The Cynefin framework by Dave Snowden et al referrenced in Chester and Allenby 2019)

Each domain calls for different approaches. The simple domain is the domain of best practices; the complicated domain is the domain of experts; the complex domain is the domain of emergence and the chaos domain is the domain of rapid response (Chester and Allenby 2019). The complex domain is one where there are unknown unknowns. In this domain behaviours of different actors interact in ways that gives rise to emergent behaviour, which is apparent only once it happens and calls for a response. The boundary between the simple domain and the complicated domain, and the complicated domain and the complex domain is blurry and often open to debate (Northrop 2011). At the transition from the complicated to complex domain, social, economic, political, institutional, and environmental factors come into play, interact with each other, and give rise to emergent behaviours. At this point, the approach of optimisation that worked for the complicated domain becomes ineffective at addressing challenges in the complex domain. Or put another way, complicated systems need attention to detail, while complex systems need attention to the behaviour of the whole system (Sammut-Bonnici 2015). Both these types of problems require different approaches to solve them.

The complexity domain, where wicked problems lie, is also known as the domain of emergence. Information systems, in this case digital infrastructure platforms, are often confronted with challenges where there are unknown unknowns, where the sheer number of potential interactions between actors and their emergent behaviours make it impossible to map all cause-and-effect relationships (Cilliers 2000). The behaviour of the system is determined by these interactions and not by the components (Ibid.). This notion of emergence has a bearing on the design, scaling, and evolution of these platforms. The approach for addressing systems located in the complex domain would call for exploring options, assessing the facts of the situation, and then formulating a response.

2.1.1 Theory of the Problem and Theory of the Solution

Per the Cynefin framework, complex societal challenges, or wicked problems, would fall under the complex domain of unknown unknowns. Beyond locating and identifying the approach for the type of challenges that we are attempting to solve, there is a need to have a theory of addressing these challenges. Majchrzak, Markus and Wareham (2016) in their paper on "Designing for Digital Transformation: Lessons for Information Systems Research from the Study of ICT and Societal Challenges", make an interesting observation about theories that attempt to understand the role of information and communication technologies (ICT) in addressing complex societal challenges. Their observation, and assertion, is that there is a need to have two types of theories - a theory of a problem and a theory of a solution. A theory, in their words, is defined as an "argument specifying relationships among conceptual elements" (Ibid.). The definition of a theory is that it is a set of principles on which a practice of an activity is based or in other words, an idea or a system of ideas used to justify a course of action. For complex problems, such as societal challenges, it is rare for there to be a singular, universally accepted problem statement. Stakeholders will have differing views on what contributes to the problem, what the outcomes should be, how they should be measured, causal links between different factors, interdependencies and how the problem can be solved. Their context shapes their understanding of the problem. The role of the theory of the problem is to "specify the role of divergent perspectives in the problem situation" (Ibid.). In addition to the theory of the problem, they propose having a theory of the solution, that addresses how and why ICT can help solve a particular societal problem and what are the conditions for success (Ibid.).

This is a useful construct in understanding and addressing complexities at the intersection of digital infrastructure platforms and the societal challenges this paper seeks to address. The complexity inherent in the design, scaling and evolution of digital infrastructure platforms stems not just from the technologically challenging and interrelated tasks of translating user requirements into technological artefacts but also from organisational factors, many of which are systemic and dynamic in nature, where user needs and organisational requirements constantly change (Benbya and McKelvey 2006). As Benbya and McKelvey (2006) highlight in their paper, "the single hardest part of building a software system is deciding precisely what to build" (Brooks 1995 referenced in Benbya and McKelvey 2006).

2.2 The Complexity Lens and Types of Complex Systems

Digital infrastructure platforms that operate in the societal space are complex systems and need an approach that is suitable to their design, scaling, and evolution, which is distinct from technology-centric linear approaches. Interactions in complex systems are non-linear, where causal relationships between multiple actors and components are generally incomprehensible and hence difficult to track (Cilliers 2001). Designing, scaling and evolving systems located in the complex domain, where there are multiple actors, each with different priorities and emergent behaviours, and where complexity manifests itself in multiple areas, from agreeing with multiple stakeholders on the nature of the problem to be solved and arriving at a theory of the problem to the choice of the solution and arriving at a theory of the solution, needs an approach that factors in these complexities.

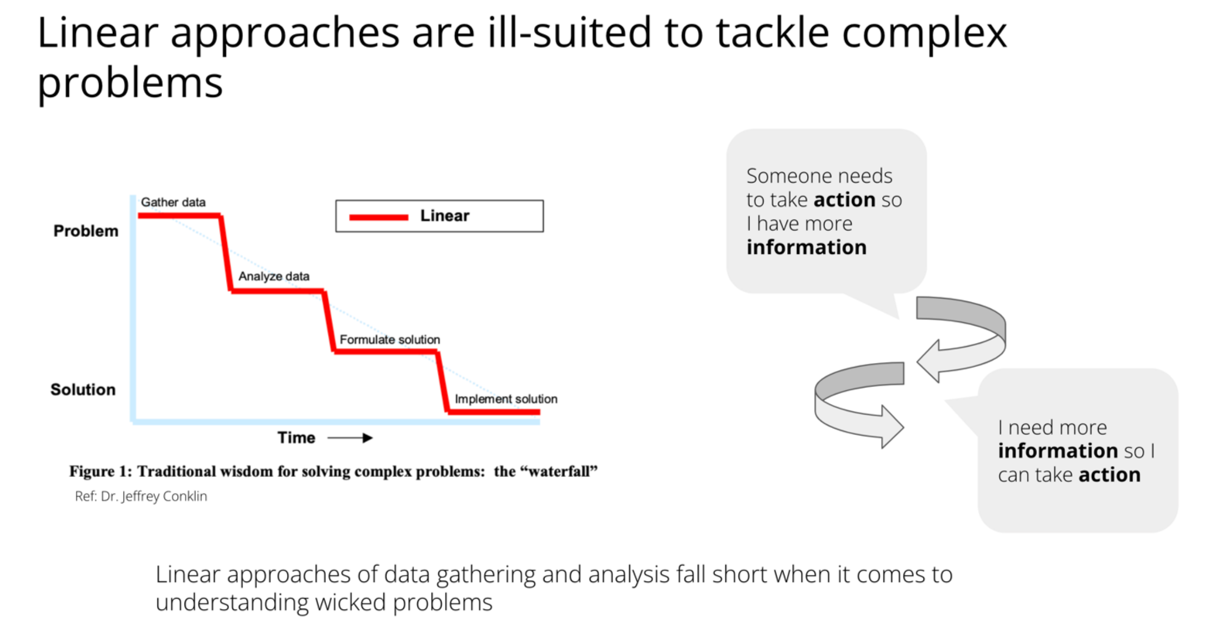

Figure 2: Linear approaches to problem solving

Source: (Conklin 2001; Kerekes 2021)

Mechanistic, engineering-focused theories assume a centrally controlled, top-down perspective to scale and evolve such systems. These approaches, while effective in designing for performance requirements of software systems and for minimizing costs, fall short in catering to the demands of emergent complexity that arise from (Benbya and McKelvey 2006) –

- Emergent issues beyond the scope of the well-defined, bounded organisational goals;
- Problems that stem from actions of individuals and groups that bely the assumption that individuals are independent, rational decision-makers, where actions are dependent on the larger socio-political considerations;
- Goals for which the system is being designed are not fixed but negotiable and themselves change and emerge as a result of the changing and constantly evolving socio-political context.

Complexity theory recognises that not everything can be understood through linear, predictable, cause-and-effect relationships (Janoske McLean, Madden, and Pressgrove 2021; Cilliers 2000). To deal more effectively with challenges of emergent complexity, where order emerges through the interactions of multiple actors, processes and environments, these systems need to be viewed through the complexity lens (Benbya and McKelvey 2006).

2.2.1 Forces of Fragmentation and Complexity

Conklin (2001) elucidates that fragmentation is what is at the root of why some problems are so difficult to deal with. Fragmentation arises when there are multiple variables involved - technical complexity, wicked problem dynamics and social complexity being the key among them. Technical complexity arises from the multitude of technologies and technology environments in action, the sheer number of interactions that take place and the rate of change at which newer technologies emerge, evolve, or become obsolete. Wicked problem dynamics arise when people or stakeholders, each have a version of the problem at hand, and each believes that their understanding is the correct one. The assumptions, perceptions, understanding of the problem and intentions all add to the wicked problem dynamics. Social complexity further adds to this fragmentation. The number of stakeholders, the structural relationship between them, the diversity among stakeholders, all contribute to the social complexity of the problem (Ibid.). These dynamics are visible and at play in the process of design, scaling and evolution of digital platforms and infrastructures. This is also why it is important to view and understand digital platforms as complex systems.

The following sub-sections highlight different types of complex systems and how the complexity lens has been applied to understand their inner workings.

2.2.2 Complex Adaptive Systems

Within the broader complexity theory, the concept of Complex Adaptive Systems (CAS) “may provide the best organisational capacity to tame wicked problems” (Yawson 2013). Complex Adaptive Systems are defined as systems that have many components that interact with and respond to stimuli based on simple rules and can direct activities towards its own optimisation (Benbya and McKelvey 2006). They respond to emergent behaviour and influence future events stemming from these behaviours. These types of systems are adaptive precisely because they have the capacity to respond to changing stimuli and influences without disintegrating

(Sandebrg, Holmstrom, and Lyytinen 2020). The behaviour of the aggregate influences and is influenced by its individual components (Holland 2019). The complexity in these systems gets amplified due to the dynamic nature of the environment within which these systems are used and the changing nature of the requirements of actors (Benbya and McKelvey 2006). Any organisation that designs, sets up or manages such systems, like digital infrastructure platforms, would be better equipped to tackle complex problems if it incorporates the lens of complex adaptive systems in their design, scaling, and evolution.

2.2.3 Complex Adaptive Business Systems

In their paper on Complex Adaptive Business Systems (CABS) and the wickedness of strategic problems, authors Tanriverdi, Rai and Venkataraman (2010) build on concepts from complexity science to understand issues of strategic alignment, integration and sustained competitive advantage in firms. Seen through the lens of complexity science, a system becomes a complex system when its elements display the following four properties in moderate measure, rather than in the extreme (Tanriverdi, Rai, and Venkatraman 2010; Benbya et al. 2020) –

- Diversity
- Adaptation
- Connectedness
- Interdependency

The state of a system is not constant or fixed. It changes as the properties change. A system can exist in different states, ranging from stable at one end to chaotic at the other and at an in-between state called the edge-of-chaos (Benbya et al. 2020). When diversity, adaptiveness, connectedness, and interdependency is low, the system can be said to be in a stable state. As the diversity, adaptiveness, connectedness, and interdependency of these systems increase, the level of complexity in the system also increases. In this state, the systems are in a constant state of change, evolution, and emergence. They cannot be said to be in a stable state, but neither are they in a chaotic state where things fall apart. When systems exhibit these traits, they can be said to be in a state of emergent complexity or the edge-of-chaos (Ibid.).

2.2.4 Complex Social Ecological Technological Systems (SETS)

Authors, Markolf et al. (2018), put forward a proposition that infrastructure systems warrant treatment as complex social, ecological, technological systems (SETS) rather than simply technological systems. They further point out that each of these systems, are interconnected and interdependent and have "agency and influence" on each other (Ibid.). While ecological systems could exist without either technological or social systems, they too are increasingly impacted by the proper functioning of the other two systems and "they cannot function or be decoupled from each other" (Ibid.). This interconnectedness and interdependency of social, ecological, and technological systems has a bearing on how our technological systems are imagined and the purpose they serve. Increasing digitalisation influences the number of applications and systems that interact with each other in the larger digital ecosystem and hence how digital infrastructures develop and evolve. Further, as digital infrastructures expand to newer domains, they will enable alternative organisational, social and technological configurations (Tilson, Lyytinen, and Sørensen 2010). As digital infrastructures expand, they will inextricably be intertwined with the technological, organisational, and domain-specific ecosystem they operate in.

2.2.5 Infrastructures as Complex Systems

Authors, Mikhail V. Chester and Braden Allenby (2019), write about the changing role of infrastructure in this rapidly changing environment and how they are "moving away from the complicated domain where optimization and efficiency were the core approaches, to the domain of complexity, where rapidly changing environments and fragmentation of goals require fundamentally new approaches" (Ibid.). As a starting point, anyone designing a technological system as a response to tackle challenges will need to locate and identify the type of domain these challenges fall under. Most technological systems have been designed to address challenges located within complicated or simple domains, where there are known-knowns and known-unknows, and where the responses are either to leverage best practices or rely on experts' inputs. These function within institutional structures and apply management practices that were designed to address challenges where the cause-and-effect relationships are known (Markolf et al. 2018). The complex domain is different. In the complex domain the cause-and-effect relationships are not known, and any technological response will need to be designed keeping in mind emergence; where there will need to be constant feedback loops to respond to a constantly changing environment. Top-down, hierarchical management structures, where expertise, knowledge and resources are siloed, will need to evolve into more open structures that encourage diversity of perspectives, operate with agility and be able to respond to emergence, and emphasise on creation of new ideas and fresh responses to complex challenges rather than relying on historical models (Ibid.).

2.3 Key Aspects in Evolving Complex Systems

When considering the challenges associated with evolving complex systems, there are a few key aspects that need consideration. Addressing complexity is the first. This includes not just the technological complexity, but complexity associated with understanding the various dimensions and motivations of actors. The next is the factors that influence the systems' inner workings that lead to the capabilities of the system. Complexity theory highlights the role of initial conditions on the behaviour of complex systems (Plowman et al. 2007). These must be considered to understand the context of these systems. The inner workings of these systems are influenced by the principles that the system follows. These principles inform decisions that impact the direction and evolution of systems. These principles can be mapped to two key considerations that systems must constantly contend with, those of generativity and control. The nature and degree of generativity and control determine aspects of stability, flexibility, centralisation, and decentralisation of these systems. Finally, for the capabilities to be actualised, they rely on mechanisms. (Zittrain 2008; Yoo, Henfridsson, and Lyytinen 2010; Constantinides, Henfridsson, and Parker 2018; Henfridsson and Bygstad 2013) The following sub-sections cover each of these key aspects that impact complex systems' evolution.

2.3.1 Addressing Complexity in Complex Systems

As discussed earlier in this paper, complex systems like digital infrastructures and platforms exist within a dynamic, complex environment with multiple actors and stakeholders, each with their interests, priorities, and perspectives on what the system should do and what problem it needs to solve.

Conklin (2001) makes a case that complex or wicked problems demand an opportunity-driven approach and that “solving a wicked problem is fundamentally a social process”, where just technology-oriented, project-management techniques do not suffice (Ibid.). The counter to forces of fragmentation is to build a shared understanding of the meanings, contexts and nature of the problem and a shared commitment towards arriving at a solution (Ibid.).

Chester and Allenby (2019) build on Conklin’s elucidation and put forward an approach that to design and manage complex infrastructures, there is a need build core competencies that are suitable for tackling complexity. These core competencies are (Ibid.). –

Shared Understanding:

There needs to be a shared understanding of the problems and of the goals and concerns of all stakeholders and move towards shared commitment of solving the problem. This is different from consensus building. It is about building collective intelligence with an awareness of the diverse interests of all actors and stakeholders.

Manage, Not Solve:

Infrastructures are all too often treated as physical assets, that are designed, built, and operated to solve a specific problem. However, in a dynamic, constantly changing environment, the problem itself changes. Hence, there is a need to evolve processes that are oriented towards adapting to these changes rather than providing a one-time solution.

Try, Learn, Adapt:

Complex environments have many actors and stakeholders, many interactions and too much distributed information for a top-down command and control system to be effective. The appropriate approach in such environments is one of experimentation that allows for rapid learning and adaptability. For adaptation to take place effectively, the principle of ‘subsidiarity’ – where decisions are made at the most local level possible, needs to be adopted.

Complexity Mindset:

Infrastructures are characterised by complexity through an integration of social, environmental, technological, and organisational interactions. Adopting a complexity mindset allows for managing and dealing with this complexity. A complexity mindset focusses on what can be over what is; relies on satisficing (satisfy + suffice) over optimising and thinking about emergent behaviours and possibilities over static problem definitions.

2.3.2 Design Principles of Complex Systems

Benbya and McKelvey (2006) put forward a conceptual model for designing information systems that can be more adaptive to the dynamic, constantly changing environment they exist in. They base their model on seven first principles drawn from biological and social science theory, which they believe is more suitable in addressing the emergent nature of the information systems than the top-down, static, engineering-focused approaches. The seven first principles framework to designing and developing complex systems, where they suggest a shift from the top-down approach to a more co-evolutionary approach, emphasises that the system should not be designed to be correct or right up-front; it should instead focus on tight coupling of components in the short-term and allow for flexibility in the longer term. The seven first principles framework covers (Ibid.). –

Adaptive Tension:

Designing information systems is not a one-time activity of creating technological artefacts based on a fixed set of requirements. Instead, it is an evolutionary process that evolves as a response to competing, and often contradictory, needs of different actors and environmental realities. And that these needs themselves change over time. This dynamic interplay of interactions of multiple actors and mechanisms create adaptive tensions that get reflected in the design, scaling, and evolution of such systems.

Requisite Complexity:

The design, scaling and evolution of any system is not done in isolation. It is instead within an external environment that provides it context. This external environment is dynamic, constantly changing, and complex. This external complexity can be managed by counteracting or matching it with a similar level of internal complexity. The greater the degree of internal counteractions available, the greater the set of external situations the system will be able to address. But since the external environment is dynamic and constantly changing, it is not easy to design a system that can cater to emergent complexity. Hence, this must be seen as process where information systems can evolve to the required level of complexity based on feedback from the external environment.

Change Rate:

While requisite complexity addresses the need for variation, the evolution of the system is directly proportional to the rate at which these variations are usable. When new requirements or issues that were not known earlier surface, there needs to be a mechanism to be able to identify and resolve these issues. Acting on feedback loops allows for these systems to respond to unforeseen requirements, thus aiding in the quicker adaptation and evolution of the system.

Modular Design:

A modular design has been proposed as a useful, if not necessary, condition for designing complex systems. Modularity refers to the loose coupling of individual subunits of the system to minimize interdependencies, where each sub-unit is independent, thus enabling the entire system to be more flexible, allowing for greater configurability and faster evolution.

Positive Feedback:

While this is similar to the earlier principle of having feedback loops, it focusses on amplifying positive feedback loops as opposed to negative feedback loops. This is especially relevant in the initial phase of the design of the system, where if negative feedback loops prevailed, actors would simply revert to the last state of order, thereby stymieing the evolution of the system.

Causal Intricacy:

There is recognition of the fact that the design of information systems is not an event but an evolutionary process that involves the interaction of multiple actors and mechanisms. However, to sustain the evolution and development of complex systems, there is a need to understand that the design, scaling, and evolution of these systems is interwoven with not just the technological but also institutional and organisational changes.

Coordination Rhythm:

It is observed that in the evolution of design of information systems, there is a duality that is experienced in the form of top-down control dictated by experts and emergent bottom-up needs led by user requirements. These forces, from inside-out to outside-in, create tension that influences in the direction of growth of the system. To achieve adaptive effectiveness, both these extremes of centralised authority and bottom-up autonomy, need to be regularized and brought into a rhythm through operating mechanisms. This mutual interaction needs to go beyond just technical process and should cover organisational, business, operational and strategic considerations.

Following Benbya and McKelvey (2006) we get an appreciation of the dynamic nature of the context that complex systems inhabit and the adaptive requirements that are more suitable to the designing of such systems.

2.3.3 The Nature of Generativity and Control

Highlighting the inherent scalability and flexibility of digital infrastructures, Tilson, Lyytinen and Sørensen (2010) posit that digital infrastructures can be extremely generative where new capabilities and services can be delivered at speed that in turn help to forge new socio-technical relationships blurring organisational boundaries. This brings into focus two key challenges having implications on how digital infrastructures are organised where they need to cater to stability and flexibility, and control and autonomy.

Generativity:

Generativity is essentially about being able to manifest the possibilities afforded by the digital infrastructures. For example, the api's in digital platforms allow generative actions by developers outside the platform to produce new innovative artefacts (Nambisan, Wright, and Feldman 2019). Here, generativity is about being able to harness change. For there to be generativity, seemingly opposing forces of stability and flexibility are required and need to be considered together (Tilson, Lyytinen, and Sørensen 2010). Stability allows actors to adopt the digital infrastructure, connect to a stable core of social and technological artefacts and operate within the sociotechnical constraints of the digital infrastructure. Stability provides the common ground for agreement on definitions, standards, and processes of change between different actors and is required for there to be a possibility of generativity. "Conversely, stability can be bolstered only by allowing flexibility" (Ibid.). Flexibility brings about variations through the different contexts that the digital infrastructure is applied to. It allows for unbounded growth and application of capabilities afforded by digital infrastructures beyond intended organisational boundaries. This flexibility has the potential to undermine stability since it blurs organisational boundaries and well-defined roles and responsibilities. These social and technological variances cater to different contexts, keeping the infrastructural core stable through the evolution of standards and governance mechanisms. So, while stability and flexibility appear paradoxical, the interplay of both these factors is crucial in ensuring generativity of digital infrastructures.

Control:

As digital infrastructures evolve, autonomy of various actors and issues of control have an impact on the evolution and growth of these infrastructures. The nature of control, whether centralised or distributed, shapes what products are built on these infrastructures, the nature of services delivered, the design of boundary resources such as api's and protocols, store of value in the form of ownership of data and also appropriation of value generated through these infrastructures (Ibid.).

This interplay between generativity and control gives rise to new sociotechnical dynamics. For instance, boundary resources like api's, on one hand, are generative since they provide access and new formations, and on the other, act as control points used to regulate behaviour. The evolution of stable socioeconomic formulations depends on how control points and generativity are balanced.

2.3.4 Understanding Generative Mechanisms

Henfridsson and Bygstad (2013) in their paper, 'The Generative Mechanisms of Digital Infrastructure Evolution', identify the mechanisms that lead to the evolution of digital infrastructures. They put forward a perspective that digital infrastructures evolve as a result of multiple interconnected mechanisms and contextual conditions. This helps to advance the understanding of why some digital infrastructures do not evolve while others do. They define generative mechanisms as causal structures that generate events which can be observed. The emphasis is on actual observable events as opposed to just causality, since causality in isolation recognises the cause-and-effect relationship and the possibility of an event taking place but does not imply that the event has taken place. The event may or may not be actualised. Hence, "generative mechanisms are the processes that make a system what it is – for example, metabolism in cells, work in factories and offices, research in laboratories." (Ibid.). If we can identify these mechanisms, it becomes easier to understand the dynamics of a system (Holland 2019).

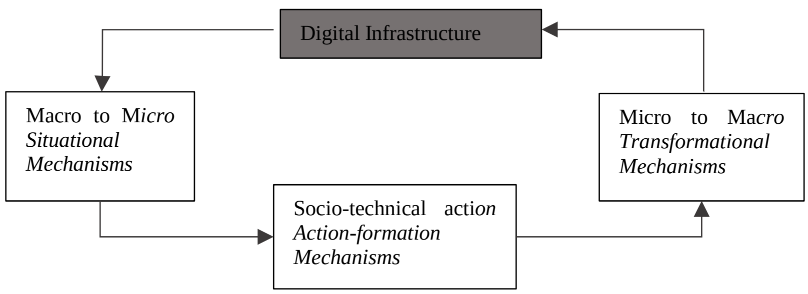

Figure 3: The self-reinforcing socio-technical mechanism

Source: (Henfridsson and Bygstad 2013)

While identifying and proposing generative mechanisms that influence the evolution of digital infrastructures, they make some assumptions (*see Figure 3*) about these mechanisms (Henfridsson and Bygstad 2013) –

Digital infrastructure mechanisms are self-reinforcing:

Owing to the diversity of actors and stakeholders that influence the governance of digital infrastructures, they are typically difficult to govern and hence rely on positive and negative feedback loops from the multitude of actors that influence the stability and change in digital infrastructures.

Digital infrastructure mechanisms are composites:

There are three interconnected mechanisms at play that influence the evolution of digital infrastructures:

- Situational mechanisms at the macro-micro level: these lay out the enabling and constraining mechanisms for the various components and how they will interface with each other.
- Action-formation mechanisms at the socio-technical action level: these outline how specific interactions and combinations generate specific action
- Transformational mechanisms at the micro-macro level: these explain emergent behaviours of individual components on the overall system

Digital infrastructures constitute social as well as technological mechanisms:

Digital infrastructures and platforms exist within different contexts. The evolution of these infrastructures is influenced by the contexts they inhabit. Their evolution takes place within social, environmental, policy, organisation, technological, etc. contexts. The unique contexts that digital infrastructures inhabit, define and influence the nature of their interactions. They may produce very different outcomes based on their unique configurations and combinations.

Following Henfridsson and Bygstad (2013), we get a framework that captures the contextual conditions and the generative mechanisms that aid in the evolution of these systems.

In their framework, Henfridsson and Bygstad consider two key contextual conditions for digital infrastructure evolution (Ibid.). -

1. Decentralised control on the social side
2. Loosely coupled architecture on the technical side

In putting forward their combinatorial perspective on the generative mechanisms that aide in the evolution of digital infrastructures, Henfridsson and Bgystad highlighted three mechanisms (Ibid.). –

1. Innovation Mechanisms

   “A self-reinforcing process by which new products and services are created as infrastructure malleability spawns recombination of resources.” (Ibid.).

2. Adoption Mechanisms

   “A self-reinforcing process by which more users adopt the infrastructure as more resources invested increase the usefulness of the infrastructure.” (Ibid.).

3. Scaling Mechanisms

   “A self-reinforcing process by which an infrastructure expands its reach as it attracts new partners by offering incentives for collaboration.” (Ibid.).

As indicated above, these mechanisms work together in a combinatorial manner, so the outcome of the innovation mechanism serves as the starting point of the adoption mechanism, which in turn works to reinforce the scaling mechanism to increase the reach of the digital infrastructure (Ibid.). The three mechanisms interact.

2.4 Proposed Conceptual Framework

Digital infrastructure platforms are complex systems that are adaptive and co-evolve with the context they operate within. This paper builds on the framework proposed by Henfridsson and Bygstad (2013) on generative mechanisms of digital infrastructure evolution. It also recognises that contextual conditions have a crucial role to play in the evolution of complex systems. The origins of these systems and its initial conditions, which form a part of their history, are of crucial importance to the behaviour of the entire system (Cilliers 2000; Plowman et al. 2007). As digital platforms evolve there are also issues of participation, incentives and governance, and platform sustainability that come into play (de Reuver, Sørensen, and Basole 2018). As part of the contextual conditions, it factors in issues of generativity and control and of sustainability of these systems. Hence, the contextual conditions in the proposed framework cover the purpose and origin; issues of generativity and control; and sustainability of the system. The proposed framework recognizes that contextual conditions play a crucial role in providing an environment for digital infrastructure evolution, and while these conditions trigger and influence the evolution, there are generative mechanisms at play that lead to the successful evolution of platforms (Henfridsson and Bygstad 2013). This paper keeps these contextual conditions and generative mechanisms as part of the framework. Additionally, this paper adds a dimension of addressing complexity to the proposed framework. The above literature review propounds that to successfully evolve digital infrastructure platforms, there is a need to address complexity, and this is added as a key dimension in the proposed framework.

Hence, the proposed conceptual framework has the following dimensions –

Table 1: Proposed conceptual framework for the evolution of digital infrastructure platforms

Key dimensions	Sub dimensions	Description
Contextual conditions	• Purpose and origin • Generativity and control • Sustainability	This covers technological and non-technological conditions under which the platform is developed. These include the purpose and origin for which the digital infrastructure platform is designed which cover its initial conditions; its technological design that addresses issues of generativity and control; and issues of platform sustainability.
Methods to address complexity	• Shared understanding • Complexity mindset • Adaptive management	Complexity arises when different actors and stakeholders do not have a shared understanding of the problem, the path to addressing it and of the solution itself. There are technological, domain-specific, environmental, policy and organisational considerations that act as forces of fragmentation adding to complexity of both, the problem, and the solution. Thus, building competencies and mechanisms aimed at addressing complexity become key considerations for organisations designing and operating digital infrastructure platforms.
Generative mechanisms	• Innovation mechanisms • Adoption mechanisms • Scaling mechanisms	Generative mechanisms of innovation, adoption, and scaling, and the interplay between them, have an impact on the evolution of digital infrastructure platforms. Innovation mechanisms deal with the creation of new products and services on the platform. Adoption mechanisms deal with the platform and the products built on the platform getting adopted by different stakeholders and actors. Scaling mechanisms deal with the scaling of the platform across a broader geography.

Source: (Conklin 2001; Chester and Allenby 2019; Markolf et al. 2018; Henfridsson and Bygstad 2013; Cilliers 2000); author's contribution

3 METHODOLOGY

This case studies a digital infrastructure platform and looks at the conditions and mechanisms that lead to its rapid evolution. It explores and attempts to understand how contextual conditions, methods that address complexity and mechanisms that enable generativity impact rapid evolution. This case draws its significance from the fact that it goes beyond looking at the technological capabilities and the mechanisms that aide evolution; it also addresses contextual conditions and how complexity is addressed, which play a crucial role in platform evolution. The case for this paper was selected based on a few criteria. First, since the focus was on studying the evolution, it was felt that the study would benefit from a long-term perspective. A long-term perspective provides an opportunity to study observations over a period of time, which is helpful in understanding the links between mechanisms and outcomes (Henfridsson and Bygstad 2013). Second, among the initial cases under consideration, it was felt that selecting a case that provided maximum access to data for empirical observation would be more suitable for analysis. Finally, access to people for understanding qualitative aspects would be required to inform and augment the data and documents. Keeping these considerations in mind, it was felt that selecting the DIGIT platform as the case would be most suitable for this paper. Following Henfridsson and Bygstad (2013), the retroduction method was followed for the case analysis, where evidence was gathered, analysed, and then mapped to the proposed conceptual framework to explain the outcome (Danermark et al. 2002, Sayer 1992 referenced in Henfridsson and Bygstad 2013).

3.1 Data Collection

In studying the case, three methods were used to collect data – interviewing, document analysis and participative immersion. First, interviews were conducted with those who were closely associated with the DIGIT platform. This included both, past and current employees. The interviewees included the Chief Executive Officer of eGov Foundation, the Chief Technology Officer, the former Chief Technology Officer, people who have been close to running the products and programs like the Senior Program Manager and the Senior Product Manager, the Vice President of special projects and the Head of Development Diplomacy among others.

Interviews were conducted in person or over an online call and recorded where possible. All interviews have interviewer-notes for reference. In many a case, there was an opportunity to have discussions and semi-structured interviews with the respondents several times. The list of interviewees is mentioned in appendix 2 and the list of questions is mentioned in the interview guide in appendix 3. The logic of the interviews was to start with their understanding of the key events at eGov Foundation and DIGIT and then, keeping in mind their functional role, asking specific questions. The interview questions were oriented towards understanding the conditions, methods and mechanisms and emphasised on those aspects. The semi-structured format of the interviews also helped to discover new information that informed the direction of the case findings. Second, documentation on DIGIT going back to a few years was made available for reviewing on the organisation's internal knowledge management system. This included archival data such as strategy documents, point-of-view papers, presentations and documentation relating to the products built on the DIGIT platform, the programs and the engagement with ecosystem partners. Some of the internal documents that this study benefited from were confidential, and hence not publishable. However, the analysis benefited in that they served to inform, and confirm or disconfirm, the interpretations on the evolution of the DIGIT platform. Finally, this study benefited from participation in multiple discussions, viewing demonstrations of the products and the platform and observations of direct use of the systems. The immersion within the contexts in which the platform is designed and products being built allowed close observation of the key issues that come up for discussion. This helped to understand the complexities that arise and how they are addressed. The nature of these discussions also helped inform a view of the key dimensions that impact platform evolution.

3.2 Data Analysis

Once the data was collected, it was analysed and mapped to the proposed framework. Many of the identified events were considered a priori, especially those relating to key business decisions and strategy, while others surfaced during the process of coding these events. This helped to establish a timeline of key events. This allowed for focusing the analysis that had the most impact on the evolution of DIGIT. Finally, each of these was mapped to the identified mechanisms and the interplay between them was called out.

3.3 Case Background

India has a federated governance structure with well-defined division of powers and responsibilities between different levels of government - the central government, state governments and municipal or local governments. The municipal bodies are democratically elected urban local governance bodies and could be of different types depending on their level of fiscal autonomy and size of the population they serve. These bodies, whether a Municipal Corporation, a Municipality or a Notified Area Council are collectively referred to as urban local bodies (ULB). ULBs can be –

- Municipal Corporations – in cities with a population of more than 1 million
- Municipal Councils – in cities with a population between 25 thousand and 1 million
- Municipal Committees - in towns and cities with a population of between 10 thousand and 25 thousand

The responsibilities and functions of the ULBs include town planning and urban development, regulation of land use, water supply, roads, bridges, fire services, public health, sanitation, solid waste management, street lighting etc. In all, 4,400 ULBs in the 29 states of India.

In this case study, the focus is on the evolution of a digital governance platform that was designed, developed, and deployed to help city and state governments in India in their digital transformation.

3.3.1 eGov Foundation and the DIGIT Platform

eGovernments Foundation (henceforth, eGov Foundation) is a Non-Governmental-Organisation (NGO) that was set-up in 2003 to aide in the process of digitisation of urban local bodies across India. In 2003, eGov Foundation started by building digital applications to automate the processes of one ULB. Over a period of time, it developed a suite of applications and expanded its reach to beyond one ULB. By 2008, eGov Foundation had developed a suite of governance applications that would cover the significant areas of operations of a ULB. The expansion to other ULBs was incremental for the next few years. Till 2014 eGov Foundation engaged with individual ULBs and designed, developed, and implemented applications for each ULB separately. In 2014, eGov Foundation had its first state-wide engagement with the

State of Andhra Pradesh with multiple applications. Andhra Pradesh is a state in southern India with 125 ULBs - 17 municipal corporations, 78 municipal councils and 31 municipal committees. The digital systems for Andhra Pradesh were built as an enterprise resource planning (ERP) system. ERP systems are built and operate as tightly bound enterprise-wide systems. So while they work well in well-defined contexts, their architectural design doesn't afford the modularity, flexibility and adaptability that is essential for rapid scale (Interview 1; Interview 6). In 2017, eGov Foundation designed the first version of its digital platform, called DIGIT, an acronym for Digital Infrastructure for Governance, Impact and Transformation. DIGIT is designed as a digital platform that adheres to a set of architectural design principles which makes it more suitable to rapidly build applications and achieve scale. In 2019, DIGIT was launched in Punjab, a state in the north of India with 169 ULBs. In Punjab, DIGIT was rolled out in 100 ULBS in 90 days with a few applications in each ULB (Interview 2). The applications on DIGIT that were deployed in Punjab were designed and developed by eGov Foundation (Interview 4). Post the implementation in Punjab, DIGIT saw a rapid scale-up in the number of ULBs that were using it as their digital platform for governance. As of April 2022, DIGIT is being used, or is in the process of deployment, in over 2,500 ULBs across India. Appendix 4 lists out the timeline of key events in eGov Foundation's journey and the evolution of the DIGIT platform, the key outputs, and the impact on scale.

Drawing on its experience of over a decade and a half in working with government departments in designing and deploying digital systems for urban governance, eGov Foundation realised that monolith ERPs do not scale well and are not equipped to deal with a dynamic and constantly changing external environment and the emergent needs of actors and stakeholders (Interview 1; Interview 6). In 2016, it moved towards a microservices based architecture and created core enabling services and data infrastructure that could be leveraged by multiple applications (Interview 4). This was version one of the DIGIT platform. The release of the first version of DIGIT consisted of only the necessary components, that would enable the immediate applications that had to be deployed in Punjab. Once deployed, individual applications built on DIGIT would undergo rapid iterations based on user feedback. The issues that got reported were not always technology related or user interface related. At times the issues mapped to a difference in the processes being followed on the ground when compared to the processes the application was designed to map to (Interview 3). This is reflective of the dynamic nature of the environment where a department that uses the application alters a process in its day-to-day working and its implication on technology systems. The other type of feedback was to factor in the variability in policies, processes and needs from all 169 ULBs where the applications were deployed. While the initial design of the applications did take into consideration diverse needs, there were instances where the proposed design did not meet the needs of some unique contexts in some ULBs. These were identified and addressed through feedback mechanisms put in place (Interview 4).

From 2018 onwards, DIGIT was being considered as a governance platform by seven other states in India. By now, a lot of the applications from the earlier ERP stack had been redesigned following the microservices architecture approach and incorporated into DIGIT (Interview 4). The result was that the key applications that are required by ULBs were developed and made available as reference applications for other states to pick up. That provided a quicker start to states, where they either had to only configure their specific policy and process considerations on to the base version of each application or add some minor customisations. This reduced a lot of friction to adoption of these applications by the states. In 2017, less than 500 ULBs were on the DIGIT platform. By 2022, 2,526 ULBs had accepted DIGIT as their governance platform.

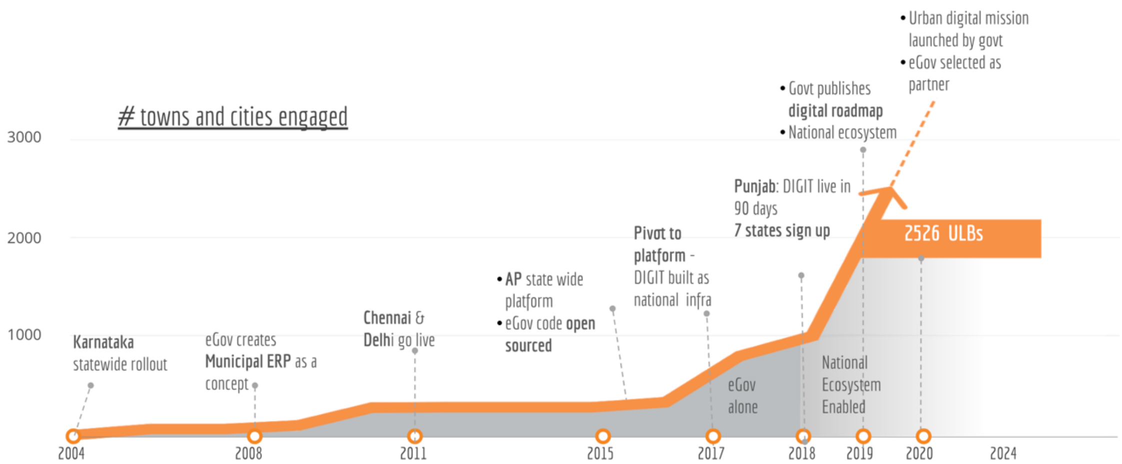

Figure 4: DIGIT platform - journey to 2,526 ULBs at various stages of implementation

Source: eGov Foundation

The next phase of growth and adoption for DIGIT came when it again modified its approach by stepping back from implementing the platform by itself in the states and ULBs (Interview 4; Interview 2; Interview 5). Instead, DIGIT focussed on strengthening the supply side of the market by enabling private sector technology organisations and systems integrators to design, develop and implement applications on DIGIT. From eGov Foundation's perspective, it had to build internal capabilities that helped the process of enabling these partner organisations. This involved creating literature and technical documentation of the DIGIT platform, the applications and the processes involved in designing, developing and deploying them (Interview 3) . It also led to the creation of training manuals and videos and in-person training sessions with the partner teams. From January 2019, eGov Foundation started enabling ecosystem partners on DIGIT. By December 2020, twenty organisations were enabled on DIGIT. This meant that these partners could directly work with state and city governments in implementing DIGIT. In addition to the reference applications that eGov Foundation had built and made available to partners and states, partners now started building new applications on the platform (Interview 5) . By the end of 2020, eight new applications were built on DIGIT by partners.

This approach helped create capacities in private sector enterprises to participate and solved for two key considerations – 1) the scaling of DIGIT to new states was not constrained by eGov Foundations internal resources and 2) it built trust in the ecosystem that DIGIT could be leveraged by others beyond just the organisation that created it.

Over the past 24 months or so, DIGIT is being extended to cover domains beyond the original scope for which it was designed and developed, i.e. as a digital governance platform for urban local bodies. It has more recently been used for emergency COVID-19 relief services; as a platform for sanitation, specifically faecal sludge management and solid waste management; and in the rural context ensure financial sustainability of village-level governments in maintaining their water assets.

3.3.2 Measuring Impact

At DIGIT, the outcomes are measured by the impact that is delivered. This is observed across three axes – deepening impact, widening impact and extending impact.

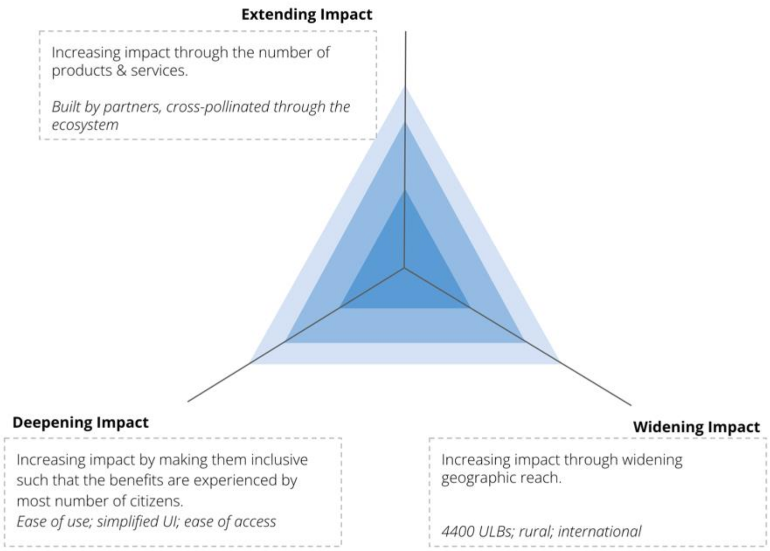

Figure 5: The three axes of delivering impact

Source: eGov Foundation

- Extending Impact: This axis is about extending impact by designing and building more products and applications on DIGIT, often along with other partners in the ecosystem. In the proposed conceptual framework in this paper, the axis of Extending Impact maps to innovation.

- Deepening Impact: This axis maps to capabilities on DIGIT that directly benefit end-user uptake, like the ability to access the services in multiple languages, the ability to use existing channels like WhatsApp to pay taxes, etc., These capabilities are then leveraged by the various products and applications on DIGIT. In the proposed conceptual framework in this paper, the axis of Deepening Impact maps to adoption.

- Widening Impact: This axis is about widening impact by increasing the geographic reach of the DIGIT platform. In the proposed conceptual framework in this paper, Widening Impact maps to scaling.

Activities on DIGIT are oriented keeping in mind this impact.

The rapid evolution of DIGIT had implications on other aspects of the organisation. It required the organisation to add new capabilities, alter internal processes, form partnerships with ecosystem, change its locus of attention from concentrating on software development to ecosystem participation and adoption, and alter the functional structure of the organisation (Interview 5; Interview 6; Interview 9).

4 CASE FINDINGS

The evolution of DIGIT was aided through the interaction of multiple mechanisms, both at the organisational and technological levels. While the digital infrastructure platform is still evolving, its rapid scaling from 2017 is characterised by its evolution along three dimensions (Interview 5) -

- The adoption of DIGIT by different state governments and ULBs, and consequently the number of users it touches
- The number of stakeholders, from civil society organisations and the private sector, aligned to DIGIT
- Innovation on the platform represented through the number of services built on DIGIT

Looking at the case study of DIGIT, it is clear that the organisation went through a learning process and evolved its approach over the years, especially from 2016 onwards, when it shifted to the platform approach (Interview 6; Interview 2). DIGIT's growth was also marked by a steady increase in the number of stakeholders and partners it engaged with. From being engaged with largely government stakeholders at multiple levels, it progressively evolved its operating model where it would engage with stakeholders from civil society organisations, policy thinktanks, private sector technology companies, etc. (Interview 5). Newer interactions created complexity, not just at the organisational level, but this complexity also reflected in the work on the DIGIT platform. There were now more stakeholders, more viewpoints, and more considerations to be taken into account while designing the platform and its applications.

Figure 6 gives an illustrative view of DIGIT's stack architecture and how, through open APIs, the data and core enabling services interact with different actors and varied contexts ('DIGIT Platform Stack Architecture Diagram').

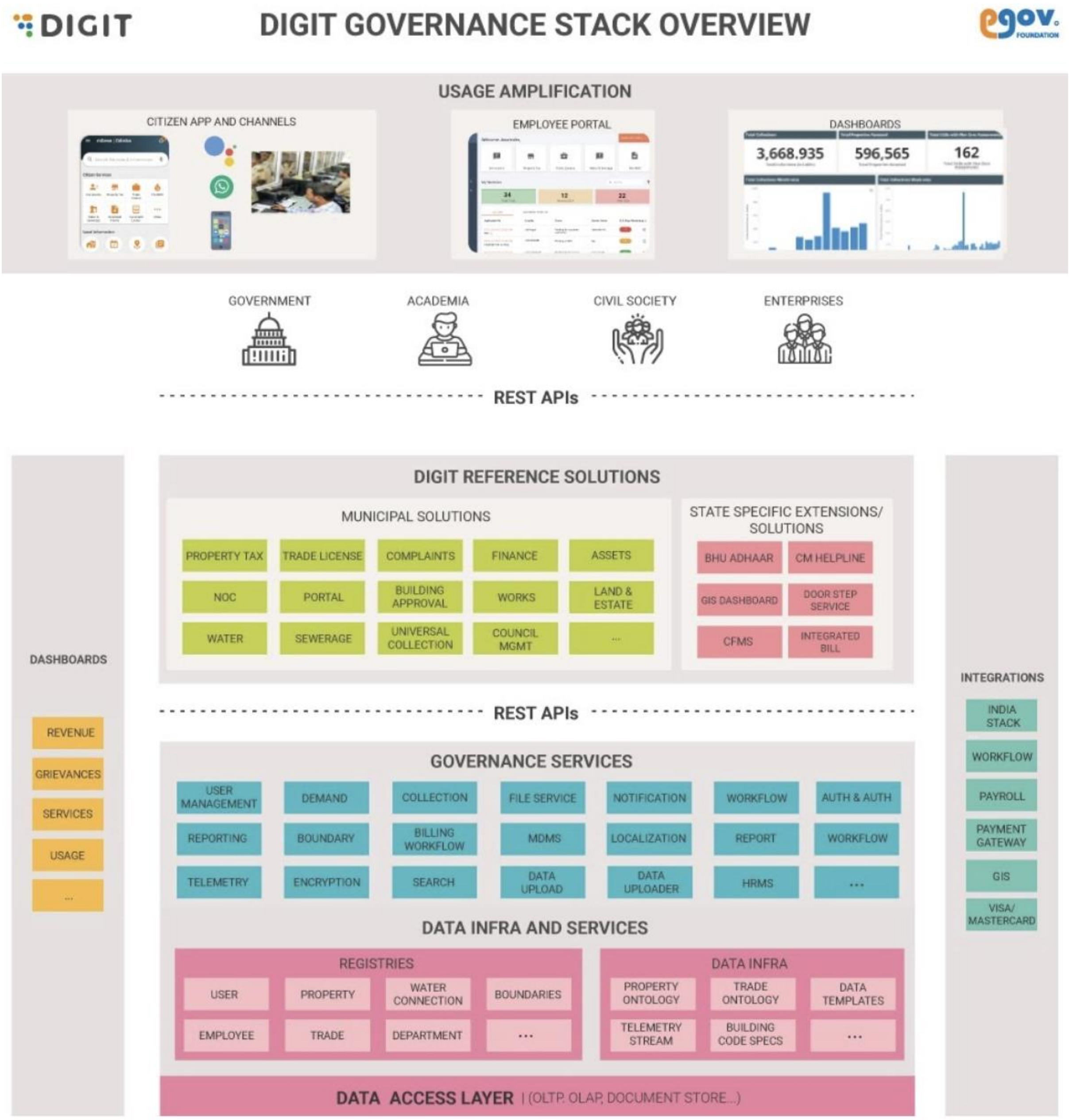

Figure 6: DIGIT’s stack architecture diagram

Source: eGov Foundation

The stack architecture diagram in Figure 6 gives an illustrative view of what the platform does. DIGIT is designed as a set of microservices and open APIs that can be leveraged to build different applications. The multiple enabling services and data infrastructure are represented as blocks. These blocks come together in different configurations to solve problems in different contexts. The data infrastructure and services layer has shared data registries, such as user registries, property registries; master data and reference master data such as boundaries and geospatial data; and data infrastructure such as the data analytics systems and authentication services. Above the data infrastructure and services layer, there is the enabling services layer that includes the user management service, the workflow management service, the reporting service, the billing service etc. These services are context invariant and can be leveraged to build multiple applications in specific context, as represented in the reference applications layer. For instance, a user service, billing service and workflow service can be leveraged by a variety of applications, from an application for property tax to an application for water charges. The applications are then used by governments, academia, civil society, and enterprises through multiple user interfaces – web, mobile, at the ULB counters, and through extensions like WhatsApp, chatbots etc. Administrators also get access to dashboards through which they can monitor their activities and make decisions. DIGIT, through its open api's can also be integrated with other applications and dashboards.

The following sub-sections map the evolution of DIGIT to the conceptual framework covering the contextual conditions, addressing complexity and the generative mechanisms.

4.1 Contextual Conditions

Following Tilson et al. (2010), Bystad & Hanseth (2019), Henfridsson & Bygstad (2013), Chester & Allenby (2019), Tanriverdi et al. (2010), there is widespread agreement that digital systems, digital infrastructure platforms included, exist within an external context with influences from social, economic, environmental, organisational, and domain-specific considerations. Complex systems also have a high degree of sensitivity to their origins and initial conditions (Cilliers 2000; Plowman et al. 2007). These contextual conditions play an important role in determining the direction and evolution of the platform.

In the case of DIGIT, the following stood out as important contextual conditions of the observed mechanisms that influence its evolution.

4.1.1 Purpose and Origin

- The platform was built to serve the organisational mission of improving the ease of living of people in India's towns and cities through civic services delivered by ULBs (Interview 6; Interview 9). This purpose defined the scope of the platform. This is a key contextual condition as the development of the DIGIT platform was bounded by this scope. As the platform evolves, the purpose gives it direction and imposes constraints.

- The platform replaced an ERP system that was already in use (Interview 4; Interview 6). Hence its starting point was not a clean slate. The applications too were rebuilt on the DIGIT platform (Interview 9). DIGIT evolved within existing technological, organisational and institutional bounds, that in that case, were fairly well defined. This determined the starting point for DIGIT where it was built to support applications that were hitherto on the former ERP system.

Both, the purpose and origin have an impact on the evolution of the platform. Till the DIGIT platform was extended to serve in a national health emergency in the early months of the Covid-19 pandemic, some of the capabilities of the platform were not actualised beyond the original purpose (Interview 1). DIGIT, in a sense, was bounded by its purpose till there was a new need in the form of a national health emergency. Similarly, when the purpose was further extended to include sanitation, health and public finance management in the form of new missions, some of the same capabilities were actualised in new contexts and newer ones added not only in the urban space but also in the rural space. Purpose defined its scope and hence it's evolutionary direction.

4.1.2 Generativity and Control

The second contextual condition that has implications on the evolution of platforms is how they are organised and how they cater to generativity and control. As discussed earlier, generativity is about being able to actualise the possibilities afforded by the capabilities of the platform. The nature of control deals with the type of control exerted by the platform in the form of degree of centralisation or decentralisation and the degree of autonomy to participants (Tilson, Lyytinen, and Sørensen 2010). This interplay of generativity and control leads to new socioeconomic interactions and is crucial in the innovation, adoption and scaling of the platform and its evolution.

In relation to generativity and control, the challenge for the teams working on DIGIT was two-fold - to make immediate fixes so that users can continue to use the applications for their work and; to abstract learnings from these feedbacks and make changes to the components of DIGIT at the architectural level, such that they are better equipped to deal with emergent issues through quick configurations rather than through code changes (Interview 1). Through feedback loops, the team at DIGIT made choices on whether to address the need through requisite changes to its microservices or to make these changes at the peripheral application level (Interview 6). While trying to match the requisite level of complexity of the platform with its external environment, the team at DIGIT has to address these adaptive tensions of a short term fix versus long term sustainability of the platform; or solving for a narrow case versus making changes such that many more needs can be addressed (Interview 1).

DIGIT addresses issues of generativity and control through a set of platform design principles (Interview 1; Interview 6). These platform design principles inform the architectural design of the platform, which in turn addresses its core capabilities and the possibility of them getting actualised.

These design principles come together to produce a set of standards, specifications, and certifications. The key design principles of DIGIT are ('Principles of the DIGIT Platform'; Interview 1; Interview 6) –

- Secure and Reliable: The design needs to ensure privacy and data security to enable trust in the information on the platform, such that people feel safe when transacting with solutions built on the platform.
- Unbundled: A deliberate process of breaking down complex challenges into their fundamental components in a manner that they can be solved more effectively.
- Scalability at Speed: Ensure rapid scalability through standardisation and modularity.

- Interoperability through open APIs: Support large number of diverse use cases and allow for easy integrability with other systems.
- Standards driven: Mitigate dependence on specific frameworks, systems and platforms by being standards drive.
- Extensible and Evolvable: Ensure extensibility and evolvability through a loosely coupled microservices architecture.
- Channel Agnostic: Ensure multi-channel access to services delivered through the platform depending on the context.
- Inclusive and Minimal: Ability to respond to contextual needs
- Federated Architecture: so that there are controls at the right levels

With each successive release, the DIGIT platform added newer core components to its capabilities and iterated on the existing ones. This proved to be a forcing function for the team to ensure that the platform components are designed in a way that make them evolvable, thus following the key design principles was imperative (Interview 1). These design principles enabled DIGIT to be extended to contexts beyond its original purpose – "it was designed for cities but the design principles allow it to work in rural or international contexts." (Interview 1).

The development of the platform capabilities is still managed and led by the internal eGov Foundation team. As of now, the control in DIGIT is largely centralised with eGov Foundation with little participation and contribution from the community and the ecosystem in actively evolving the platform. This however is changing with DIGIT opening up the governance of the platform to partners from the civil society, market players, academia and governments (Interview 6). Ecosystem partners have the opportunity to contribute code back to the platform and participate in its evolution, though this capability hasn't been actualised, except on a couple of occasions, where new products built by partners have been contributed back (Interview 5).

4.1.3 Platform Sustainability

The third contextual condition that is important to consider in the evolution of platforms is their ability to sustain themselves. In the case of DIGIT, it is supported by philanthropic funding and its success is measured in societal impact and not in financial metrics. To that extent, the direction of the platform was set by the needs of the mission that was funding it. That has a bearing on the evolution of the platform where it can provide a level playing field for marketing participation and fill the gap for poor government capacity (Interview 9). The other key implication of this is that the evolution of the platform was not oriented towards generating revenue for itself, and in the absence of revenue generating mechanisms, long term sustainability of the platform needs to be addressed either through continued philanthropic funding, institutionalisation of the platform within an organisational set-up, community participation or a combination of these (Interview 7). There is a difference between sustainability of the organisation and the sustainability of the platform that needs to be called out here - while sustainability of the organisation would translate to having the resources to run an organisation, sustainability of the platform may or may not need the organisational resources that houses it for its sustainability (Interview 7). In open-source platforms such as DIGIT, an ecosystem of developers, designers and managers could support the platform.

Platform sustainability has a direct impact on the evolution of the platform, as what it will optimise for will determine the direction and the mechanisms that are put in place to support its evolution.

4.2 Methods to Address Complexity

Through the discussions with the respondents and from their testimonies, there is almost unanimous acknowledgement of the fact that managing a platform like DIGIT is complex. Based on the responses, the understanding is that complexity arises from the following key factors –

- Incomplete understanding of the environments in which the digital products are going to be used owing to the sheer variability of conditions on the ground

- Divergent, often contradictory, objectives of stakeholders and needs of actors
- The technical complexity of designing and evolving the core components of the platform that allow for stability and generativity
- Changes in policy and processes at different levels of government
- Emergent behaviour of different actors when they use the systems

The most often cited reason as the cause of complexity is understanding and defining the problem that needs to be solved. At one end, the platform tries to solve for context invariant problems and at the other it needs to address very real issues that the users and beneficiaries face in very specific contexts (Interview 9). The respondents framed this differently depending on their functional role in the organisation. For example, the partnerships and account management teams citied the various needs of the different stakeholders they engaged with as being challenging in understanding how to frame the problem that is being solved. Product teams designing applications had similar views though their issues were more focussed on what problems were being solved through the applications being built on the platform. Engineers found it challenging to balance the immediate needs of the problems that were being solved by individual products built on the platform with the stability of the platform design.

The mechanisms and processes that emerged, arose in response to challenges that the team faced (Interview 4). These have evolved over a period of years and in many ways, are still evolving. While some of them, such as developing a shared understanding with the partners they work with, have been instituted more formally in the processes the organisation follows, others, such as developing a complexity mindset and adaptive management practices are a composite of a few processes and are still evolving (Interview 9).

4.2.1 Shared Understanding

As evidenced from the testimonies of the respondents, one of the primary challenges is in arriving at a common understanding of the problem and the approach to be taken for the solution with all the partners that eGov Foundation, and hence DIGIT, is engaged with. The digital platform and the applications generally have multiple stakeholders – the state government administrators, the ULB employees, civil society organisations that work with interest groups, think tanks that advise governments in specific domains, technology teams of all these organisations as well as functional teams from within eGov Foundation. One of the ways that eGov Foundation found to be effective in tackling this aspect of complexity, is to arrive at a shared understanding and a shared narrative about the problem and the approach for the solution with its partners. They do that through a series of dialogues and workshops with partners. The output is generally published through point-of-view and strategy documents and through the articulation of pivotal problems. The organisation defines pivotal problems as those problems, which when solved, would allow others in the ecosystem to address other problems. The pivotal problems then become the unifying thread around which the platform and product development takes places.

4.2.2 Complexity Mindset

One of the challenges that the team faced during the development of the first version of DIGIT and its early applications, and to a large extent continues to face today, is knowing how much information is needed before a problem can be defined and how to draw these boundaries. A key competency that is required is tolerance for ambiguity (Interview 9). In the initial period of developing the first version of DIGIT and then early applications on it, the team went in with a waterfall approach where it gathered information, analysed it, decided on the course of action and then executed on it. Over the subsequent years, they've adopted a more agile approach, not just in the development of technology but also in how it approaches the rollout of the applications and the growth of the platform. Through learnt experiences, the approach the organisation now takes is more calibrated, where it builds applications and then develops the platform components only based on the scope of a specific version limited by the context. For instance, they first try and solve for the pilot ULBs, build capabilities and evolve from there (Interview 3). While this doesn't completely map to developing a complexity mindset, the underlying mechanisms that enable such a calibrated approach have elements that do. By breaking down the progress into small milestones, the organisation forces itself to continuously plan, deliver on those plans and then recalibrate based on the progress. It is a move in the direction that maps to developing a complexity mindset. At eGov Foundation, some of the ways in which they capture the essence of a complexity mindset is to draw the contrast between an optimisation mindset and a complexity mindset. This is borrowed from the Societal Platform thinking that eGov Foundation heavily leaned on to inform its platform approach.

At eGov Foundation, one of the ways in which they articulate Societal Platform thinking is captured in axioms, such as:

"Solve for what works as scale as opposed to scaling what works."

"Instead of solving everything yourself, distribute the ability to solve."

These axioms recognise that conditions will the different in different contexts and the nature of the problem will evolve. Hence, when designing digital artefacts, programs, process, the lens that needs to be applied is one of evolvability.

The table below brings out the differences between an optimisation mindset and a complexity mindset -

Table 2: Optimisation versus complexity mindset

Optimisation mindset	Complexity mindset
scale what works	what works at scale
better solutions	better capacity to solve
my organisation	open ecosystems
plans are important	process of planning is important
focus on "what is"	focus on "what can be"

Source: Societal Platform Thinking, eGov Foundation

From this perspective, the organisation has internalised some aspects of complexity thinking that is crucial while building the platform. This has a bearing on how problems are viewed and addressed on DIGIT with a direct impact on the evolution of the platform.

4.2.3 Adaptive Management

As outlined by Chester and Allenby (2019), in the face of constant change, infrastructures need to constantly evolve. Hence, managers of these systems need to bring in this perspective in their work where these systems like platforms need to be seen as beyond just the fixed assets that they are developing. As discussed earlier in this paper, these systems are often characterised by wicked complexity and hence, managers need to evolve practices that go beyond optimisation techniques suitable for problems that lie in the complicated domain towards mechanisms that address complexity (Ibid.).

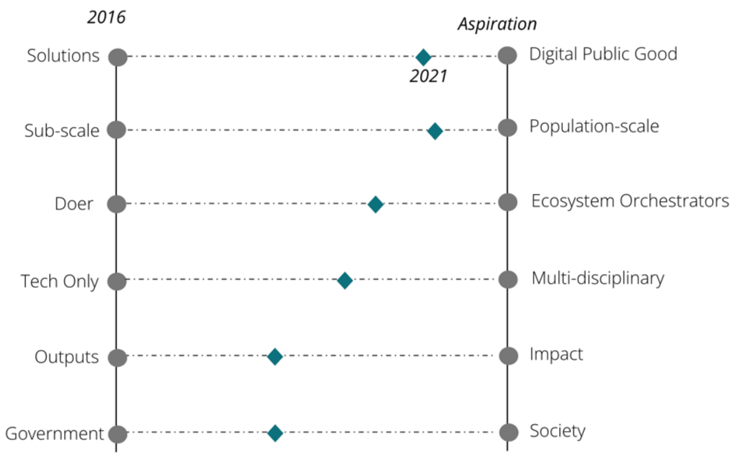

Figure 7: Strategic shifts the organisation recognises it needs to make

Source: eGov Foundation

As eGov Foundation and DIGIT evolved from designing and deploying bespoke applications to building an ERP system to designing and building the DIGIT platform, the structure of the organisation evolved to address the changing needs of managing the requirements of the approach. When building and managing an ERP system the emphasis was on the software; when building a platform the emphasis is on ecosystem participation, adoption and innovation on the platform (Interview 9). This required some strategic shifts, prominent among which are captured in the Figure 8 and elaborate on below -

Solutions to Digital Public Goods:

eGov Foundation made a shift once, when it moved from ERP systems to an open digital platform approach. One of the shifts it made was to move from designing point-solutions to building open products that would work across multiple contexts with minimal customisation. These were still, however, bounded by a geographical context. This shift needs to continue further to make these products geographically agnostic and think of them more as digital public goods, rather than reference applications or products.

Sub-scale to Population Scale:

This is one of the shifts that eGov Foundation has been making and the work on DIGIT is reflective of this change. Which is to think about its work at population-scale, which in India's context would translate to all individuals within a ULB, all ULBs within a state and all states within a country.

Doer to Ecosystem Orchestrator:
This is again one of the shifts eGov Foundation had started making and is continuing to make. Going from doing everything itself, it is increasingly getting the ecosystem to participate. On the DIGIT platform this is done by opening-up the platform governance to multiple stakeholders. Hence, its management practices are shifting from focusing on doing things and tracking project plans, to ensuring that it works with others to get things done.

Tech-only to Multidisciplinary:
eGov Foundation started off as a primarily technology and engineering focused organisation. Hence, all its processes, people and management practices were modelled on an engineering organisation. Recognising that technology alone does not ensure success in delivering the intended impact, eGov Foundation had gradually started moving towards being multi-disciplinary. Starting with program management, it gradually incorporated other functions like product management, partnerships, policy, monitoring and evaluation, etc. as part of its core functions. Consequently, the number of people in core technology and engineering functions as a percentage of overall organisational strength has declined over the years.

Outputs to Impact:
In a complex environment that eGov Foundation operates in, understanding the contribution of a digital platform like DIGIT can be challenging. The tendency for most technology driven organisations is to measure their contributions as outputs. For instance, the number of products built on the platform, the number of core components built, number of knowledge artefacts put out, etc. Given that the role of DIGIT is evolving, it has started moving towards measuring impact delivered in terms of benefit to the actors, i.e., number of organisations enabled on DIGIT, number ecosystem interactions, etc.

Government-Focused to Society-Focused:
DIGIT came into existence primarily to digitise the operations of city and state governments. Over the years, its scope has expanded to other domains that require the participation of multiple stakeholders. As things stand today, in addition to governments, DIGIT engages and enables other organisations in helping solve complex societal challenges.

Making these strategic shifts has called for changes in processes, orientation of people within the organisation, its relationship with its partners and being in a continuous process of change.

While these are not, by any measure, definitive shifts that will address complexity in managing digital infrastructure platforms, they are indicative of the types of shifts required to manage digital infrastructure platforms in a dynamic environment. These shifts, of adapting to dynamic and constantly changing social, technical, political, and organisational environments, are indicative of adaptive management practices that recognise complexity and factor that into their organisational processes.

4.3 Generative Mechanisms

Generative mechanisms are those structures and processes that generate events that can be observed and make the system what it is (Henfridsson and Bygstad 2013). As discussed earlier in this paper, digital infrastructure platforms like DIGIT do not evolve in isolation. They evolve within a complex environment with multiple interconnected relationships.

Based on the inputs from respondents and through participatory understanding, the mechanisms have been mapped to the conceptual framework.

4.3.1 Innovation Mechanisms

As discussed earlier in this paper, eGov Foundation was set-up with the intention of alleviating urban governance challenges by leveraging technology. The DIGIT platform was hence designed and build to operate within the domain of urban governance. The complementarity of a lot of the core enabling services used in different applications allowed for rapid development of applications bounded within the municipal governance context.

In the recent past, DIGIT has been leveraged to address needs beyond the originally defined bounds of the platform. The respondents inform us of two such prominent cases which are evident of the innovation on the platform beyond its intended purpose –

1. Repurposing the platform to respond to the Covid-19 pandemic

2. Leveraging the platform for doorstep delivery of governance services

During the early months of the Covid-19 pandemic in India, the entire country was in a state of an unprecedented lockdown and transporting and delivering essentially services was critical. The challenge in a country as large as India, with a federated governance structure, was to be able to be able to facilitate the movement of vehicles carrying essential supplies. This needed a digital solution that could be deployed rapidly and be available to multiple actors; vehicle drivers, the police department, medical services, private sector manufacturing and distribution organisations, city, state and central administrative units and border checkpoints. The idea was to develop a trust-based system that could be used by multiple actors and could scale rapidly. The team at DIGIT, working with multiple partners – volunteer organisations, different government departments, private sector participants etc, addressed this complexity, where the core enabling services of the platform were repurposed and in less than 15 days, a nation-wide E-pass service was developed and deployed to facilitate the movement of essential goods (Press trust of India, 2020, 'EGov Foundation Launches COVID E-Pass Platform for Movement of Essential Goods and Service Providers', Business Standard; Sharma, P., 2020, 'E-Pass Has Use Cases beyond Covid-19', Business Standard).

The other case where innovation mechanisms came to the fore beyond the immediate purposes that DIGIT was designed for, was a doorstep delivery of governance services launched by the state of Andhra Pradesh. In a unique initiative, the state government established a doorstep service delivery system through the formation of Ward Secretariats across the state, in both urban and rural areas. This was initiated through the creation of a new department - The Housing and Ward Secretariat department, where each ward secretariat is staffed with 10 secretaries and is supported by Ward volunteers - 1 Ward volunteer for every 50 households. Volunteers are enabled with a handheld device or can enter requests in a nearby ward secretariat office system on behalf of citizens. In all, there are 30,000 ward secretaries and 150,000 volunteers across the state taking government services to the doorstep of people. Services such as applying for a water service, paying property taxes, filing a public grievance and knowing its status, applying for a building permit, etc. were delivered through the ward volunteers via a digital service built on DIGIT. This network was rapidly repurposed during the Covid-19 pandemic to aide in food and vaccination programme delivery.

In both these cases, sensing and being aware of these emerging needs needed a mechanism to first identify the role for DIGIT and then to be able to innovate. In DIGIT's case, the partner engagement teams facilitate this two-way exchange of information - inside-out of the new capabilities of the platform that partners and governments can leverage and outside-in to identify emerging needs that could be relevant across multiple contexts (Interview 3; Interview 5; Interview 6). Through this innovation mechanism, the managers of the DIGIT platform prioritise the enhancement or new development of enabling services.

4.3.2 Adoption Mechanisms

For DIGIT to evolve, it was important that it was adopted not just by the governments but also by private sector partners, civil society organisations and by the end beneficiaries. Private sector partners provide the necessary technical expertise that the state governments can leverage in building applications on DIGIT and civil society organisations serve as advisors to governments and highlight issues of citizens and communities that the programs that use DIGIT are meant to serve. The mechanisms by which more partners across governments, private sector and civil society organisations started using DIGIT are referred to as the adoption mechanism.

Designing the platform in a manner that made it possible to for applications built on it to be contextual, scalable, and extensible served as the preconditions for DIGIT to be adopted by a wide variety of partners. While these were necessary conditions, they were not sufficient. To increase adoption, eGov Foundation worked on creating demand for the platform by the states and creating supply of trained developers who could work on DIGIT through the ecosystem (Interview 5). As indicated above, DIGIT was starting to be used for newer innovative services and these innovations demonstrated the applicability of the platform across multiple use cases. The outcome of the innovation mechanisms served as reinforcing factors that fed into the demand side of the adoption mechanisms. The eGov Foundation team also worked with governments in helping them adopt the platform. This included training employees of the state governments on the use of the applications built on the platform, drawing-up rollout plans for the applications across different ULBs, providing advisory support and working with them on the outreach plans for citizens to use the applications (Interview 1; Interview 3).

To develop the supply side, eGov Foundation actively engaged in training of partners on DIGIT, putting out technical, enablement, and implementation documentation, conducting workshops supporting partner organisations through technical and program advisory work (Interview 5). These helped strengthen the capabilities of partners in adopting DIGIT. Engaging with civil society organisations allowed managers of the DIGIT platform to sense the crucial needs of the final beneficiaries and through programmatic and technical interventions, ensure that these capabilities are reflected and actualized through the platform and the solutions built on it. To address issues of adoption by citizens, the eGov Foundation team works with governments on measuring adoption on different products, helping them with the marketing and communication activities and providing program support (Interview 1; Interview 3). These largely address capacity constraints within governments.

4.3.3 Scaling Mechanisms

We refer to the mechanisms by which the digital infrastructure platform expands to newer geographies as scaling mechanisms. As discussed earlier in the case background, DIGIT has seen rapid expansion to newer geographies. In the initial years of the platform's growth, scaling mechanisms were largely internal to the organisation. Internal teams at eGov Foundation reached out to potential state governments (Interview 2; Interview 3). Once there was enough trust in the DIGIT platform and enough capacity in the market players, eGov Foundation encouraged partner organisations in the ecosystem to approach state government directly to engage with them, with eGov Foundation providing advisory and enablement support (Interview 7, Interview 9). Once the DIGIT platform had significant interest and tracking in states, with it being accepted by over 2,000 of the 4,400 ULBs across India, eGov Foundation signed a memorandum of understanding with the Ministry of Housing and Urban Affairs of the Government of India (Interview 2). Under this agreement, DIGIT is adopted as a national digital governance platform that the central government will take it to the remaining ULBs across India in an effort to encourage digital transformation in these ULBs. Here we see policy as a key lever of scaling (Interview 7).

Scaling also has an aspect of direction. In deciding the direction the platform should take in expanding its set of core components as it scales, DIGIT followed an opportunity-driven approach. This was partly by design and partly owing to the immediate needs the platform had to cater to. DIGIT started off with capabilities mapped to the urban governance context, and as the context evolved to sanitation, public finance management and rural contexts, the set of applications on DIGIT expanded, there was a need to build enabling components that could cater to those needs (Interview 6). It responded to the opportunities and through a series of such feedback loops, expanded its suite of core enabling services and hence the capabilities of the platform.

The adoption and innovation mechanisms worked as reinforcing levers to the scaling mechanisms. The fact that many new innovative applications were developed on the DIGIT platform and that DIGIT, and the applications developed over the platform, had achieved a fair bit of adoption from multiple stakeholders, accelerated scaling. Hence, the three mechanisms of innovation, adoption and scaling work in a combinatorial manner and reinforce each other resulting in the rapid evolution of the platform.

5 DISCUSSION

This paper addresses the research question, 'what causes the evolution of digital infrastructure platforms?' We started by recognising the nature of digital infrastructure platforms as complex systems. Leaning into complexity theory, we elucidated that management structures, methods and mechanisms designed for simple or complicated systems are not suitable for complex systems. For digital infrastructure platforms to evolve, they need to be seen through a complexity lens.

Supported by the framework put forward by Henfridsson and Bygstad (2013), we map our findings from the DIGIT platform to two aspects they pointed out that cause the evolution of platforms - contextual conditions and generative mechanisms. In addition, recognising that addressing complexity is a crucial aspect of platform evolution, this paper proposes a third aspects – methods of addressing complexity. Thus, to understand the evolution of digital infrastructure evolutions, organisational actors need to consider the contextual conditions, methods of addressing complexity and the generative mechanisms and the interplay between them. Within each of these aspects, this paper identifies the most crucial aspects that cause the evolution of the DIGIT platform.

Within the contextual conditions, the purpose and origin of DIGIT, generativity and control and platform sustainability are identified as the most important contextual conditions. While these emerged as the three most important contextual conditions in the case of DIGIT, these may not necessarily be the case for other platforms. It is important to highlight that in DIGIT's case, its purpose of improving the ease of living of people in India's towns and cities; its transformation from an ERP system to a digital infrastructure platform; the design principles that impact generativity and control; and finally issues of sustainability of the platform, all play a crucial role in impacting the evolution of the platform.

Within the methods of addressing complexity, having a shared understanding with ecosystem partners and stakeholders, developing a complexity mindset as a competency and having adaptive management practices were identified as the most important methods. Prior studies, like the ones referred to in this paper, recognise that systems like digital infrastructure platforms are unlike digital applications. These are complex systems not just because of the technical complexity that goes into the design and building of these systems but because of the context they operate in. These dynamic, complex environments have interests, perspectives and priorities of different actors each acting as a force of fragmentation (Conklin 2001). Hence, when considering the evolution of digital infrastructure platforms, recognising complexity and addressing it becomes crucial.

In the case of DIGIT, this realisation itself was an evolutionary process and in many ways, it is still evolving. Taking inspiration from complexity science and the role of complexity in the evolution of digital infrastructure platforms, this paper proposes three mechanisms for addressing complexity - of building a shared understanding, developing a complexity mindset and having adaptive management practices that will help organisations address complexity (Conklin 2001; Chester and Allenby 2019; Markolf et al. 2018). As discussed earlier in this paper, having a shared understanding of the problem and the solution that will help solve it, is a crucial aspect in addressing complexity that arises at the intersection of multiple stakeholders, needs of actors, domain considerations and policy. When working on designing and evolving digital infrastructure platforms, this provides the basis for what needs to be built, how it will be used and what success could look like. The second key aspect in the proposed framework under addressing complexity is for organisations and managers of digital infrastructure platforms to develop requisite competencies through a complexity mindset. Following Chester and Allenby (2019) this paper proposes that organisations running digital infrastructure platforms should be concerned with what can be over what is; satisficing over optimising; and thinking about emergent behaviours of actors and their interactions over static problem definitions. The third aspect that helps to resolve complexity is in developing adaptive management practices. In the case of DIGIT, these were captured in the key strategic shifts of the role the platform was expected to play. For instance, the shift from developing point solutions and move towards developing digital public goods. These shifts require changes in processes and operations internally and have implications on how organisations managing digital infrastructure platforms are structured to manage them.

Finally, it is the generative mechanisms that actualise the capabilities of the platform. Borrowing from Henfridsson and Bygstad's (2013) framework, this paper explores innovation, adoption and scaling mechanisms at DIGIT. It is these mechanisms, and the interplay between them, that are studied in this paper. In the case of DIGIT, innovation, adoption, and scaling are all seen from the impact lens, where impact is defined as meeting the stated mission objective of improving the ease of living of people.

This paper suggests that while considering the evolution of complex systems like digital infrastructure platforms, the contextual conditions, methods of addressing complexity and generative mechanisms play a crucial role. These three aspects will have implications on the choices that organisations and managers faced with challenge of managing the evolution of complex systems will need to make.

5.1 Limitations and Future Research

This paper builds on a framework to understand issues that impact the evolution of digital infrastructure platforms. While the case analyses data from primary interviews, organisational documents and through immersive participation, future studies could address some of the limitations of this paper. First, the pool of respondents could be expanded. In this paper, we have taken an inside-out perspective that is more relevant for managers of the platform responsible for platform evolution. However, future studies could complement this with an outside-in perspective on the effectiveness and impact of the methods and mechanisms on external stakeholders.

Second, the causal paths identified through the framework, covering contextual conditions, methods to address complexity and generative mechanisms, that lead to the evolution of digital infrastructure platforms, even if most prominent, are relatively high level. This paper does not claim that these are exhaustive.

Thirdly, the case responses tended to focus on the positive outcomes. Any future research that adopts this framework to study the evolution of digital infrastructure platforms would do well to factor in negative and neutral outcomes.

Finally, the role of technology in addressing wicked challenges is advancing at a rapid pace. While this paper focusses on digital infrastructure platforms, there are recent adjacent developments at the intersection of digital technology and societal challenges that could be studied. Some of these include recent developments in digital public goods (Sæbø et al. 2021), digital public infrastructure, and open protocols and how they are being leveraged to address societal challenges, as areas for future research.

6 CONCLUSION

Digital infrastructure platforms are characterised by complexity arising from the dynamic contexts within which they operate and the multitude of interactions between different actors. This paper starts out by discussing the nature of digital infrastructure platforms and their applicability to solving complex societal challenges. It discusses how these platforms are complex systems and need to be viewed through the complexity lens. Then, it discusses the nature of complexity and the multiple forces of fragmentation that contribute to complexity. Finally, it discusses key aspects impacting the evolution of complex systems, principles that inform their inner workings and how complexity can be addressed. This paper proposes a framework that helps understand the conditions and mechanisms that cause their rapid evolution. The framework factors in the contextual conditions, methods of addressing complexity and the generative mechanisms that impact the evolution of digital infrastructure platforms.

This study provides a perspective in that it is the combinatorial understanding of these three aspects of the proposed framework that would better equip organisations in addressing the challenges that arise in platform evolution. By taking a long-term perspective of the evolution of the DIGIT platform that considered its origins, issues of platform sustainability, principles that inform platform architecture and the mechanisms through which generativity is actualised, we were able to answer our research question - what conditions and mechanisms cause the rapid evolution of digital infrastructure platforms? By mapping the case of DIGIT to the conceptual framework, we were able to identify the contextual conditions, methods of addressing complexity and generative mechanisms that led to the rapid evolution of DIGIT.

Organisations and managers, designing and operating these digital infrastructure platforms will do well to recognise these aspects as they go through their journey of digital infrastructure platform evolution.

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8 APPENDICES

8.1 Appendix 1: Rittel and Webber’sCriteria for Wicked Problems

S. No.	Rittel & Webber’s criteria for wicked problems
1	*No exhaustive formulation of a problem;* There is no general agreement on what the problem is. We don’t understand the problem till we work out a solution. Defining the problem and the solution is the same thing. Crafting a solution for the problems changes the understanding of the problem.
2	*Wicked problems have a no final rule;* The problem-solving process has no final point. Since we cannot define the problem, we cannot tell when the problem has been resolved. We keep on trying to find a solution. We stop trying when we run out of resources like time, money, stakeholders lose interest or political realities change.
3	*No true-or-false solutions, only good-or-bad;* Choosing a solution is a matter of judgment.
4	*No immediate or ultimate test of a solution;* Solutions to wicked problems generate multiple consequences of different types. It is hard to know how these consequences interact and play out.
5	*Every solution a “one shot operation”;* As this is the only option, it is not possible to learn what a good solution would be with trying. It is not possible to undo the consequences of a solution.
6	*No exhaustive set of well-described potential solutions to choose from;* Different stakeholders will have different views of acceptable solutions.
7	*Every problem is essentially unique;* There are no classes of solutions that can be referred to and applied.

	Every problem is without precedent thus experience does not help address it.
8	*Every problem a symptom of another problem;* A wicked problem is a set of interlocking issues and constraints that change over time.
9	*Representations of a problem numerous and choice of representation determines the solution;* The cause of wicked problems can be interpreted in many ways. The interpretation then determines the nature of the solution.
10	*The planner has no right to be wrong;* Problem solvers are held liable for the consequences of their actions.

Sources:

Zhang and Kim's (2016) adaptation of Rittel & Webber's distinctive properties of wicked problems; Kerekes' (2021) interpretation of Rittel & Webber's wicked problems ; Robert M. Yawson's (2013) summation of wicked problem(Yawson 2013)

8.2 Appendix 2: List of Interviewees

Identification	Name	Profile	Interview Recording	Timeline
Interview 1	Abhishek Jain	Chief Product and Technology Officer, Swasth Health Foundation. Former Chief Technology Officer, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 2	Krishnakumar Thyagarajan	Vice President of Special Projects, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 3	Omkar Deshpande	Program Manager, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 4	Elzan Mathew	Director of Engineering, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 5	Ajay Rathod	Senior Partnerships Manager, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 6	Manish Srivastava	Chief Technology Officer, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 7	Gautham Ravichandar	Director and Head of Funding and Development Diplomacy, eGovernments Foundation	Notes of the interviewer. Voice recording.	April 2022
Interview 8	Satish N.	Senior Product Manager, eGovernments Foundation	Notes of the interviewer.	April 2022
Interview 9	Viraj Tyagi	Chief Executive Officer, eGovernments Foundation	Notes of the interviewer. Voice recording.	May 2022

8.3 Appendix 3: Interview Guideline

The interviews with the respondents were conducted in a semi-structured format. The logic was to start broad with their understanding of eGov Foundation and DIGIT keeping in mind their functional role, and then asking specific questions. The semi-structed format of the interviews also helped to discover new information that informed the direction of the case findings.

The following were the questions that were asked to the interviewees –

Background of eGov Foundation and DIGIT

- Please help us understand eGov Foundation's journey from creating bespoke applications to designing and running a digital platform.
- What were some of the key events in this journey?
- Given that eGov Foundation is set-up as a not-for-profit organisation with no revenue stream, how does it support DIGIT and what implication does this have on the sustainability of the platform?

The DIGIT Platform

- What were the key reasons to shift from an ERP system to a digital platform?
- Why did eGov Foundation choose to go with a platform approach?
- What implications did the shift of moving from an ERP system to a digital platform mean for the organisation?
- What are some of the principles that guide the development of the DIGIT platform?
- How is the platform governed?
- What factors influence, or determine, the growth of the platform in terms of new components or capabilities?

Partners and the Ecosystem

- What is the role of the ecosystem and partners in the evolution of DIGIT?
- Do partners contribute to the development of the platform?
- Being an open-source platform, does all the development of the platform and its components happen internally or do DIGIT also get contributions from the ecosystem?
- What are the incentives for partners and what are the mechanisms through which the partners are engaged with DIGIT?
- Given that a lot of the engagement of eGov Foundation has been with governments, can you help us understand the nature of these engagements?

Innovation, Adoption, Scaling

- How does the platform enable innovation?
- Can you give a few examples of innovation on DIGIT?
- What processes or mechanisms enable innovation on the platform?
- What accordingly to you are the most effective mechanisms?
- How does eGov view adoption? (Depending on the response - program; platform; applications;) please elaborate.
- What are the mechanisms that support adoption?
- What is the role of partners in scaling DIGIT? Has it changed over time?
- What are some of the successful mechanisms that have led to rapid scaling of DIGIT?
- Were the methods that were used for initial scaling of the platform repeatable?
- What is the interplay between innovation, adoption and scaling?

Addressing Complexity

- Given the nature of the environment eGov operates in with multiple stakeholders, each with their needs, successfully designing, scaling and evolving DIGIT appears complex. How is this complexity addressed?

- Was there a need to realign internal competencies and mindsets?
- How is managing an organisation that runs and ERP system different from an organisation that runs an open digital platform?

8.4 Appendix 4. Timeline of Key Events

Year	Key events	Outputs	Scale
2003	1 application in a few wards of a ULB	1 application; focus on digitisation	1 ULB
2004	All wards go live in 1 ULB	1 application; focus on digitisation	1 ULB
2005	Agreement for rollout with 5 applications across multiple ULBs	5 application; focus on digitisation	~60 ULBs
2007	Agreement for state-wide rollout	Multiple applications	~215 ULBs
2008	The concept of a Municipal ERP is developed	Municipal ERP is built with 14 applications; later 24 applications	~250 ULBs
2009	Municipal ERP taken to ULBs	Slow adoption	~275 ULBs
2011	Worked with a partner for the first time	Multiple applications	~350 ULBs
2015	Andhra Pradesh state-wide rollout	Multiple applications developed by eGov go live across all ULBs in a state	~550 ULBs
2016	eGov ERP system goes open source	All source code is made openly available	~550 ULBs
2017	Pivot to a digital platform	eGov Foundation moves to a platform approach; first version of the DIGIT	~750 ULBs
2018	DIGIT live in Punjab	DIGIT platform goes live	~950 ULBs
2018	7 states sign-up to DIGIT	Go-to-market strategy pays off	~950 ULBs
2019	Shift towards strengthening the ecosystem	Enablement mechanism put in place; enablement artefacts created and partners trained; 20 ecosystem partners enabled on DIGIT; up from 2 in 2019	~2,000 ULBs
2020	DIGIT used outside of the municipal governance context; leveraged in a national health emergency Covid-19 lockdown	National epass system is developed in 7 days on DIGIT	~2,200 ULBs
2021	DIGIT is used as a platform in two other missions in addition to the Urban Mission	Non-urban, applications developed on DIGIT. 1st rural application; 1st Faecal Sludge Management application designed and developed on DIGIT	~2,300 ULBs
2022	DIGIT is adopted by the government of India as the national platform	DIGIT is made available as a separate instance with ten reference applications	DIGIT achieves path to sustainability

Source: Interview responses; eGov Foundation documents

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THE CASE OF THE DIGIT PLATFORM

supervised by

Veiko Lember (PhD)

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