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Configurational Analysis of Infrastructuring in Digital Identity Platforms

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ABSTRACT

Digital identity platforms provide unique identity to residents. These also facilitate provision of public services in associated domains like banking, digital payments, healthcare, etc. Such horizontal expansion in multiple domains imparts digital infrastructure characteristics to such platforms. This research ascertains combination of attributes driving infrastructuring of digital identity platforms using fuzzy set qualitative comparative analysis (fsQCA) and further substantiated by qualitative contextual knowledge. Several key observations regarding necessity and sufficiency of solutions are made. Although based on Indian digital identity platform Aadhar and other public application program interfaces, this research has global implication since such systems are being implemented in several countries in pursuance of United Nations sustainable development goal (SDG 16.9). This research makes several conceptual, theoretical, public policy and methodological contribution using fsQCA with unique characteristics of organized complexity, configurational approach, and equifinality.

KEYWORDS

Aadhar, Architecture, Digital Infrastructure, fsQCA, Public Digital Platform

INTRODUCTION

Provision of digital identity to residents of a country has got much attention in current public governance discourse (Mir et al., 2020). United Nations 16th Sustainable Development Goals SDG[1] recommended that every country provide its citizens a legal identity for provision of public services by the year 2030 as per United Nation charter for SDG 2016. However, very few countries have fully implemented comprehensive digital identity systems.[2]

In several cases, digital identity has been provided based on digital platforms. Such systems are termed digital identity platforms. Digital platforms have extendible software codebases as the platform core on which eco system partners develop complementary value-added applications for platform users (Tiwana, 2018). In commercial business domains, leading digital platforms are known to expand into adjoining business domains pursuing a revenue maximization strategy (Constantinides, Henfridsson and Parker, 2018) (e.g., Facebook and Google expanding to fields of advertisement,

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digital publishing, marketing, analytics, entertainment, etc.). Due to such horizontal expansion in adjoining domains, these digital platforms have transformed as digital infrastructures of modern society (De Reuver, Sorenson and Basole, 2018). Infrastructures are defined as the "substructure or underlying foundation; the basic installations, which are critical for continuance and growth of a community or corporate e.g., roads, rail, power plants, transportation etc." (Star and Ruhleder,1996). Digital infrastructures, similarly, are computing and network resources that allow multiple stakeholders to orchestrate their services and content and are critical for society or corporations to survive and function (e.g., digital infrastructures in different sectors like health, education, urban transportation, energy supply, government, and digital payments, etc.) (Henfridsson and Bygstad, 2013).

Digital identity is important for society as it augments effectiveness of public governance. Effectiveness of public governance is its ability to ensure that welfare measures undertaken by government reaches intended beneficiaries, and digital identity can facilitate this aim (Melin et al., 2016). Increased effectiveness of public governance is possible using digital identity since it ensures targeted delivery, less leakage, and reduced overhead cost (Mukhopadhyay et al., 2019). Due to such efficiencies, digital identity systems are also used in related domains of direct government welfare transfer, banking, finance, healthcare, education, rural wages disbursal, etc. for better delivery and service provisioning to public. Similar to infrastructural behavior in business oriented digital platforms, such expansion imparts infrastructure nature to digital identity platforms as well. In this research, such phenomena have been termed as infrastructuring of digital identity platforms.

Transformation of digital platforms to infrastructures is an evolutionary process, and certain features and attributes are needed in digital platforms to drive such evolution. However, characteristics and attributes identified for driving infrastructuring in business oriented digital platforms may not directly apply in case of digital identity platforms due to absence of any monetary agency like revenue maximization in a "nonprofit public good" system of digital identity (Ansell and Miura, 2020). Hence, the relevant question then is, what attributes drive digital identity platforms to expand in adjoining service domains and acquire characteristics of digital infrastructure? This is an important question since digital identity platforms are not used merely for provision of digital identity, but also to provide complementary services in core sectors of public governance like banking, financial inclusion, healthcare, etc. Many countries across the globe are establishing digital identity platforms and public digital infrastructures in pursuance of United Nation Sustainable Development Goal, 2030 (Martin, 2021). This is an unexplored area, having global relevance, in otherwise exhaustive digital platform literature. With such background, the research objective to be addressed, in this research, is to examine drivers of infrastructuring in digital identity platforms. Architects and designers of digital identity platforms can build such drivers in platform design for facilitating shared public digital infrastructure used for social governance. Regulatory and governing policies for such Digital Public Infrastructures (DPI) can also be, accordingly, tailored for providing optimal benefit to society. This is one of the most prominent aspects of present research.

LITERATURE REVIEW

The literature review for this research was carried out using keywords 'digital platforms' 'digital infrastructure' and 'digital identity platforms' in leading research databases (ProQuest, EBSCO, and Emerald Insight) from 2010-23. While substantial research literature is available regarding infrastructuring of business oriented digital platforms (Constantinides, Henfridsson and Parker, 2018; De Reuver, Sorenson and Basole, 2018; Plantin et al., 2018), much less research literature exists concerning infrastructuring of digital identity platforms. However, need for conducting such research has been felt in Information System (IS) research community. Leading authors in IS research fields like Constantinides, Henfridsson and Parker, 2018 as well as De Reuver, Sorenson and Basole, 2018 etc. have called for research focuses on infrastructuring phenomena of digital platforms used for different social applications. Helmond et al. (2019) mentioned Facebook transforming from a social media digital platform to a digital infrastructure by migrating into diverse fields of advertisement, marketing, analytics, and publishing. Infrastructuring has been enabled by Open Authorization (OAuth) API based integration between digital platforms (Evans and Basole, 2016). However, there is a dearth of similar research regarding infrastructuring of digital identity platforms in extant research literature.

Research literature on the subject, as per the outcome of the literature review, can be organized around five major themes. The first theme identifies basic differences between digital platforms and digital infrastructures. The second theme is about infrastructuring of digital platforms. The third theme, in which not much research literature exists, is about infrastructuring of digital identity platforms. In order to understand current trends in the subject, latest research literature on the subject for the year 2022-23 appears as a separate (fourth) theme in the literature review. It is also essential that research containing contrarian and opposite perspectives, as regards the research problem, is also considered while framing the research question. Accordingly, the fifth theme of research literature pertains to such literature where authors have expressed contrarian and non-conformist views on the subject. Results from all five themes have been substantiated with primary data subsequently.

Digital Platforms and Digital Infrastructures

The first theme emerging in the literature review is regarding differences between digital platforms and digital infrastructure, as seen in Table 1. Digital platforms differ from digital infrastructures in aspects of sharing, openness, and modes of platform control (Hanseth and Lyytinen, 2010). While digital platforms are shared only amongst a particular user community, digital infrastructures are universally shared across society. There is a partial degree of openness in the case of digital platforms, which is decided by the platform owner. In the case of digital infrastructure, openness is practiced at a very high degree as this is created by joining heterogenous networks through open standards and interfaces. De Reuver et al. (2018) argued that while platforms follow centralized control, which is exercised by the platform owner, the control is distributed and dynamic in case of digital infrastructure. Differences between digital platforms and digital infrastructures, as revealed in the literature review, have been further analyzed from primary data and empirical examples in subsequent paragraphs.

Infrastructuring of Digital Platforms

The second theme that emerges from the literature review is regarding infrastructuring of digital platforms. Several researchers have examined infrastructuring of digital platforms in different industry and social settings. Kazan et al. (2018) studied infrastructuring of digital payment platforms in the United Kingdom and concluded that such infrastructuring aids value creation and value delivery. Andrade et al. (2021) examined Internet of Things (IoT) and the need for a dynamic information infrastructure for

Table 1. Differences between digital platforms and digital infrastructures

Ser No.	Characteristics	Digital Platform	Digital Infrastructure	Reference
1	Sharing of IT capabilities	Shared across platform owner, developer, and user community	Universally shared across society, corporations, or organizations	Star and Ruhelder (1996; Hanseth and Lyytinen (2010))
2	Openness	Openness by design choices and policy decisions of platform owner	More complete openness to interconnect heterogenous systems	Kayworth and Sambamurthy (2000)
3	Evolution	Dictated by architectural choices and market preferences	Unlimited evolution with time	Hanseth and Lyytinen (2010)
4	Control	Centralized control exercised by platform owner	Decentralised and distributed, which is dynamically negotiated	Edwards et al. (2002)

success of IoT integrated devices and systems. Other notable research contributions in such types of research literature include Spagnoletti et al. (2015) for Digital Platforms Supporting Online Communities (DPsOC) in the healthcare sector; Tan et al. (2015) for Multiple Service Platform (MSP) with Alibaba as a case study; and Mukherjee (2019) for Indian 4G telecom for Reliance Jio. These authors concluded that infrastructuring is a natural progression of digital platforms for value creation and value addition.

The infrastructuring of digital platforms has been examined by several authors in the case of social media platforms as well. These include Nieborg and Helmond (2019) for Facebook's level 2 APIs contributing in infrastructuring; Helmond et al. (2019) for Facebook transformation to digital infrastructure due to expansion in digital marketing and publishing; and Gehl and McKelvey (2019) for darknet like Tor, Freenet, Invisible Internet Project (IIP) etc.

Infrastructuring of Digital Identity Platforms and Emergence of Digital Public Infrastructure (DPI)

The literature review reveals that not much research literature is available, which is focused on infrastructuring of digital identity platforms. For infrastructuring to take place, digital identity systems expand in adjoining fields where digital identity is used like banking, healthcare, finance, government benefits disbursal, etc. Masiero and Bailur (2021), in a special issue of a journal on digital identity, emphasized conducting research on such expansion of digital identity in different domains which are related to socio economic development. Recordon and Reed (2006) had earlier argued about the potential of infrastructuring of digital identity systems using Open ID 1.0 framework. Bazarhanova (2020) highlighted that when a digital identity platform is integrated with other systems to extend enterprise capabilities, the platform becomes part of the user-enterprise infrastructure. However, implications of dependencies upon such dominant industry platforms and infrastructures – in the light of the complex, recursive relations between platform and infrastructure definitions – is not yet well understood. Infrastructuring of digital identity platforms has also been expanded to explain recent emergence of Digital Public Infrastructures (DPI) in different countries. DPI are shared infrastructures providing equitable access to everyone in society, enable layered innovation on top of each other, and work in a decentralized manner to fuel economic growth of society (Raghavan et al., 2019). Digital identity along with digital payments and sharing of data between such infrastructures has been held as important pillars of DPI (Singh, 2019). In that sense DPI is seen as public good. Working as a building block, digital identity platforms allow other platforms to build new solutions and innovate on top of their structure. Examples of DPI include digital identity platforms enabling solution in digital payments, healthcare, banking, and finance sectors in India. Such infrastructuring of digital identity platforms gives rise to DPI (Sandhu et al., 2023). This research, by addressing such issues related to DPI, is highly significant in current policy and social governance domains.

Research Literature: Year 2022-23

Recent research literature on the subject shows increased emphasis on two aspects related to infrastructuring of digital platforms. First aspect is increased use of digital platforms as public digital infrastructure that are being used for social welfare and governance; and second, greater emphasis on need for regulations over such infrastructure. These two aspects have been highlighted in several recent research papers. Busch (2022) examined infrastructuring of digital platforms and observed that digital platforms have developed as societal infrastructures providing digital service of general interest (as public good), which is a provision of essential goods and services for the public community. The need of regulation of digital platforms, when these transform as infrastructures, was examined by Hermes, Schreieck and Thatcher (2022). Authors recommended that:

Degree of essentiality of a digital platform and its appropriation of infrastructural properties are two dimensions indicating the magnitude of potential damage that a platform can cause, in case, it abuses its power, thereby indicating an increased need for regulation. (Hermes, Schreieck, and Thatcher, 2022)

Accordingly, the author recommended that current research focus needs to shift from digital platform's market power to platform infrastructure regulation. Infrastructuring of digital platforms was also examined for music streaming digital platforms (Tilson, Lyytinen and Sorenson,2010); messaging platforms (Pierson, 2021); and digital payments platforms as societal infrastructures leading to a cashless society and digital payments (Palmer et al., 2022). Nubel et al. (2021) recommended that a set up comprising of federated digital platforms, which act like social infrastructure, can prevent fragmentation of value chain due to a shared infrastructure vision. Similar results for pharmaceutical industries were observed by Joglekar et al. (2022) where authors stated that alignment in cross platform affects results in social infrastructures, which improves industry value chain proposition. In another important research work on the subject, Hesmondhalgh et al. (2023) examined digital platforms and infrastructures from a new perspective. Authors integrated digital platforms and digital infrastructures research paradigms from popular Science and Technology Studies (STS) and further combined them in a legal and cultural perspective to analyze its impact on media and cultural aspects. Stehlin and Payne (2023) examined infrastructuring of micro mobility platforms in Austin, Texas and concluded that this represents a deepening of the neo liberalization of transport, in which infrastructural properties emerge from private platforms. Thus, researchers see that recent literature on infrastructuring of digital platforms is focused on societal applications of such phenomena and the need for its greater platform regulation (Busch, 2022).

Research Literature With Contrarian View on Digital Infrastructuring

In addition to the above, there exists certain research literature with nuanced but contrarian views on the relevance and significance of digital platform infrastructuring. In this class of research literature, the emphasis is on limitations and restricted impact of digitalized infrastructural transformation. Greenstein (2021), while examining the proliferation of digital infrastructures, observed that transformation of digital systems into digital infrastructures does not make universal and economic contribution to society. Hardaker (2022), while examining infrastructuring of digital platforms in replacing brick and mortar retail chains in Germany, observed that such infrastructuring undermines digitalization by shifting power to platforms itself, thereby defeating the very purpose of infrastructuring. Milskaya and Seeleva (2019) analyzed digital economy in Russia and observed that digital infrastructure, on its own, cannot significantly influence the path of digital economy. In addition, dangers of infrastructuring of digital platforms in vulnerable networks like darknet were highlighted by Spagnoletti et al. (2015).

Thus, a section of research literature on the subject contains a contrarian view on significance and contribution in economic growth accruing due to infrastructuring of digital platforms. However, such research is few and far between. A far more significant section of IS research community has recommended infrastructuring of digital platforms contributing to economic growth and must be included in future research agendas (Constantinides, Henfridsson and Parker, 2018; De Reuver, Sorenson and Basole, 2018). Moreover, research work of authors like Greenstein (2021), which includes a pessimistic outlook of digital infrastructuring, is premised on the absence of network effects in semi developed or rural countryside where digital services have few takers, primarily because of less willingness to pay for such services in low-income groups. Thus, the pessimistic school of scholars does not see value in digital infrastructuring. However, such a premise suffers from a major limitation. Digital platforms used for social purposes like digital identity platforms, on the contrary, have the advantage of greater network effect in rural low-income areas since more platform usage provides more economic gain to rural populations in terms of government welfare transfer and rural banking applications, etc. Hence, the pessimistic outlook regarding infrastructuring of digital identity platforms is misplaced. This has also been validated subsequently by empirical data in qualitative analysis.

Literature Review Themes Validation Using Primary Data

To understand and expand on the nature of infrastructuring of digital identity platforms, it was deemed fit to substantiate the results of five literature review themes with primary data. Accordingly, six semi structured interviews were conducted with senior managers and designers of major non-profit public digital platforms in India. All six societal digital platforms, which are part of India's Digital Public Infrastructure (DPI), are based on digital identity platforms. Elaborate interview protocols were prepared prior to interviews and are given in the Appendix. Details of interviews are summarized in Table 2. Several interview questions pertained to issues that emerged in the literature review.

The most important aspect regarding infrastructuring of digital identity platforms that emerged from interviews is the rise of Digital Public Infrastructures (DPI). Interviewee number 1 (from India's digital identity program UIDAI Aadhar) was of the opinion that digital identity platform features are being made available for digital authentication purposes in almost every field, which, in turn enables other to provides innovative solutions, both in the government sector (social welfare delivery, banking, finance, healthcare, digital payments, etc.) and by private corporations (customer onboarding, digital payment verifications, etc.). Because of this reason, evolution of such systems takes place as digital infrastructure, which is similar to shared physical infrastructures like electricity, water supply road, rail, etc. This is enabled by unbundling core problems as infrastructures, which enable other system innovations on top of it using open standards, open-source code, and standard interfaces. Another aspect regarding the nature of such infrastructuring of digital platforms was revealed by Interviewee numbers 3, 5, and 6. Interviewees suggested that infrastructuring of digital identity platforms represents a confluence of social needs promoted by the government and revenue needs of business. Such convergence is good for the society.

Social ubiquity, omnipresence and the resulting critical nature of such systems after transformation as societal digital infrastructure was also stated by Interviewee numbers 2, 4, and 5. It was implied that such digital platforms, upon infrastructuring, are widely used and are all pervasive, which makes these critical for society. An important aspect of infrastructuring of digital platform is revealed when several interviewees articulated that after infrastructuring of societal digital platforms, a very high number of transactions on such infrastructure are recorded. This was stated by interviewee numbers 2, 4, 5, and 6, who are primarily involved in system operations. This reveals that scalability features of such infrastructures. Another major difference between digital platforms and digital infrastructuring is regarding governance and control of such systems. Interviews substantiate literature review finding of a loose and decentralized control in digital infrastructures as compared to centralized control in digital platforms. This was stated by interviewee numbers 1, 2, 4 and 6. Another revelation in primary data is regarding factors that drive infrastructuring of such platforms. Interviewees reveal that architecture and design of such platforms are tailor-made for infrastructure like expansion and transformation. This

Table 2. Details of interviews

Ser No.	Interviewee	Role	Interview Duration
1	Interviewee 1, Digital identity Platform	System design	90 minutes
2	Interviewee 2, Digital identity Platform	Operations of system	60 minutes
3	Interviewee 3, Digital payment platform	System engineering and design	75 Minutes
4	Interviewee 4, Digital education platform	Technology team,	60 Minutes
5	Interviewee 5, India Stack	India stack storage technology layer	60 Minutes
6	Interviewee 6, Digital health care platform	Healthcare platform design and operations	90 Minutes

was stated by Interviewee numbers 1, 3, 4, 5. As regards the process of digital infrastructuring, it was revealed that one digital platform operating over other platform, results in infrastructure like digital structures. This was stated by interviewee numbers 1, 4 and 5.This is called Platform over Platform or PoP. In another major revelation, interviewee numbers 1, 2, 4 and 6, articulated that considerations applied in business oriented digital platforms infrastructuring cannot be applied to digital identity platforms due to the absence of any profit motive or monetary agency in such platforms. Primary data also revealed several architecture and design attributes in digital platforms that drive infrastructuring of digital platforms and have been considered appropriately in subsequent sections.

RESEARCH GAP AND RESEARCH QUESTION

Literature review and subsequent analysis based on primary data reveal certain research gaps on the subject of infrastructuring of digital identity platforms. One major unanswered question is what drives infrastructuring in non-profit public good societal digital platforms like digital identity platforms in the absence of any business profit agency. One possible answer, as revealed in interviews, is such drivers of infrastructuring are built in architecture and the design of such platforms. Some attributes driving infrastructuring is revealed in primary data; some others are given in theoretical lenses being used; and some of these are mentioned in extant research literature as well. These attributes need to be rigorously examined to answer the pertinent question: what attributes or combination of attributes drive or facilitate infrastructuring of digital identity platforms? Certain attributes of digital identity platforms may aid expansion in adjoining domains, which makes these platforms akin to digital infrastructure. Can researchers also find other attributes that are mentioned in some research literature references but may have not had an essential role in the infrastructuring process? This is identified as a critical research gap in digital platform research literature.

This research gap is very important for understanding the expansion of digital platforms as infrastructures for societal usage. Even when exhaustive research literature exists on business and commercial applications of digital platforms, research on societal applications of such platforms is very sparse. Several authors like De Reuver, Sorenson and Basole. (2018) have recommended IS research to be undertaken in the field of social application of digital platforms. Societal digital platforms are collectively being addressed now as Digital Public Infrastructure (DPI) and have been included as a major milestone to be achieved by United Nation Development Program (UNDP).[3] This will, in turn, help achieve four social development goals – first, building partnerships and alliances between public and private sectors to catalyze collective social action, second, delivering government support in social digital transformation, third, catalyzing population scale technology for society wide benefit delivery, and fourth, shaping local digital eco systems for development purposes. United Nations Sustainable Development Goal (SDG) number 9 articulates the importance of digital infrastructures to promote sustainable development and innovation[4] and mandates countries to achieve such goals by the year 2030. Very few countries in the world have fully functional Digital Public Infrastructures. For example, more than one billion eligible people around the world in different countries do not have even basic legal identity systems. If platform owners and managers know, necessary and sufficient attributes which facilitate infrastructuring of digital identity platforms, then it will aid in transformation of such platforms to shared digital infrastructure. This would provide economic growth and act as public good. It is, therefore, imperative that attributes and features of digital identity systems are identified that promote and drive infrastructuring of such systems to become a Digital Public Infrastructure in the real sense.

Accordingly, the research question addressed is: What configuration of attributes drives the infrastructuring of digital identity platforms?

THEORETICAL LENS

The digital platform's infrastructuring is an evolving phenomenon. In several cases it is not *a priori* planned but evolves as a platform gets integrated more and more with other platforms and systems (e.g., Google Map as a digital platform, which got integrated or embedded with multitude devices and applications with passage of time, and today it has become de facto global cartographic infrastructure). However, every digital platform does not automatically get to acquire infrastructure characteristics. Though many attributes of digital infrastructure are mentioned in literature, only certain attributes or combinations of attributes of digital platforms may drive infrastructuring.

To ascertain attributes that drive digital platforms as infrastructure, there is a need to base this research on theoretical foundations that best explain behaviors of such infrastructures. Digital infrastructures have been studied based on two major streams of infrastructure studies. The first one is the complexity paradigm and the second one is the network-relational paradigm (Alderman and Goodwin, 2022; Henfridsson and Bygstad, 2013). In the complexity paradigm (Holland, 1995), digital infrastructures result from the integration of the multitude of heterogeneous and autonomous units having nonlinear mutual interdependencies and use information technology to order themselves into a coherent system (Braa et al., 2007; Hanseth et al., 2006). The first theoretical lens used, for this stream of infrastructural studies is, hence, complexity theory (Holland, 1995). According to complexity theory, as applied in information systems, order emerges through the interactions of organisms or agents. 'Agent' is a general term used to designate semi-autonomous entities (i.e., parts of systems), such entities as technologies, processes, people, groups, firms, industries, etc. (Ferber and Weiss, 1999). This gives rise to the assemblage of heterogeneous elements in forming digital infrastructure.

In the complexity paradigm, the second theory used in this research is the theory of the Large Technical System (Hughes, 1983). As per this theory, infrastructures are like Large Technical Systems (LTS). Digital infrastructure as LTS refers to systems that are materially integrated, or "coupled", over large spans of space and time through gateways and standards (e.g., ethernet integrating incompatible networks) as an internetwork of semi-independent heterogeneous systems (e.g., internet, which is integrated by the TCP/IP standard). It is also argued by authors that the study of infrastructures requires an examination of entire systems rather than focusing on individual artifacts (e.g., research on electric infrastructure should examine the complete electrification process rather than individual artifacts like dynamos or light bulbs) (Der Vleuten, 2006).

This underlying principle of examining the whole system, as recommended by the theory of LTS, implies that the infrastructuring process in a complex system like digital platforms cannot be understood by focusing on a single attribute in isolation but through a combination of attributes. This is the reason why a configurational set theory-based approach is followed in this research. In the configurational approach, there are multiple combinations acting through multiple causal paths, which results in a particular outcome to occur. Investigations of digital infrastructure should seek to analyze how different mechanisms are configured and triggered to produce successful outcomes (Henfridsson and Bygstad, 2013). This approach is accepted as a rational research approach to examining causal complexity (George and Bennett, 2005).

The second stream of infrastructural studies is based on the network-relational paradigm (Alderman and Goodwin, 2022; Henfridsson and Bygstad, 2013). In this paradigm, digital infrastructures are more than their physical dimensions; rather they are a group of relations (often networked) between actors (i.e., social or institutional and mediators like policies, mechanisms, conducts, resources, or discourses) (Henfridsson and Bygstad, 2013; Tilson, Lyytinen, Sorenson,2010). First theory in this paradigm is actor network theory (Callon, 1986), which defines infrastructures getting created by processes in which multiple human actors translate and inscribe their interests into a technology and create a relational network.

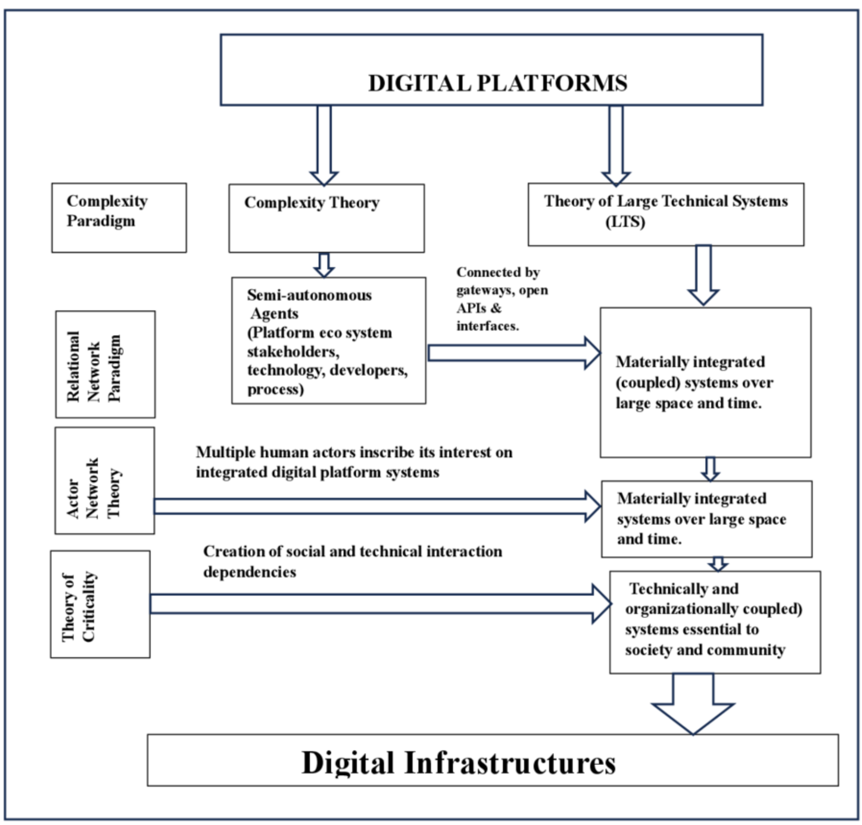
Second theoretical lens applied in network-relational paradigm is theory of infrastructure criticality propounded by Bowker and Star (1999). This approach emphasizes interacting dependencies that are created due to infrastructuring of any system in a society. Such criticality engenders social chaos and breakdown once infrastructures fail. Infrastructuring of digital platforms, as examined from this perspective, emphasizes the potential of social dependencies created once platforms transform as infrastructures.

Integrated Theoretical Framework

This research contributes to the existing theoretical foundation of digital platforms by broadening its application in the field of public digital infrastructures. This has been described as a contribution of "concept travelling in theoretical domain" (Van de Ven, 1989). The integrated theoretical framework, combining two research paradigms (complexity and relational network) and four associated theoretical lenses (complexity theory, theory of LTS, actor network theory, and theory of infrastructure criticality), which have been described above, is shown in Figure 1.

The theoretical framework figure depicts the complexity paradigm and its two theories in horizontal orientation. Relational network paradigm and its two theories are shown in vertical orientation. Digital platform has been shown at the top and digital infrastructure after transformation is shown at the bottom of model. First, we use the complexity paradigm in designing the theoretical framework, which is shown in the theoretical model in horizontal orientation. Applying associated complexity lenses (Holland, 1995) digital platforms get identified as collective of semi-autonomous agents (platform eco system stakeholders, technology, developers, processes, etc.). This is valid since digital platforms have been described as complex systems (Abbot, 2007). Then, second lenses

Figure 1. Integrated theoretical framework



under the complexity paradigm (i.e., theory of LTS (Hughes, 1983)) is applied. At this stage, digital platforms 'agents', shown as the output of application of complexity theory, get transformed as materially integrated systems over large space and time. Now, we employ the relational network paradigm, shown in vertical orientation in integrated theoretical framework, as seen in Figure 1. Using associated actor network theory (Callon, 1986), multiple social and human entities inscribe its imprint on materially integrated systems obtained earlier while applying the complexity paradigm. As a result, these integrated systems get transformed as technological and organizational loosely coupled systems. Now, applying the second theory of relational network paradigms (i.e., theory of infrastructure criticality) (Bowker and Star, 1999) due to which organizationally and technologically coupled systems of previous stage, acquire critical connotations. This is because disruption of digital infrastructures will result in chaos and turmoil in society (Edwards, 2002). This integrated theoretical framework is used to select candidate attributes of digital platforms, which enables infrastructuring of such platforms. These attributes, once tested for its contribution to infrastructuring, will also enable validation of this theoretical framework.

SELECTION OF CANDIDATE ATTRIBUTES BASED ON PRIMARY DATA, THEORETICAL LENS, AND LITERATURE REVIEW

As the research question shows, this research seeks to find attributes that drive the infrastructuring of digital identity platforms. In this research, features that may contribute to infrastructuring of digital identity platforms are named candidate attributes. Candidate attributes have been selected by comparing the outcome from three different sources – primary data, theoretical lens used, and extant research literature analyzed in the literature review. Apart from the preceding literature review and theoretical lenses used in this research, data from six semi structured interviews with senior managers/designers of digital public infrastructures have been used, the details of which have been shown earlier in Table 2.

The selection of candidate attributes has been done by a three-stage process. In the first stage, all candidate attributes emerging from primary data are listed, as shown in Table 3. In the second stage, those candidate attributes are selected from Table 3, which correspond to research paradigms and theoretical lenses used in this research (complexity or network-relational paradigm of infrastructural analysis). The research paradigm and theoretical lens used for each of the 15-candidate attributes, emerging from primary data in stage 1, are also shown in Table 3. Those attributes not corresponding to complexity or the relational-network paradigm are discarded at this stage. In the third stage, for each selected candidate attribute from the second stage, a reference research literature is found out, where this attribute has been described as contributing to infrastructuring of digital platforms. Those attributes of digital platforms finalized after the second stage but not referred to specifically in extant research literature are discarded. After these three stages, a final list of candidate attribute emerges, which are further analyzed in subsequent stages of this research.

In the first stage, 15 attributes were compiled from primary data (interviews), which contribute to infrastructuring of digital identity platforms. These 15 attributes along with its interviewee number, definitions, research paradigm and literature reference are listed in Table 3.

The first digital platform attribute considered to be driving infrastructuring, in stage 1 selection (primary data), is heterogeneity (Interviewee numbers 1, 3, 4, 6). Further in stage 2 selection of this attribute, heterogeneity is again deemed as a candidate attribute since it is based on the complexity paradigm of infrastructural research (Holland, 1995). Subsequently, in the stage 3 selection of this attribute, it is found that heterogeneity has been referred to in extant research literature as a factor in digital platform infrastructuring. Heterogeneity is defined as an attribute that emerges due to the integration of multiple actors, organizations, and technologies associated with digital systems and has been described as a digital platform feature leading to infrastructuring of digital platforms (Yoo et al., 2010). Thus, heterogeneity is a suitable candidate attribute for subsequent analysis.

Based on primary data (stage 1), essentiality (Interviewee numbers 4 and 5) is the second platform attribute for platform infrastructuring. Essentiality is defined as a perception of someone that no viable alternative exists to achieve a specific objective (Hermes, Schreieck and Thatcher., 2022). Although essentiality attribute is based on complexity theory (stage 2), there is no significant research literature indicating it to be a factor for digital infrastructuring (stage 3). Hence, essentiality is discarded as a candidate attribute based on stage 3 considerations.

Distributed control (Interviewee number 1, 2, 3, 5, 6) is the third attribute emerging from primary data (stage 1) related to digital infrastructure. It is defined as a control mode in a digital system, which is not centrally organized and is dynamically negotiated. In stage 2 consideration of candidate attributes, platform control is a characteristic that belongs to a socio-technical paradigm (Kapoor et al., 2021). Hence, distributed control is not considered as a candidate attribute for digital platform infrastructuring since this research is based on complexity and the relational-network infrastructure research paradigm and not the socio-technical paradigm.

Openness (Interviewee number 1, 2, 3, 6) is the fourth attribute emerging from primary data (stage 1), which may contribute to infrastructuring of digital platforms. Openness is, mostly, about the use of open standards and interfaces (Tiwana, 2015). It belongs to the complexity paradigm of infrastructural research (stage 2) and hence has been considered as a factor contributing to infrastructuring of platforms (Holland, 1995). Openness has been referred to as a source for infrastructuring in several research literatures (stage 3). Openness is important for application developers to create mash ups and platform over platform design using Open APIs, which may lead to the creation of digital infrastructures from platforms (Evans and Basole, 2016). It has also been argued that openness is essential for infrastructures for achieving reliability (Joode and Bruijne, 2006). Hence, openness is considered a candidate attribute for further research.

Similarly, generativity (Interviewee number 1, 2, 4, 6) is the fifth platform attribute based on primary data (stage 1). It belongs to the complexity paradigm of infrastructural research (stage 2) and has been considered contributing to the infrastructuring of platforms (Holland, 1995). Coming to the stage 3 selection, generativity is defined as a system's capacity to produce unanticipated change through unfiltered contributions from broad and varied sources (Zittrain, 2006). The generativity attribute in digital platforms enables innovation (Yoo et al., 2010). Since generativity is referred to in several research literatures as associated with infrastructuring, it is a candidate attribute for further research.

Embeddedness (Interviewee number 2, 5) is the sixth attribute in primary data for consideration (stage 1). It is described as the entanglement of one technology with another apparently unrelated technology and as such belongs to assemblage paradigm (stage 2). Hence, this is not considered as candidate attribute.

Based on primary data, scalability (Interviewee number 1, 3, 5, 6) is the seventh attribute being considered (stage 1). In stage 2 considerations, scalability is another candidate attribute and is directly related to Theory of LTS (Hughes, 1983). The scalability attribute is a critical agent of infrastructuring in digital platforms. Scalability is defined as an ability of a system to expand without much modification in algorithm and perform without any degradation when working at higher traffic volume (Bondi, 2000). Mukhopadhyay et al. (2019) also held the scalability attribute as the most important attribute of digital identity platforms. Since scalability is referred to in several research literatures as associated with infrastructuring (stage 3), it is considered as a candidate attribute.

Based on primary data, the evolving nature of platform (Interviewee number 3, 6) is the eighth attribute being considered (stage 1). It is described as a gradual process by which a digitally enabled infrastructure changes into a more composite form. It entails both social and technical elements and thus belongs to the socio-technical paradigm of infrastructural studies (stage 2). Hence, this is discarded as a candidate attribute at stage 2.

Modularity (Interviewee number 1, 2, 4, 5) is the ninth platform attribute being considered (stage 1). Modularity is based on the complexity paradigm of infrastructural research and can be said to be based on theory of LTS (stage 2). Modularity as mediating attribute in digital infrastructures has been observed by several authors like Baldwin and Woodard (2009); Henningsson and Eaton (2016); Tiwana (2015), etc. (stage 3). Modularity is defined as a design feature that enables changes and development in a sub system without creating a ripple effect in other sub systems. Modularity enables module in one eco system to act as platform for other system. This may lead to infrastructures composed of multiple such digital platforms. Hence, modularity is considered as a candidate attribute.

Ubiquity (Interviewee number 1, 2, 3, 4, 5) and criticality (Interviewee number 1, 2, 3, 4, 5, 6) are the tenth and eleventh platform attribute emerging in primary data (stage 1). Ubiquity and criticality are based on actor network theory (relational network paradigm) and theory of infrastructure criticality respectively (stage 2). The criticality attribute makes a system akin to physical infrastructures like rails, road, power supply, and water supply networks whose disruption will create chaos and trouble for society. Similarly, the attribute of ubiquity is based on the all-pervasive presence of certain digital systems in society or corporates. Such systems are called ubiquitous systems. Since criticality and ubiquity are referred to in several research literatures as associated with infrastructuring, both are considered as candidate attributes (Helmond et al., 2019; Star and Ruhelder, 1996).

Adaptability (Interviewee number 5) is the 12th attribute being considered (stage 1). It is defined as the capability of a technology's use without change and the readiness with which it might be modified to broaden its range of uses (Monterio, Pollock and Williams, 2014). Although this attribute is based on the complexity paradigm (stage 2), it is somewhat similar to the generativity attribute and is not considered as candidate attribute.

Efficiency (Interviewee number 2, 4, 5); responsiveness (Interviewee number 1, 5) and pricing (Interviewee number 6) are the last three attributes emerging in primary data (stage 1). Since these are based on strategic choice paradigm of infrastructural research (Henfridsson & Bygstad, 2013), these attributes are discarded as candidate attributes at stage 2.

Hence, after considering all 15 digital platform attributes emerging from primary data (stage 1) and subsequent elimination processes based on research paradigm of interest (stage 2) and recommendations available in extant research literature (stage 3), seven digital platform attributes have been shortlisted for further analysis for its contribution in driving infrastructuring of digital identity platforms. These seven attributes have been summarized as per the corresponding research paradigm and theoretical lens with definition and reference in Table 4.

Each of these seven candidate attributes makes significant contribution in infrastructuring of digital identity platforms and complement each other in varying degrees. Heterogeneity features represent the capability of digital platforms to connect with diverse digital systems, sometimes though gateways, and form an eco-system that may take shape as digital infrastructures (Hanseth and Lyytinen, 2010). In a business oriented digital platform context, it is a heterogeneity attribute that makes Android, to work as operating system, for physically different devices like mobile cell phone, home computers, television, etc. while still retaining its core design. This is just as water, steam, and ice, which are three examples of a natural heterogeneous design where while physical characteristics are manifestly different, the core chemical composition may not change much. Heterogeneity in turn is made possible by the openness attribute. Openness may be exercised in form of use of open nonproprietary standards, open-source software, and open standards. This ensures interoperability between different digital platforms that integrate to form digital infrastructures (Evans and Basole, 2016). This is again exemplified by an almost 70.89% market share of Android, which follows open standards compared to 28% of Apple IOS, which has closed and privately owned standard systems.[5] Similarly, generativity attributes represent capability to execute unanticipated innovations in response to demands of integrating and provide new solutions when digital platforms turn into digital infrastructure (Thomas et al., 2014). Next, the scalability attribute represents capability of digital platforms to provide services as digital infrastructure to a much higher user base without degradation of service. One good empirical example of generativity and scalability is India's digital identity platforms Unique Authority of India (UIDAI) Aadhar. When Aadhar was launched in year

Table 3. Candidate attributes emerging from primary data, associated research paradigm/theoretical lens and literature reference

Ser No.	Digital platform attribute	Interviewee	Definition	Research Paradigm/ Theoretical lens	Reference
1	Heterogeneity	Interviewee number 1,3,4,6	Use of diverse technology, operators, user and design communities, standards, and regulators – joined through gateway	Complexity paradigm/ complexity theory	Holland (1995); Hanseth and Lyytinen (2010)
2	Essentiality	Interviewee number 4,5	A perception of someone that no viable alternative exists to the resource of interest to reach a specific objective.	Complexity paradigm (identical to criticality)	Hermes, Schreieck, and Thatcher (2022)
3	Distributed control	Interviewee No 1,2,3,5,6	Control over infrastructure is distributed and dynamically negotiated.	Sociotechnical paradigm	Hanseth and Lyytinen (2010)
4	Openness	Interviewee number 1,2,3,6	Open standards, protocols and interfaces which enables joining of new modules through non-proprietary interfaces. decoupling between subsystems, standard interfaces, open boundary resources	Complexity paradigm/ theory of large technical system	Hughes (1983); Hanseth and Lyytinen (2010)
5	Generativity	Interviewee number 1,2,4,6	Ability to produce new product / services which are unanticipated	Complexity paradigm/ theory of large technical system	Zittrain (2006)
6	Embeddedness	Interviewee Number 2,5	Entanglement of one technology with another apparently unrelated technology	Assemblage paradigm	Furstenau et al (2019)
7	Scalability	Interviewee number 1,3,5,6	Ability to provide service to much higher user bases without any degradation in quality	Complexity paradigm/ theory of large technical system	Walsham and Sahay (2006)
8	Evolving	Interviewee Number 3,6	A gradual process by which a digitally enabled infrastructure changes into a more complex form. It entails both social and technical elements	Socio technical paradigm	Henfridsson and Bygstad (2013)
9	Modularity	Interviewee number 1,2,4,5	Loose coupling between components and change in one component can be done without affecting others; Decomposed core and changes in one part do not affect other parts of platform core.	Complexity paradigm/ theory of large technical system	Baldwin and Woodard (2009)
10	Ubiquity	Interviewee number 1,2,3,4,5	Embeddedness in other markets and industries to the extent that it is widely available, shared and is indispensable.	Actor – network theory	Helmond, Nieborg and Der Vlist (2019)

continued on following page

Table 3. Continued

Ser No.	Digital platform attribute	Interviewee	Definition	Research Paradigm/ Theoretical lens	Reference
11	Criticality	Interviewee number 1,2,3,4,5,6	A digital substrate or foundation on which continuance or growth of organisation or community depends. Any disturbance or breakdown will have disruptive effect on organisation or society just like physical infrastructure like roads and electricity	Theory of Infrastructure criticality	Star and Ruhelder (1996)
12	Adaptability	Interviewee Number 5	Refers to the breath of a technology's use without change and the readiness with which it might be modified to broaden its range of uses	Complexity paradigm generativity attribute used in lieu	Monterio, Pollock and Hanseth (2013)
13	Efficiency	Interviewee Number 2,4,5	Delivering service at lowest life cycle cost and highest output to society	Strategic choice paradigm	Beckert (1999); Fox (1994)
14	Responsiveness	Interviewee Number 1,5	Infrastructure services designed to meet user demand and address needs of society	Strategic choice	Beckert (1999); Fox (1994)
15	Pricing	Interviewee Number 6	Suitable pricing for infrastructure services at marginal cost	Strategic choice	Beckert (1999); Fox (1994)

2010, it was not planned to integrate it with hundreds of other social sector services like government welfare disbursal, finance, banking, healthcare, etc. But due to in-built attributes of generativity and scalability, Aadhar is being used to provide billions of transactions per month in banking for unbanked (500 million Jan Dhan Accounts[6]), Direct Benefit Transfer (DBT) to poor citizens, digital payments, universal healthcare, etc. Thus, it can be said that using open standards and generative capability makes digital identity platforms integrate with heterogeneous systems to provide services at a much higher scale. This makes such digital infrastructures critical and ubiquitous for society. These are critical for society as any disruption in such systems will have adverse impacts just like the disruption in physical infrastructure like water supply or power grid will have on society. Thus, these seven candidate attributes have mutual interaction and dependencies. Impact of these attributes have been qualitatively analyzed later on in research papers with corresponding datasets to estimate impact of such attributes on infrastructuring of digital platforms.

Research Model

As discussed above, seven candidate attributes have mutual interaction and nonlinear interdependencies. As digital identity platforms transition towards infrastructuring, these attributes affect each other due to such mutual interactions and dependencies. Hence, the authors seek in this research combinations of attributes driving infrastructuring of digital identity platforms. Moreover, as per the theory of LTS, the configurational perspective is needed to examine digital identity platforms. The research model in Figure 2 depicts such infrastructure enabling seven candidate attributes working in a combination and driving digital identity platforms to transform as digital infrastructures. The research diagram also depicts mutual interdependencies and interaction in functionalities between candidate attributes. Based on the research model, the propositions to be examined are as follows: infrastructuring of

Table 4. Final list of candidate attributes with associated theoretical lens and literature

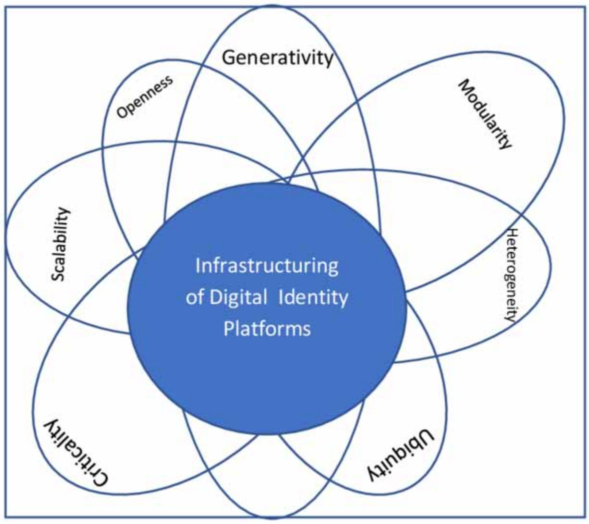
Infrastructural Studies Research Stream	Foundational Theory	Reference Literature	Digital Platform Attribute enabling infrastructuring	Definition	Reference Literature
Complexity	Complexity theory Infrastructures result from integration of multitude of heterogenous and autonomous units having nonlinear mutual interdependencies. Digital Infrastructures may use information technology to order itself into a coherent system.	Holland (1995) Braa *et.al.*, 2007	Heterogeneity	Use of diverse technology, operators, user and design communities, standards, and regulators – joined through gateway	Hanseth and Lyytinen (2010)
	Theory of Large Technical Systems (LTS) LTS refers to systems which are materially integrated, or "coupled" over large spans of space and time through gateways and standards (e.g ethernet integrating incompatible networks) as internetwork of semi-independent heterogenous systems (e.g Internet which is integrated by TCP/IP standard	Hughes (1983)	Openness	Open standards, protocols and interfaces which enables joining of new modules through non-proprietary interfaces. decoupling between subsystems, standard interfaces, open boundary resources.	Hanseth and Lyytinen (2010)
			Generativity	Ability to produce new product / services which are unanticipated	Zittrain (2006)
			Scalability	Ability to provide service to much higher user bases without any degradation in quality	Welsham and Sahay (2006)
			Modularity	Loose coupling between components and change in one component can be done without affecting others;	Baldwin and Woodard (2009)
Network relational	Actor – Network Theory The process by which multiple human actors translate and inscribe their interests into a technology, creating a relational network	Callon, 1986	Ubiquity	Embeddedness in other markets and industries to the extent that it is widely available, shared and is indispensable.	Helmond, Nieborg and Der Vlist (2019)
	Theory of Infrastructure Criticality Digital infrastructures evolve as meaningful and essential aspect of social structures	Bowker and Star (1999)	Criticality	A digital substrate or foundation on which continuance or growth of organisation or community depends. Any disturbance or breakdown will have disruptive effect on organisation or society just like physical infrastructure like roads and electricity	Star and Ruhelder (1996)

digital identity platform is driven by configuration of some or all attributes of modularity, openness, generativity, heterogeneity, scalability, ubiquity, and criticality.

RESEARCH METHODOLOGY

As per the Theory of Large Technical Systems (LTS), which is used as an underpinning theoretical lens in this research, the preferred method to examine the phenomenon of infrastructuring in systems like digital identity platform should be based on a configurational approach where a combination of platform attributes causes infrastructuring phenomenon, instead of focusing on individual attributes in isolation (Hughes, 1983). The preferred research method for such combinational configurations

Figure 2. Research model



analysis is fuzzy-set Qualitative Comparative Analysis (fsQCA), which has been employed to examine the research question. It is a set theory based configurational approach employed to analyze the outcome of interest caused by a combination of variables. QCA is a research approach that draws the best features of both qualitative and quantitative methods (Ordanini et al., 2014). fsQCA was developed by combining fuzzy set logic (Zadeh, 1978) with Qualitative Comparative Analysis (QCA).

The basic tenets of QCA are: organized complexity (enables finding out unpredictable, nonlinear, non-additive, and non-probabilistic conception by rejecting any permanent causation in a moderate number of variables); configurational approach (a set of configuration of variables impacting the outcome instead of analyzing individual causal elements); conjunctural logic (conjunctural logic indicates that any outcome may be possible for a combination in future, which may not be related to solutions achieved in the past); equifinality (one or more than one combination of causal factors or antecedents may be equally effective in predicting outcomes, one particular combination can be adopted to achieve the desired outcome that may be necessary or a sufficient condition), causal asymmetry (combination of causal factors leading to an outcome of interest may need not be the same set of antecedents where desired outcome is missing). Simultaneously, fuzzy arithmetic has been used, which provides values between 0 (exclusion from set) and 1 (full membership of set) and 0.5 being the cross over point. fsQCA enables researchers to find out which combination of conditions are more important compared to others. Configurational solutions with strong causality are core solutions, and others are peripheral solutions having less causality.

Reasons of Suitability of fsQCA Over Conventional Quantitative Methods

There are several reasons for adopting fsQCA over conventional quantitative analysis methods. First, digital platforms, which are complex systems (Abbot, 2007), possess attributes having mutually non-linear and unpredictable interdependence in which conventional quantitative analysis tools based on the Gauss Markov criterion of linear relationship cannot be applied. Second, the infrastructuring of digital platforms cannot be analyzed by focusing on individual drivers but by the configurational approach in organized complexity perspective (Park and Mithas, 2020) as well as on the basis of theory of Large Technical Systems (Hughes, 1983). Unlike conventional quantitative methods, which are largely variance-based null hypothesis testing methods, QCA follows a set theory approach and predicts a combination of variables, which results in outcome of interest. Complex systems can be better analyzed using a set theory based configurational analysis. Third, fsQCA provides both necessary or sufficient conditions and counterfactual analysis for desired outcomes to occur (Schneider and Wagemann, 2010). Fourth, quantitative analysis is based on stringent assumptions of exogeneity, randomness in sampling, perfect noncollinearity, zero conditional mean, and homoskedasticity, all of which may not be supported in this research case. The basic advantage of fsQCA lies in the fact that it does not use such stringent assumptions and hence, in social science research, is a better tool for analysis (Ragin, 1987). Fifth, fsQCA is most suited for a moderate number of independent variables. Greckhamer et al. (2018) postulated that fsQCA is an effective tool for analysis for both small N (<50) and large N (>50). Similar recommendations are made by Pappas and Woodside (2021). This research has a large N database (N= 51). Lastly, regression analysis does not fit well with asymmetric cause-effect analysis. Infrastructuring is an asymmetric phenomenon. fsQCA permits asymmetric consistency in solution, where both the presence and absence of any variable is examined with the same level of consistency.

CASES USED IN THIS RESEARCH

UIDAI Aadhar and Application Program Interfaces (APIs)

In India, the Unique Identification Authority of India (UIDAI Aadhar) is a national digital Identity platform.[7] UIDAI Aadhar has provided a unique 12-digit identity number to the approximately 1.39 billion residents of India using a set of demographic and biometric data of residents. Primarily three Application Program Interface (API), one each for authentication, e KYC (Know your customer), and enrolment of resident Indians have been provided. Each of the functionality are all encapsulated as an independent but loosely coupled microservice.

In this research, these three APIs of UIDAI Aadhar (enrolment, authentication, and Know Your Customer e KYC) have been taken as three different cases for analysis. Yin (2013) stated that APIs represent an instance of extreme case in the digital platform eco system. Ghazawneh and Henfridsson (2010) used the same research approach by using four API of Apple as different cases to study boundary resources of digital platform. UIDAI Aadhar architecture has been shown in Figure 5 in the Appendix.

The UIDAI Aadhar infrastructuring phenomenon has been examined in several research papers in recent past. Mir et al. (2020) examined UIDAI Aadhar from Design Theory (DT) and Critical Success Factor (CSF) lenses and concluded that uniqueness, security, and privacy are important design goals of Aadhar, which aids in infrastructuring. Mukhopadhyay et al. (2019) examined UIDAI Aadhar in provision of government welfare delivery and concluded that scalability is a key attribute of such platforms enabling such activities. Pati et al. (2015) conducted analysis of UIDAI Aadhar from the project management perspective and observed infrastructuring of this platform in view of its usage in government subsidy disbursal and rural wages payment. In an ethnographic study of UIDAI Aadhar, Singh (2019) outlined infrastructure and innovation potential of this platform due to its integration with a large number of external applications. Thus, it is seen that infrastructuring of UIDAI Aadhar is ascribed to different platform attributes by researchers. This research examines such infrastructuring from a configurational perspective.

India Stack, Unified Payment Interface Layer, and Application Program Interfaces (APIs)

India Stack is a multi-layer stack of digital services built over digital identity platform UIDAI Aadhar.[8] It is a set of cloud-based APIs that provides value added functionality like presence-less authentication, electronic Know Your Customer (e KYC), digital locker[9] (used for storing and granting access for individual documents), digital signatures, cashless payment using Unified Payment Interface (UPI)[10], healthcare layer, e commerce, and a consent layer for residents. India Stack is based on UIDAI Aadhar, the digital identity platform of India, for its operations. Basically, India Stack set of APIs, are built on top of digital identity platform UIDAI Aadhar database, and all services are extended, as a service, based on the Aadhar database. Hence, India Stack is an appropriate case to examine infrastructuring of digital identity platforms.

Raghvan et al. (2019) examined India Stack and observed that due to its extensive deployment for social welfare, India Stack layers are transformed as digital infrastructure. Similarly, Kuzev and Hall (2023), in a policy research paper, observed that India Stack along with several similar systems in Brazil and the European Union, enable affordable, accessible, and inclusive Digital Public Infrastructure (DPI). Agarwal and Vitthal (2022) also examined India Stack APIs and concluded that by building technologies and making them accessible to general masses at no extra cost, India Stack is a true public good infrastructure, democratizing access to public services in a large and fragmented society. Authors observe that this is the reason India Stack is being replicated in many different countries. Thus, India Stack transformation as Digital Public Infrastructures has been noticed by the IS research community. In this research API of several layers of India Stack and associated digital products at different layers, Unified Payment Interface (UPI), healthcare, Open Network for Digital Commerce (ONDC), Digital locker, m passport, etc. have been examined. A total of 44 APIs of India Stack has been employed as a case study. India Stack functional design has been shown in Figure 6 in the Appendix.

Sunbird and Application Program Interfaces (APIs)

Sunbird is an education sector multipurpose societal digital platform providing digital tools for learning and education solutions like content service, collaboration service, registration service, credentialing service, language service, measurement service, and telemetry service.[11] Prominent learning platforms using Sunbird Include-Government of India teacher training and learning platform DIKSHA[12] (Digital Infrastructure for Knowledge Sharing) and Infosys Ltd learning platform WingSpan Lex.[13] Sunbird works based on UIDAI Aadhaar database and draws most of its functions on the basis of digital identity platforms. Thus, it is an appropriate case for study of infrastructuring of digital identity systems. Taskeen et al. (2021) examined the building block approach based digital platforms and observed that Sunbird being such a platform used in the education sector can be molded for usage in different countries to meet different requirements. Authors observed that such societal platforms are used in India and several other countries in sub-Saharan Africa. The Sunbird platform was also examined by Choudhary et al. (2021), and the authors observed potential for infrastructural deployment of such platforms for public education. Hence, it is seen that Sunbird has potential of significant transformation as digital infrastructure for societal usage and accordingly is being used across several countries.

A total of four (4) APIs of Sunbird has been used in this research. Sunbird functional design has been shown in Figure 7 in the Appendix. The complete list of platforms/APIs, along with references, has been shown in Table 8 in the Appendix.

Data Sources

In this research, both primary and secondary data sources have been used. Primary data source includes six semi structured interviews conducted with different stakeholders from UIDAI Aadhar, India Stack, Sunbird, and other India Stack layers. Interviewees were carefully selected to include managers, platform designers, platform architects, and business managers. API design and specification made available by UIDAI Aadhar, India Stack, and Sunbird, for the developer community, were studied in detail for the application of fsQCA. API application documents of private entities and users of such interfaces were also examined. The interview protocol, used as primary data, is shown in the Appendix. The details of six semi structured interviews, details of which appear in Table 2.

In addition, secondary data like publicly available blogs, corporate whitepapers, and other open-source nonproprietary data sources like YouTube interview videos, blogs, corporate web sites, corporate whitepapers, and hackathon data programmable web and Wayback Machine etc. Data sources used are summarized in Table 9 in the Appendix. Both primary and secondary data were used for two purposes – first, to select candidate attributes and second to create database for application of fsQCA.

RESULTS

At this stage, when the research question, theoretical framework, research methodology, data sources, and database are established, the fsQCA process is applied on the database to obtain configurations of attributes driving infrastructuring of digital identity platforms. The research process, based on fsQCA, is shown as a flowchart in Figure 3. After selection of candidate attributes driving infrastructuring (Table 4), data preparation is done (on candidate attributes against each of platform/APIs) for the application of fsQCA. Thereafter, the resulting dataset is tested for reliability/validity. Finally, fsQCA software[14] is applied on the dataset to obtain different solutions for infrastructuring of digital identity platforms.

Data Preparation

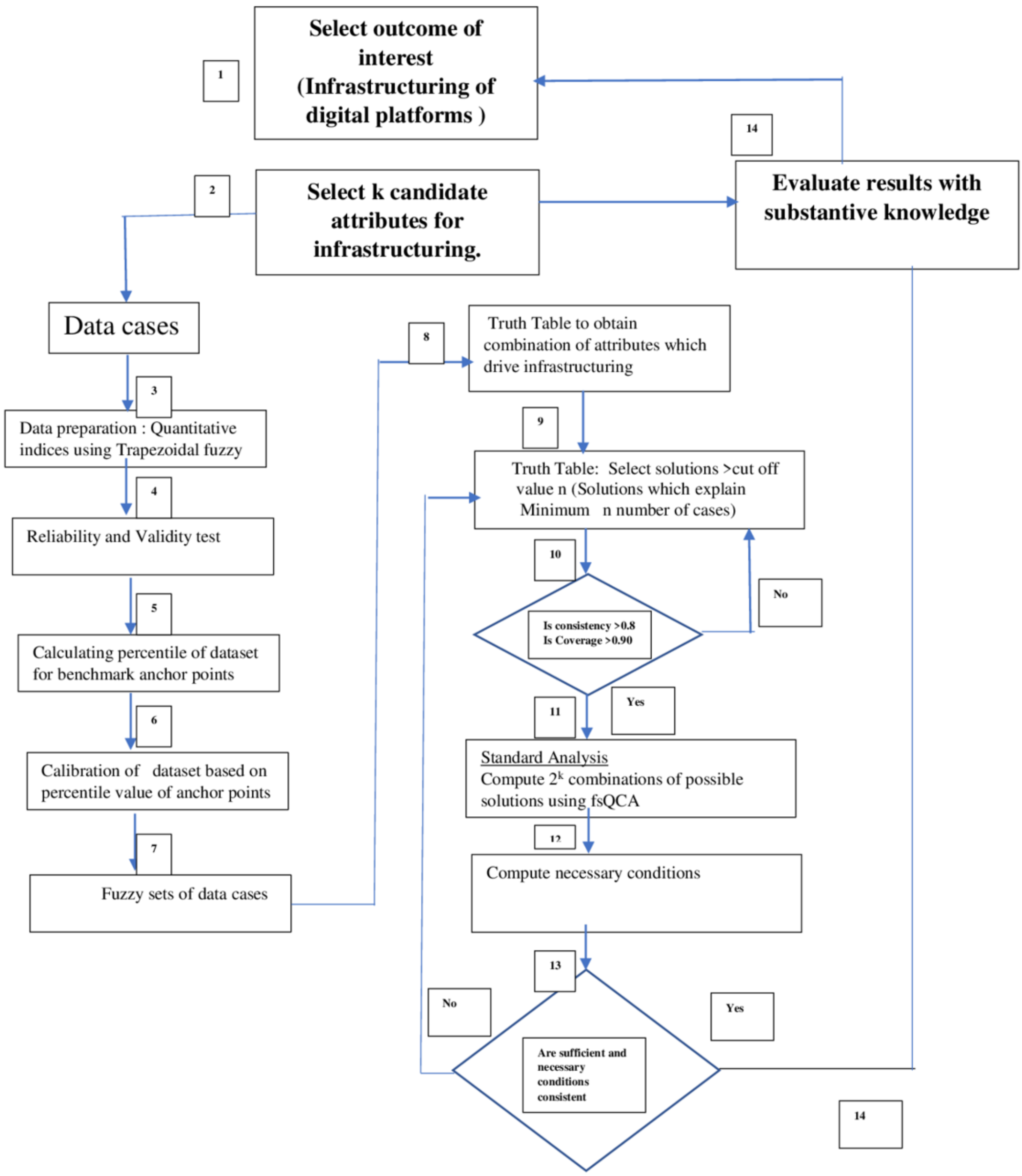
For configurational examination to determine combination of attributes driving infrastructuring of digital identity platforms (using fsQCA), there is a need to provide a single numerical input for candidate attributes in respect of all platforms/API in dataset. This is the step of data preparation (step 3 in flowchart shown in Figure 3). Data preparation has been done in three stages to obtain single numerical input for application of fsQCA; 51 platforms/APIs is collected from platform/API design document available of each platforms/APIs (Table 8). Detail platform/API specifications have been provided by UIDAI, India Stack layers, and Sunbird as well by as by the number of user organizations that use such APIs. The list of references is also provided in Table 8 in the Appendix. In the second stage of data preparation, relevant text of Platform/API design and specification text is qualitatively categorized in 4 classes: Very high, High, Medium, and Low, based on specific classification criterion of Trapezoidal fuzzy arithmetic method (Sriramdas, Chaturvedi and Gargama, 2014). This classification is done for each of the seven candidate attributes for all 51 APIs in database. The details of domain experts used for such coding appear Table 10 in the Appendix. Individual coders are assigned weights corresponding to their experience in respective domains as well as their past coding experience. Authors were present with domain experts during the classification process. This way, instead of simple weightage, experience and expertise of coders is incorporated in data preparation. In the third stage of data preparation, qualitative data has been converted to numerical indices in a form suitable for input to fsQCA using Trapezoidal Fuzzy Arithmetic method (Sriramdas, Chaturvedi and Gragama, 2014).

Let coding of design data for each of 51 digital platforms, which is done by four different coders, in 4 different categories of very high, high, medium and low be designated by Mi1, Mi2, Mi3 and Mi4 for modularity attribute. Similar 4 coding classification has been done for remaining six digital platform attributes. Since each of the coders have different weightage given, let hj be weightage of coders.

Then for each of the digital platform attribute, following can be mathematically shown as per Trapezoidal fuzzy arithmetic:

$$M_i = \sum_{J=1}^{m} hjM_i \ \ for\ i = 1\ to\ 4\ (for\ 4\ different\ values\ of\ trapezoidal\ vertices)\ and\ j = 1\ to\ 3\ (for\ each\ domain\ expert)$$
$$= \left(h1M1 + h2M1 + h3M1\right) + \left(h1M2 + h2M2 + h3M2\right) + \left(h1M3 + h2M3 + h3M3\right) + \left(h1M4 + h2M4 + h3M4\right)$$

Figure 3. Flowchart showing fsQCA research process



The identical procedure is followed for the remaining six independent attributes as well for four vertices (left end point, left center point, right center point, and right end point) of the trapezoid and averaged out to have the single input for each variable to be used in fsQCA analysis. This results in numerical value in a scale of 1-10 for each of seven variables for all 51 cases used in this research. fsQCA does not provide functionality to examine validity and reliability of the dataset (step 4 in flowchart shown in Figure 3). This is to be done outside fsQCA (Pappas & Woodside, 2021). In this research, IBM SPSS software has been used for such tests (Flowchart step 4). Cronbach Alfa of all seven variables was examined which is 0.881 (threshold value being 0.7). For validity test of data, R software was used for finding out the Kendall Tau correlation coefficient. The Kendall Tau correlation coefficient is preferred since it does not need assumptions of normalization, linearity, and homoscedasticity in data. The results show that variables correlations are below the accepted benchmark of 0.80 (see Table 11 in the Appendix).

After obtaining the single numerical value for each of the attributes for all members of the dataset under examination, these values need to be calibrated against an external standard for determining the membership of outcome set (Ragin, 1987). This calibration is done as a membership of a fuzzy set where a value of 1 indicates complete inclusion in the outcome set and 0 indicates complete exclusion in the outcome set with 0.5 being the cross over point. This is called the calibration of dataset. However, in this research, based on recommendation of Pappas and Woodside (2021), the authors take three benchmark threshold values for calibration as 0.05 (complete exclusion), 0.95 (complete inclusion), and 0.50 (cross over point) for calibration. To ascertain which values, correspond to breakpoints, the percentile method has been applied on dataset (step 5 in flowchart shown in Figure 3). The use of percentile methods for calibration provides advantage of calibrating data regardless of origin of data (Pappas & Woodside, 2021). IBM SPSS software has been used for finding percentile values that appear in Table 12 in the Appendix (step 6 in flowchart shown in Figure 3). The final calibrated dataset is given in Table 13 in the Appendix.

Combination of Attributes Driving Infrastructuring: Truth Tables

Once the calibrated dataset is obtained, fsQCA software is applied to find different conjunctural combination of attributes causing infrastructuring of digital identity platforms. The fsQCA 4.0 software from the compass is used for the analysis.[15] This results in a truth table, as seen in Table 5. Truth tables (step 8 and step 9 in flowchart shown in Figure 3) provide different combinations of independent causal variables resulting in outcome of interest. Combinations of solutions are optimized using Option command, based on a frequency cut off value. In this research, a cut off value of 1 has been taken based on recommendation of Pappas and Woodside (2021). The combinations of attributes in truth tables are analyzed in terms of consistency and coverage. Consistency expresses the degree to which an antecedent combination approximates a given outcome. It is like the significance level in regression analysis (Fiss, 2008; Park & Mithas, 2020). Similarly, coverage specify the extent to which a configuration of attributes is able to explain the outcome (Rihoux and Ragin, 2008). Coverage is like R2 a regression analysis (Rihoux and Ragin,2008). Threshold values used in this research are 0.80 for raw consistency; 0.50 for PRI consistency; and raw coverage 0.90 (Pappas & Woodside, 2021).

DISCUSSION

Different conjunctural configurations of attributes have been shown in Table 5. The top row shows a combination of attributes of criticality and ubiquity representing 31 cases having the raw consistency

Table 5. Truth table showing conjunctural configurations

Modularity	Openness	Generativity	Scalability	Heterogeneity	Criticality	Ubiquity	Number of cases	Degree of Infra	Raw consistency	PRI consistency	SYM consistency
0	0	0	0	0	1	1	31	1	0.999871	0.997923	0.998698
0	0	0	1	0	1	1	17	1	0.999946	0.998684	0.998978
0	0	0	0	0	0	1	2	1	0.887771	0.517623	0.566538
0	0	0	0	0	0	0	0	0	0.502813	0.143378	0.178123
0	1	1	1	1	1	1	1	0	0.501121	0.513288	0.18881

of 0.999871, which is above the benchmark value of 0.80. PRI consistency of this solution (0.997923) is also above benchmark value of 0.50. Similarly, the second row shows solution (17 cases), which is a combination of scalability, criticality, and ubiquity with raw consistency value (0.999946) and PRI consistency (0.998684). Both these values are much above respective benchmark value of 0.80 and 0.50 respectively. The last three rows have raw and PRI consistency value much lower than benchmark value and are not an acceptable solution. Thus, truth table provides 48 cases having consistency and raw coverage values above the accepted threshold values. These need to be analyzed and discussed further to obtain parsimonious and intermediate solution. Hence, a standard analysis is done to determine parsimonious and intermediate solutions of research question (step 11 of flow chart shown in Figure 2).

Parsimonious and Intermediate Solution

All four solutions (excluding all 0 solutions, which are irrelevant) with associated data are shown diagrammatically in Figure 4. P1a is a combination having criticality and ubiquity attributes. The remaining attributes do not contribute to this solution. This solution has the highest raw coverage (0.972899); its unique coverage is 0.598824. This is a parsimonious solution as its overall solution coverage is 0.901231, and the solution consistency is 0.996182. Such high values above benchmark implies that characteristics of criticality and ubiquity working as combinational configuration best

Figure 4. Parsimonious and intermediate solution

Solution	Modularity	Openness	Generativity	Scalability	Hetg	Criticality	Ubiquity	Raw Consistency	Raw Coverage	Unique coverage
(p1a) crticality1 *ubiquity1	⊗	⊗	⊗	⊗	⊗	●	●	0.997729	0.972899	0.598824
(p2a) ~modularity1*~openness1* ~generativity1* scalability1*~hetrg1* criticality1* ubiquity1	⊗	⊗	⊗	●	⊗	●	●	0.987128	0.951633	0.310261
(p3a) modularity1*~openness1* ~generativity1*scalability ~hetrg1 *crticality1 *ubiquity1	⊗	⊗	⊗	⊗	⊗	⊗	●	0.821487	0.463172	0.017523
(p4a) modularity1*openness1 *generativity1*scalability1 *hetrg1* crticality1* ubiquity1	●	●	●	●	●	●	●	0.772815	0.606771	0.115597
Parsimonious Solution : Criticality*Ubiquity Solution Coverage 0.901231 Solution Consistency 0.996182										
Intermediate Solution Solution Coverage 0.772198 Solution Consistency 0.989921										

explain the infrastructuring of digital identity platforms and cannot be excluded from any solution. P2a is a solution having a combination of ubiquity, criticality, and scalability attributes. This solution has raw coverage of 0.951633; unique coverage of 0.310261. Solution coverage is 0.772198, and solution consistency is 0.989921. All these values are above benchmark values (Pappas & Woodside, 2021). Hence, the combination of scalability, ubiquity, and criticality is an intermediate solution. For P3a (the configuration having only the ubiquity attribute); its raw coverage is 0.463172, which is below benchmark value of 0.90. Unique coverage (0.017523) is also very low. Similarly, for P4a (configuration having all attribute) both its raw coverage (0.606771) and raw consistency (0.772815) are below benchmark values of 0.90 and 0.80 respectively. Its unique coverage (0.115597) is much less. Hence, these solutions overlap or are subsumed in the parsimonious and intermediate solutions. As a result, P1a and P2a are only two solutions that emerge after the fsQCA standard analysis, Thus, the **first key observation** emerging from this research is that of criticality, ubiquity, and, to a lesser extent, scalability attributes provide sufficient conditions for driving infrastructuring of digital platforms. The remaining attributes have either a peripheral or no causation effect on the infrastructuring of digital platforms.

Parsimonious and intermediate configurations, as obtained, represent sufficient conditions. It is also essential to establish that these combinations or individual attributes are necessary conditions or are otherwise for infrastructuring (step 13 of flow chart shown in Figure 2). Necessary conditions have been derived using fsQCA 4.0, as seen in Table 6. Criticality and ubiquity are two single necessary variables having consistency value (0.935578 and 0.902841) higher than the benchmark value of 0.80. Their coverage value (0.991376 and 0.927193) is higher than the benchmark value of 0.95. The scalability attribute has a consistency value of 0.892938 above benchmark value of 0.80 and coverage value of 0.952185 very near to the benchmark value of 0.95. This leads to the **second key observation**; criticality, ubiquity, and scalability attributes provide as a configuration, both a necessary and sufficient condition for infrastructuring of digital identity platforms. Other solutions (P3a and P4a) have been found to be irrelevant and peripheral in nature. This leads to the third key observation. Contrary to popular belief, attributes like modularity and generativity and openness, etc. are not essential attributes for infrastructuring in the case of digital identity platforms. Modularity and generativity features may contribute to digital platform evolution in several other ways but are neither necessary nor sufficient in themselves to drive infrastructuring. This is the **third key observation** emerging from this research.

Supplementary Analysis of fsQCA Results

fsQCA results are needed to be cross evaluated with contextual case analysis for further rigor and exactness (Ragin, 1987). Kent (2008) argued that fsQCA outcomes be checked with use cases in descriptive senses. Accordingly, attributes of digital platforms emerging in fsQCA analysis have been compared with contextual data available in contemporary discourse. Details of such qualitative analysis appear in Table 7.

Table 6. Single necessary conditions

Ser No.	Attribute/Configuration	Consistency	Coverage
1	Modularity	0.701476	0.771038
2	Openness	0.752191	0.901961
3	Generativity	0.710821	0.933220
4	Scalability	0.892938	0.952185
5	Heterogeneity	0.752631	0.923181
6	Criticality	0.935578	0.991376
7	Ubiquity	0.902841	0.927193

Table 7. Supplementary qualitative analysis

Serial No.	Major Organisation/Product/services integrated and using UIDAI Aadhar	Years of Integration with digital identity platform	Average usage per unit period
1	Financial Inclusion – Jan Dhan Accounts (Bank account for poor unbanked)	2014-2023	500 million accounts in August 2023, Approx 2 Bn US Dollar equivalent deposits in Indian Rupees[16]
2	Saving account validated by Aadhar (e KYC)	2017-2023	761.3 million saving account linked with Aadhar till Jan 2023[17]
3	Aadhar Enabled Payment System (AEPS)	2010-2023	447.21 million transactions worth 6 billion US Dollar equivalent in Indian Rupees in Mar 21[18]
4	Direct Benefit Transfer for citizens (electricity, cooking Gas, Public Distribution System Ration, Agriculture, and crop insurance, etc.)	2013-2023	313 schemes from 53 central government ministries for 900 million people totaled 375 billion US dollar equivalent in Indian Rupees distributed[19]
5	Rural Employment Guarantee payments (MNEREGA)	2006-2023	144.1 million individuals and 300 billion US dollar equivalent in Indian Rupees in wages in the financial year 22-23[20]
6	Income Tax (ITR and PAN card integration with UIDAI Aadhar)	2017-2023	510 million Income Tax Permanent Account Numbers (PAN) inked to Aadhar till 2023[21]
7	Passport integration with Aadhar	2014-2023	1.1 million passports in 2022[22]
8	Educational Scholarship	2016-2023	16 ministries, 52 schemes, 15 lakh students[23]
9	UIDAI Aadhar and Ayushman Bharat citizen healthcare integration	2018-2023	1.35 billion cumulative beneficiaries[24]
10	Aadhar enabled biometric employee attendance	2014-2023	7440 central and state organizations with 2.6 million employees[25]
11	Mobile phone connectivity	2016-2023	All four major mobile phone carriers (Airtel, Jeo, Vodafone, and BSNL) on board users only through Aadhar[26]
12	Municipal documents like birth certificate, marriage certificate, and death certificate etc	2015-2023	Several states providing Aadhar linked municipal certificates[27]
13	Educational certificates	2017-2023	All educational certificates accessible through the National Academic depository (NDMLAD)[28]
14	Land records	2019-2023	400 million land parcels in 0.62 million villages accessible through Digital India Land Record Modernisation Program (DILRMP)[29]
15	Driving License	2021-2023	Mandatory for contactless service
16	Pensions, Provident Fund, and Gratuity	2017-2023	Linked to Aadhar, s[30]

UIDAI Aadhar

Ubiquity can be qualitatively defined as embeddedness in other markets and industries to the extent that it is widely available, shared, and is extensively used (Helmond et al., 2019). Primarily, UIDAI Aadhar (issued to 1.39 billion resident Indians)[31] is used for digital authentication services (approximately 1.6 to 2 billion authentications per month in year 2023)[32] and electronic Know Your Customer (e KYC), which ranged to approximately 300 million e KYC per month in year 2023.[33] Various schemes in which UIDAI Aadhar and its APIs have been employed are shown in Table 7. It would be seen that in every aspect of public governance – education, healthcare, taxation, government subsidy disbursal, etc., UIDAI Aadhar has been used at very large scale. UIDAI Aadhar is, hence, deeply embedded in almost every aspect of life in India. This fits well with the definition of ubiquity (Helmond et al., 2019) regarding embeddedness of such platform in society.

This leads to the fact that any significant disruption in UIDAI Aadhar functionality will have wide ranging disturbance and chaos in banking, finance, social welfare project, public transactions, municipal certificates, cellular onboarding, payments, pensions, etc. As a corollary, the continued functionality of UIDAI Aadhar is critical for society in India. In the last two columns of Table 7, the year of commencement of an API/application and its average usage per unit time has been given. It is seen that within four to five years of launch, a very high volume of transactions is carried out for each of API/application of UIDAI Aadhar. This fits well with the definition of scalability (Bondi, 2000); Mukhopadhyay et al. (2019) also held scalability as the most important feature of Aadhar.

Hence, criticality and ubiquity attributes are key drivers of infrastructuring of UIDAI Aadhar. Infrastructuring is further strengthened by a scalability attribute, which is inherent in the UIDAI Aadhar platform as a design feature.

India Stack and Sunbird

Forty-four APIs of India Stack, examined in this research for infrastructuring enabling features, are driven by attributes that are common with UIDAI Aadhar. As regards ubiquity attribute-usage of different layers of India Stack, it is growing very rapidly – India Stack platform digital locker has 142 million registered users and 4.6 billion documents.[34] Under digital payment Rs 3.46 billion gets transferred per month in approximately 340 million transactions.[35] As in year 2023, more than 310 million digital signatures have been issued.[36] This way India Stack solutions are rapidly becoming ubiquitous and critical for Indian society. India Stack solutions are highly scalable – after its launch in year 2016, digital locker has scaled up its repository by 4.32 billion documents of 67 million users. Similarly, Sunbird architecture has the potential for high ubiquity, criticality, and scalability due to its diverse APIs.

Hence, inferences emerging from this qualitative contextual analysis are consistent with fsQCA results. Hence, the proposition is supported by both fsQCA and qualitative contextual results and analysis.

RESEARCH CONTRIBUTION, LIMITATIONS, AND FUTURE RESEARCH RECOMMENDATIONS

Theoretical Contribution

This research makes a substantial theoretical contribution by validating two different research paradigms of infrastructural studies in an integrated manner, which has not been done before. Two different infrastructural studies research paradigms (i.e., complexity and relational network) (Henfridsson and Bygstad, 2013) with four associated theoretical lenses in cases of digital platforms have been applied on candidate attributes of infrastructuring of digital identity platforms. Accordingly, while doing so, this research broadens concepts of infrastructuring for digital platforms. Van de Ven (1989), recommended that extending the range of application where a theoretical lens can be applied improves the theory itself; and he called it "concept travelling in theoretical domain" (i.e., precisely fitting a variety of applications). Accordingly, this research extends the application of complexity and relational-network perspective of infrastructural studies to infrastructure transformation of popular digital identity platforms.

Conceptual Contribution

This research makes a conceptual contribution by identifying necessary and sufficient conditions for infrastructuring of digital identity platforms. Such research has been called upon as part of the recent recommended research agenda (Constantinides et al., 2018; De Reuver et al., 2018). This research answers call of such academicians by identifying essential platform attributes enabling infrastructuring and hence, is a research contribution. All countries that are implementing digital identity platforms as part of UN SDG 2030 mandate will benefit from this research. In addition, this research also sets aside the impression that certain platform attributes like modularity and generativity are absolutely essential for infrastructuring.

Contribution to Digital Platform Literature

This research makes two important contributions to digital platform literature. First, most of the existing research literature on infrastructuring of digital platforms have conducted a qualitative analysis of subject (Constantinides, Henfridsson and Parker, 2018; De Reuver, Sorenson and Basole, 2018). This is the first research to examine the infrastructuring phenomenon quantitatively backed up by a qualitative contextual analysis. Second, several researchers have called for research on social applications of digital platforms (De Reuver, Sorenson and Basole, 2018). This research answers calls of such academicians by examining societal application of digital platforms in the form of digital identity platforms, which in turn, evolves as a digital infrastructure by expanding in multiple domains of authentication, financial service, banking, municipal services, healthcare, education, etc.

Methodological Contribution

This research makes a methodological contribution by examining digital identity platforms using a configurational approach as against examining the impact of individual variables on outcome of interest. Digital platforms have been examined by many researchers but always such research has been conducted by examining impact of a single variable on outcome of interest: e.g.Tiwana (2018); Ghazawneh, and Henfridsson, (2013); Cusumano et al. (2020), etc. The application of the fsQCA method uniquely examines digital platforms using a set theory approach. Due to this research approach, multiple methodological aspects like organized complexity, equifinality, conjectural causation, and asymmetric solutions in the form of multiple possible solutions are applied to digital identity platforms for the first time as a research method.

Contribution to Government, Policy Planners, and Regulators

This research shall also provide necessary insights in respect of institutional expansion for digital identity platforms for public welfare and social inclusion in multiple domains of banking, government subsidy disbursal, education, healthcare, etc. Government, policy makers, and regulators may benefit from this research by making appropriate policies and executing implementation and regulation of such implementation. In addition, the infrastructure aspect of digital platforms underscores its criticality to society, which is a useful input for policy makers and regulators. This must be taken a note of, and social policies should be framed accordingly. This is an important contribution since cases used in this research UIDAI Aadhar and India Stack are under consideration for implementation in almost 20 more different countries including Sri Lanka, Egypt, Algeria, Morocco, the Philippines, and Myanmar, etc. (Martin, 2021). Designers, policy makers, and regulators in all these countries shall benefit from this research.

Limitations and Future Research Opportunities

One of the limitations of this research is the relatively smaller dataset for application of fsQCA. However, the database size of N=51 is much above sample size recommended for fsQCA studies by Greckhamer et al. (2018) as well as by Pappas and Woodside (2021). The first reason for a smaller dataset is the incipient nature of the research topic where much data is not available about digital identity platforms. The second reason is secrecy surrounding digital platform design, which is aggressively guarded by designers. Still, adequate secondary design data exists in the public domain to have a number of cases sufficient for application of fsQCA (Pappas & Woodside, 2021). This research can be expanded further to include more digital identity platforms from other countries for a more comprehensive cross case analysis. The second limitation is regarding accuracy and precision of results from fsQCA. To compensate for this a separate qualitative analysis has been carried out to cross evaluate fsQCA results. This limitation presents a future research opportunity. A quantitative research based on second generation quantitative analysis method like Structured Equation Model (SEM) can be carried out and results compared with the fsQCA result to improve accuracy and exactness of research.

CONCLUSION

This research has ascertained drivers enabling infrastructuring in digital identity platforms using fsQCA, both as a research approach and as a methodology. Infrastructuring of digital identity platforms is essential for the provision of complementary public services, and this research shall be useful to concerned stakeholders. In particular, contribution of this research in establishing Digital Public Infrastructures (DPI), in pursuance of UN SDG goals, 2030 is both noteworthy and significant. This research is based on Indian DPI use cases. India’s DPI has diversified consumer choice, incentivized entrepreneurship, advanced competition, prevented dependency on service providers, improved quality of life for individuals, and enhanced opportunities for businesses to fairly operate in the economy (Kant, 2023). As Indian DPI are being replicated across many countries, this research would have a global interest among such countries.

COMPETING INTEREST AND FUNDING STATEMENT

Corresponding author, on behalf of all authors, hereby, declare that authors have no competing interest and have received no funding for this research.

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APPENDIX

Interview Protocol

Interview procedure: Face to face or by E mail. If face to face, then to be recorded (if agreed to by interviewee) and later transcript made. Any unstructured response from interviewee to be allowed and encouraged.

Role of Interviewee: Senior Official, Software architecture and design, UIDAI Aadhaar (Or other case studies used in this research).

Opening Statement: I am Prashant Kumar Choudhary currently PhD (EFPM) research from MDI, Gurgaon. My research topic is "Configurational Analysis of Infrastructuring in Digital Identity Platforms".

This interview is being conducted for understanding architecture attributes of digital platforms which enables it to work as digital infrastructure.

RQ1: What configuration of attributes drive infrastructuring of digital identity platforms?

Questions

1. Hello sir, how long has you been associated with UIDAI Aadhaar project (or project name used in case study).
2. Your association with UIDAI Aadhaar (or project name used in case study) has been in which all capacity.
3. Tell us about your background and how you got associated with UIDAI Aadhaar (or project name used in case study).
4. In UIDAI design (or project name used in case study), which all platform design features are most important and can be mentioned as essential to platform architecture and design.
5. Can you please elaborate as to why these features are important in terms of its contribution to achieving platform goals.
6. As UIDAI Aadhar (or project name used in case study), is used in almost every aspects of life in India (like banking, finance, healthcare, education, government welfare disbursal, rural wages, loans, scholarship, insurance, private companies for customer authentication etc) – it has become sort of digital infrastructure of society. What are your views on this?
7. Can you suggest some more examples of digital platforms transforming as digital infrastructure of modern society.
8. As platform designer, what all are important features in digital platforms – which contribute to its infrastructuring?
9. Is UIDAI Aadhar authentication feature being used in other platforms/ system and upto what extent such integration facilitates innovation?
10. Does your system use proprietary or open standards or open APIs and software? What benefits accrue from using open standards and software / API?
11. Is modularity in core software design essential for digital platform infrastructuring?
12. In your opinion, is there difference between such design features in digital platforms facilitating infrastructuring in commercial digital platforms and societal not for profit public good platforms like UIDAI Aadhar.
13. How does such societal platform as yours promote social as well as business concerns by its design and architecture?
14. Does widespread usage of your platform make such systems akin to digital infrastructure?
15. If answer to above question is yes, then what is nature of such infrastructuring and how does it differ from original platforms.

16. What would be approximate volume of daily or monthly or yearly number of transactions on your platform. Does high number of user base make it very critical to society?
17. How have you designed the system so that it does not malfunction or maintains same level of efficiency at higher volumes?
18. How is platform manged or controlled for all platform participants?
19. There are a number of stakeholders and participants in your platform. How is this manged by architecture/ design perspective?
20. If your platform is widely used and is essential for day to day functioning of society, how is this ensured in platform design for its availability as essential system?
21. Your platform needs to work with a large number of other systems. Some of these may not be planned beforehand. How do you, as designer ensure such integration with other systems.
22. As platform manger or designer, so you embed features for interworking with other systems right at the beginning of platform design or you incorporate these as systems evolve.
23. How do you ensure that all platforms are working effectively with efficiency – by a suitable design feature or by operation practices or by combining both of these?
24. If there are some malfunctions or system glitches, how it is ensured that these remain responsive within reasonable time frame with limited downtime? Have you built lot of redundancy in system?
25. How do you take pricing and other managerial decisions in operating your system? What all are considerations for these decisions, considering that these are societal platforms?

Figure 5. UIDAI Aadhar architecture

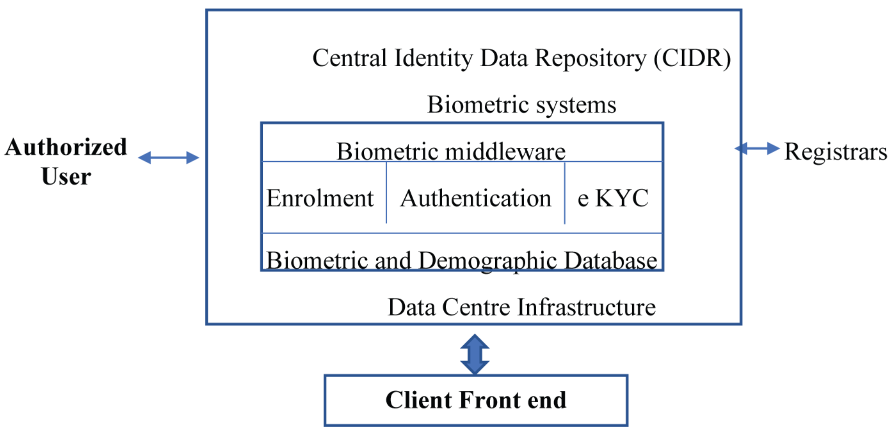

Figure 6. India Stack Functional design

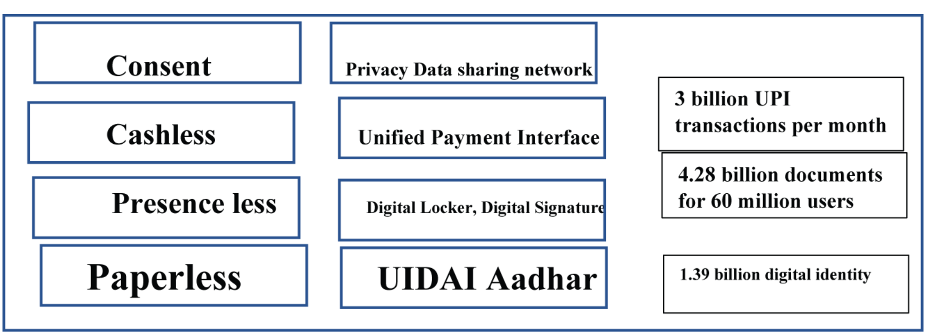

Figure 7. Sunbird Functional design

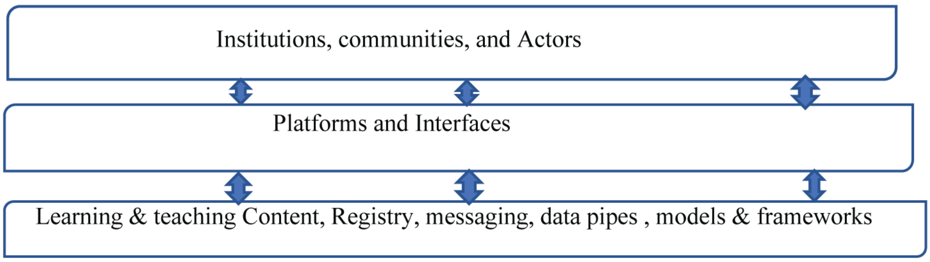

Table 8. List of Digital Identity Based platforms/API

Ser No.	Name of Digital Identity Platform API	Reference
1		
2	UIDAI Authentication API	https://uidai.gov.in/images/resource/aadhaar_authentication_api_2_5.pdf
3	UIDAI Aadhar E KYC API	https://uidai.gov.in/images/resource/aadhaar_ekyc_api_2_5.pdf
4	UIDAI Enrolment API	https://www.uidai.gov.in/en/914-developer-section.html
5	Indiastack UPI e NACH API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://decentro.tech/resources/enach-apis/
8	Indiastack Ftech request API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7#https://business.paytm.com/docs/api/fetch-upi-options/
9	Indiastack Payment API 1	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7#https://docs.oracle.com/cd/F42401_01/PDF/User_Guides/Oracle-Banking-Payments_Modules/UPI.pdf
10	Indiastack Payment API 2	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7#https://docs.oracle.com/cd/F42401_01/PDF/User_Guides/Oracle-Banking-Payments_Modules/UPI.pdf
11	Indiastack Transaction status check API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://nulm.gov.in/PDF/UIDAI-APIerrorcode.pdf
12	Indiastack Validation API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7#https://business.paytm.com/docs/api/account/validate-beneficiary-api/
13	Indiastack Complaint status API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://www.npci.org.in/user-complaint-status
14	Indiastack Request API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://decentro.tech/resources/upi-apis/
15	Indiastack MDM API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://www.npci.org.in/PDF/
16	Indiastack E SIGN API	https://apidashboard.io/apis/indiastack-esign
17	Indiastack verification API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://upiapi.in/
18	Indiastack document API	https://www.scribd.com/document/362193204/NPCI-API-Descriptionsb9bceb7# https://upiapi.in/
19	Sunbird create content API	http://docs.sunbird.org/latest/apis/
20	Sunbird Asset API	http://docs.sunbird.org/latest/apis/

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Table 8. Continued

Ser No.	Name of Digital Identity Platform API	Reference
21	Sunbird Textbook API	http://docs.sunbird.org/latest/apis/
22	Sunbird course API	http://docs.sunbird.org/latest/apis/
23	ONDC Seller App Meta APIs- cancellation API	https://docs.setu.co/commerce/ondc/retail/api-reference#/category~Seller_App_Meta_APIs/path~/get_cancellation_reasons/post
24	ONDC return API	https://docs.setu.co/commerce/ondc/retail/api-reference#/category~Seller_App_Meta_APIs/path~/get_return_reasons/post
25	ONDC Seller rating API	https://docs.setu.co/commerce/ondc/retail/api-reference#/category~Seller_App_Meta_APIs/path~/get_rating_categories/post
26	ONDC Meta API feedback	https://docs.setu.co/commerce/ondc/retail/api-reference#/category~Seller_Meta_APIs/path~/get_feedback_categories/post
27	ONDC callback API	https://github.com/ONDC-Official/ONDC-Protocol-Specs/blob/master/protocol-specifications/core/v0/api/core.yaml
28	ONDC Search API	https://github.com/ONDC-Official/ONDC-Protocol-Specs/blob/master/protocol-specifications/core/v0/api/core.yaml
29	ONDC Init API	https://github.com/ONDC-Official/ONDC-Protocol-Specs/blob/master/protocol-specifications/core/v0/api/core.yaml
30	ONDC Track API	https://github.com/ONDC-Official/ONDC-Protocol-Specs/blob/master/protocol-specifications/core/v0/api/core.yaml
31	Fintech Account Aggregator (AA) API	https://api.rebit.org.in/
32	Fintech Financial Information Provider API	https://api.rebit.org.in/
33	Fintech Financial Information User callback API	https://api.rebit.org.in/
34	Indiastack e Sign API	https://apidashboard.io/
35	Indiastack Digilocker Issuer Pull URL request API	https://www.digilocker.gov.in/resources
36	Indiastack Digilocker Issuer Pull doc response API	https://www.digilocker.gov.in/resources
37	Indiastack Digilocker Issuer Pull doc response API	https://www.digilocker.gov.in/resources
38	Indiastack Digilocker Issuer Pull doc response API	https://www.digilocker.gov.in/resources
39	Indiastack FASTag Mock API	https://fastag-api.setu.co/api/mock; https://docs.setu.co/payments/fastag/api-reference
40	Indiastack FASTag UAT API	https://fastag-api.setu.co/api/UAT https://docs.setu.co/payments/fastag/api-reference

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Table 8. Continued

Ser No.	Name of Digital Identity Platform API	Reference
41	Indiastack FASTag Prod API	https://fastag-api.setu.co/api/Prod https://docs.setu.co/payments/fastag/api-reference
42`	Indiastack health API	https://developers.google.com/open-health-stack/android-fhir Set of Kotlin libraries for building offline-capable, mobile-first healthcare applications using the HL7 FHIR® standard on Android.
43	Indiastack health API information gateway	https://developers.google.com/open-health-stack/fhir-info-gateway
44	Indiastack health API information gateway SDK	https://developers.google.com/open-health-stack/android-fhir
45	Indiastack Passport API	https://apiseva.co.in/passport-api.aspx
46	NSDL PAN API	https://apiseva.co.in/pan-card-nsdl-api.aspx
47	NSDL PAN Verification API	https://apiseva.co.in/pan-card-verification-api.aspx
48	NSDL PAN status verification API	https://apiseva.co.in/pan-application-status-verification-api.aspx
49	Udyog Aadhar registration API	https://apiseva.co.in/udyog-aadhaar-registration-api.aspx
50	Udyog Aadhar verification API	https://apiseva.co.in/udyog-aadhaar-verification-api.aspx
51	QR and UPI API	https://apiseva.co.in/qr-code-and-upi-id-api.aspx

Table 9. Data Sources

Serial No.	Data Source	Description
1	Public domain Aadhaar and UPI documents	white papers, technical documents,www.uidai.gov.in ; preserved in wayback machine or archive.org, crunchbase
2	Interviews	Six interviews with different stakeholders of UIDAI Aadhar, Indiastack and Sunbird
3	Blogs	http://aadhaar-articles.blogspot.com/
4	Aadhaar resources platforms	https://rethinkaadhaar.in/resourceshttp://www.theunbiasedblog.com/tag/hackathonhttps://github.com/topics/aadhaar
5	Other corporate Aadhar-related websites	http://www.forbesindia.com/blog/economy-policy/aadhaar-the-next-best-thing-after-the-cell-phone/
6	Aadhaar hackathon blogs and websites	http://khoslalabs.com/hack.html https://www.hackerearth.com/sprints/aadhaar-application-hackathon/
7	Indiastack technology websites	https://indiastack.org/ https://oswaldlabs.com/accelerator/partners/aadhaar-bridge/

Table 10. Details of coders and domain experts

Expert	Designation	Years of experience		Area of responsibility	Prior understanding of Computer Assisted Qualitative Content Analysis Software	Number of hours spent with authors	Weightage
		Digital Platform design	Digital Platform operations				
Expert 1	Project Manager	2	10	Digital Platform operations	yes	60 hour over 30 day	0.45
Expert 2	Developer	Nil	7	API designer	No	40 hours over 30 days	0.30
Expert 3	Sales manager	Nil	Nil	Sales and liaison	No	30 hours over 30 days	0.25

Table 11. Reliability and Validity Test

		N	%	Reliability Statistics				
Cases	Valid	50	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items			
	Excluded	1	.881	.889	51			
	Total	51	100.0					
Correlations for all pairs of data series (method=Kendall)								
	Modu	**Open**	**Gener**	**Scal**	**Het**	**Crti**	**Ubi**	**Deg**
Mod	1	0.721	0.233	0.041	0.052	-0.07	0.039	0.142
Open	0.721	1	0.178	0.202	0.221	0.118	0.165	0.321
Gener	0.233	0.178	1	0.441	0.487	0.301	0.319	0.08
Scal	0.041	0.202	0.441	1	0.405	0.476	0.333	0.018
Het	0.052	0.221	0.487	0.405	1	0.356	0.409	0.296
Crti	-0.07	0.118	0.301	0.476	0.356	1	0.529	0.328
Ubi	0.039	0.165	0.319	0.333	0.409	0.529	1	0.378
Deg	0.142	0.321	0.08	0.018	0.296	0.328	0.378	1

Table 12. Calibrated Values

Name of digital platform/API	Modularity	Openness	Generativity	Scalability	Heterogeneity	Criticality	Ubiquity	Degree of infrastructuring
UIDAI Authentication API	0.8	0.8	0.89	0.95	0.85	0.8	0.95	0.8
UIDAI Aadhar E KYC API	0.90	0.89	0.92	0.95	0.6	0.9	0.95	0.9
UIDAI Enrolment API	0.85	0.78	0.86	0.90	0.5	0.8	0.9	0.7
Indiastack	0.67	0.6	0.55	0.88	0.52	0.95	0.90	0.8
Sunbird	0.88	0.55	0.78	0.62	0.42	0.88	0.55	0.8
Indiastack UPI e NACH API	0.71	0.82	0.45	0.25	0.16	0.78	0.65	0.7
Indiastack Ftech request API	0.51	0.71	0.55	0.76	0.52	0.87	0.83	0.6
Indiastack Payment API1	0.87	0.81	0.85	0.81	0.83	0.76	0.87	0.7
Indiastack Payment API 2	0.85	0.84	0.88	0.79	0.77	0.77	0.86	0.8
Indiastack Transaction status check API	0.88	0.82	0.81	0.91	0.54	0.91	0.92	0.8
Indiastack Validation API	0.81	0.86	0.83	0.75	0.77	0.89	0.90	0.7
Indiastack Complaint status API	0.80	0.83	0.82	0.88	0.72	0.91	0.92	0.8
Indiastack Request API	0.61	0.71	0.77	0.73	0.75	0.78	0.81	0.7
MDM API	0.64	0.62	0.68	0.76	0.76	0.87	0.84	0.8
Indiastack service API	0.82	0.81	0.76	0.71	0.72	0.71	0.81	0.7
Indiastack verification API	0.81	0.72	0.76	0.85	0.71	0.76	0.81	0.7
Indiastack document API	0.77	0.82	0.71	0.85	0.76	0.89	0.82	0.8
Indiastack Digital locker API	0.83	0.81	0.81	0.88	0.79	0.72	0.89	0.8
Sunbird create content API	0.81	0.78	0.72	0.89	0.75	0.85	0.89	0.8
Sunbird Asset API	0.62	0.67	0.71	0.89	0.72	0.89	0.88	0.7
Sunbird Textbook API	0.72	0.78	0.71	0.82	0.71	0.87	0.86	0.8
Sunbird course API	0.87	0.81	0.75	0.89	0.76	0.88	0.88	0.8
ONDC Seller Meta API	0.98	0.76	0.77	0.87	0.82	0.97	0.91	0.75
ONDC return API	0.91	0.72	0.67	0.89	0.81	0.91	0.93	0.71

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Table 12. Continued

Name of digital platform/API	Modularity	Openness	Generativity	Scalability	Heterogeneity	Criticality	Ubiquity	Degree of infrastructuring
ONDC Seller rating API	0.89	0.71	0.75	0.81	0.64	0.80	0.97	0.89
ONDC Meta API feedback	0.842932	0.786613	0.635864	0.62398	0.903019	0.828447	0.877632	0.842932
ONDC callback API	0659618	0.750399	0.6924	0.735153	0.855084	0.737176	0.901482	0.959618
ONDC Search API	0.901636	0.647201	0.782771	0.72404	0.615273	0.690648	0.780691	0.901636
ONDC Init API	0.6811	0.846018	0.788699	0.894129	0.672968	0.877791	0.815471	0.8811
ONDC Track API	0.612804	0.616382	0.739299	0.76859	0.775052	0.652071	0.744362	0.812804
Fintech Account Aggregator (AA) API	0.983557	0.627528	0.689596	0.649084	0.798683	0.632498	0.636263	0.983557
Fintech Financial Information Provider API	0.686743	0.808606	0.804167	0.737581	0.675147	0.846734	0.841211	0.686743
Fintech Financial Information User callback API	0.864384	0.671818	0.924034	0.716161	0.209629	0.889921	0.686196	0.864384
Indiastack e Sign API	0.611178	0.651897	0.612065	0.829915	0.828575	0.801637	0.865336	0.811178
Indiastack Digilocker Issuer Pull URL request API	0.878205	0.869047	0.884529	0.856987	0.7286	0.70865	0.85786	0.978205
Indiastack Digilocker Issuer Pull doc response API	0.694567	0.420512	0.404649	0.260608	0.683873	0.6858	0.700192	0.694567
Indiastack Digilocker Issuer Pull doc response API	0.702114	0.761634	0.809902	0.864988	0.8393	0.742457	0.749461	0.902114
Indiastack Digilocker Issuer Pull doc response API	0.613111	0.667274	0.792324	0.667729	0.791317	0.683061	0.772567	0.613111
Indiastack FASTag Mock API	0.629949	0.787603	0.828816	0.719072	0.821689	0.718311	0.783499	0.629949
Indiastack FASTag UAT API	0.857619	0.665262	0.647411	0.880148	0.665485	0.893077	0.650319	0.857619
Indiastack FASTag Prod API	0.747488	0.753581	0.846338	0.837928	0.445853	0.782457	0.833022	0.947488
Indiastack health API	0.633252	0.665622	0.758541	0.731244	0.707189	0.859712	0.845606	0.833252

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Table 12. Continued

Name of digital platform/API	Modularity	Openness	Generativity	Scalability	Heterogeneity	Criticality	Ubiquity	Degree of infrastructuring
Indiastack health API information gateway	0.785807	0.773356	0.648793	0.72421	0.605133	0.744916	0.812059	0.885807
Indiastack health API information gateway SDK	0.634213	0.653908	0.622225	0.776376	0.783068	0.618191	0.787352	0.734213
Indiastack Passport API	0.778663	0.773222	0.713274	0.8638	0.875863	0.831219	0.852384	0.778663
NSDL PAN API	0.706859	0.758978	0.80585	0.688499	0.885397	0.74854	0.879576	0.906859
NSDL PAN Verification API	0.947768	0.61531	0.674857	0.759443	0.665899	0.810216	0.892564	0.947768
NSDL PAN status verification API	0.740032	0.624	0.663505	0.645561	0.685194	0.888465	0.968567	0.740032
Udyog Aadhar registration API	0.835797	0.954326	0.925585	0.971763	0.616698	0.642591	0.872412	0.835797
Udyog Aadhar verification API	0.890619	0.759765	0.78071	0.689197	0.838863	0.734058	0.868896	0.990619
QR and UPI API	0.865532	0.697481	0.704122	0.696809	0.763776	0.673505	0.863326	0.965532

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