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Informal smart urbanism: A case study of digital resilience in Mathare informal settlement

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Abstract

Informal smart urbanism is an emerging field that explores how digital technologies shape urban development in contexts marked by informality. We understand informality as a dynamic set of interactions that arise when formal regulations fail to meet people's needs. Our study analyses digital resilience practices—the everyday ways households respond to shocks through digital technologies. These practices are widespread but often overlooked, especially given the vulnerabilities inherent in informal settings. We explore how repetitive digital practices form extra-legal rules. In Mathare, Kenya, four forms of digital resilience practices emerge: (1) belt tightening: households with low resilience use digital networks to receive digital gifts, replacing non-digital support; (2) maladaptive: digital tools are used in ways that undermine community resilience; (3) adaptive: digital platforms are used to strengthen household resilience in the short term; and (4) transformative: digital technologies systemically improve household resilience in the long term.

Keywords

Africa, digitalization, informality, Kenya, smart urbanism

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摘要

非正规智慧城市化是新兴研究领域，主要探究数字技术在非正规环境下如何影响城市发展。我们认为，非正规性是正规制度规范难以满足人们的需求时，所衍生出的动态互动集合。本文分析了数字韧性实践，即家庭利用数字技术应对突发冲击的日常方式。这类实践普遍存在，却往往被忽视，非正规环境本身存在的脆弱性更是加剧了这一情况。本文探究重复性数字实践如何形成法外规则。在肯尼亚的马萨雷 (Mathare)，出现了四种数字韧性实践：(1) 节流型：低韧性家庭利用数字网络接收线上馈赠，取代非数字化帮扶；(2) 失配型：数字工具的使用方式反而削弱了社区韧性；(3) 适应型：数字平台被用于在短期内增强家庭韧性；以及 (4) 变革型：数字技术系统性地长期改善家庭韧性。

关键词

非洲、数字化、非正规性、肯尼亚、智慧城市化

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Introduction

Digital technologies increasingly invade all aspects of urban life, be it through dashboards managing traffic flows, the use of laptops in schools, CCTV cameras, or the use of social media. Scholars of smart urbanism critically examine how these technologies operate within cities, arguing that their effects are conditioned, mediated, and contested by layered systems of governance, social relations, and the political economy. Consequently, the impacts of digital technologies vary across geographies (Guma, 2019; Luque-Ayala and Marvin, 2015; Sarkar, 2019).

While cities in the global South quickly digitalize, this is still relatively understudied (Luque-Ayala and Marvin, 2015; Guma, 2019, 2024; Sarkar, 2022). Informality is at the heart of urbanism in the global South, especially in Africa (Anyamba, 2011; Roy, 2005; Simone, 2001). It is often incorrectly perceived as a substandard aberration, which emerges in the absence of “modern” formal services and infrastructure (Anyamba, 2011; Banks et al., 2020; Guma, 2019; Schramm and Bize, 2023; Simone, 2001). This coincides with persistent

narratives around urbanization in the global South as problematic, while cities in the global North are perceived as innovative global nodes (Roy, 2005). By contrast, we perceive informality as a diverse, innovative, yet precarious set of urban interactions which emerges in contexts where formal laws and structures are unsuitable. It is a default practice, when laws, regulations, norms, and values are inappropriate (Roy, 2005). Its sheer magnitude renders it the norm rather than the exception of urbanization processes in the global South (Anyamba, 2011).

In the past decade, informality has emerged “as a marker” of smart urbanism (Guma, 2024). Scholars critically assess digital practices, governance arrangements, and the effects of digitalization on livelihoods (Anyamba, 2011; Chambers, 2019; Datta, 2018; Guma, 2019; Guma and Wiig, 2022; Kimari, 2021; Odendaal, 2006; Sarkar, 2019, 2022; Schramm and Bize, 2023; Van Tuijl et al., 2026). We frame this emerging body of scholarly work as informal smart urbanism. Although digital technologies are often promoted as tools for pro-poor development, their technocratic implementation—without accounting for the realities of informal contexts—is unlikely to be effective

(Guma, 2019; Luque-Ayala and Marvin, 2015; Odendaal, 2006; Sarkar, 2019).

We zoom in on the effects of informality on digital resilience practices, defined as the everyday activities of individuals, households, and organizations to recover from or live with exogenous shocks, through the design, deployment, and use of digital technologies (Boh et al., 2023; Tim and Leidner, 2023). These are indicated by the use of digital platforms on mobile phones or computers after a household has faced a shock, such as employment loss, illness, theft, or fire. We study these in informal settlements, which are deeply vulnerable due to neglect, discrimination, and substandard housing, infrastructure, and services. At the same time, they house over 1 billion people (Satterthwaite et al., 2020). Within this vulnerability context, households are forced to constantly live with and/or adapt to shocks (Van Stapele, 2016). In this article, we analyze how households negotiate uncertainties following shocks by using digital platforms on their phones or computers or through e-services and infrastructure. We are aware that digital technologies also impact resilience through other processes, including privacy concerns, e-planning, smart buildings, and smart grids (Luque-Ayala and Marvin, 2015), but these are outside our scope.

Our research question is: *How does informality influence the digital resilience practices of households in Mathare, Nairobi?* The case study is relevant for two reasons. First, Nairobi is at the frontier of ICT development, being referred to as Africa's Silicon Valley, where among others policy support, the extensive use of M-Pesa, cheap mobile phones, and the digitalization of municipal services have led to a relatively large role for ICT (Guma, 2019; Poggiali, 2017; Pollio, 2024). Second, Mathare has been a testbed for water ATMs (Sarkar, 2019), shedding light on how households of a relatively digitalized informal settlement within a digital

frontier city in the global South use digital technologies to cope with shocks.

Our contribution is both theoretical and empirical. Theoretically, we contribute to the emerging body of work on informal smart urbanism (see for instance Sarkar, 2019) by exploring digital resilience practices. Most studies on digital resilience are sectoral, analyzing for instance water ATMs (Guma, 2019, 2023, 2024; Sarkar, 2019, 2022) or health (Bonina et al., 2021). The digital resilience practices of households, however, cut across sectors, as they cope with multiple shocks simultaneously. We aim to move beyond a sectoral approach by turning to the resilience literature (e.g. Folke, 2006). Without doing justice to this burgeoning body of literature, we explore how household resilience practices are repeated and standardized, which we conceptualize as emerging extra-legal rules. Empirically we aim to envision how Kenya's digital master plan can enable the digital resilience of households in informal settlements. The remainder of the article discusses theory, research methods, findings, debates, conclusions, and recommendations.

Theory

Informal smart urbanism

Informality is found in all layers of urban development, whether it relates to decision making over dinner instead of during formal governance processes, or entails an entrepreneur selling products on the street. Many people, including urban elites, benefit from informal decision making in their favor, bribery, or illegal renting out of informal housing (Banks et al., 2020). Informality is thus not just a practice of the urban poor; it is an organizing logic (Roy and AlSayyad, 2004). We describe how informality relates to smart urbanism based on four characteristics, leading to a conceptual framework.

State of exception: Informality as an historical construct. Informality emerges and endures when formal planning systems cannot cope with the rate of urbanization and/or are unrelated to local customs and values (Roy, 2005). In post-colonial cities, unequal planning practices set up in the colonial era have led to the emergence of informality and informal settlements—a practice that still endures (Guma, 2019; Odendaal, 2006; Sarkar, 2019). The mismatch between laws and the way that people live and work deepens when contexts change during shocks and when new (digital) technologies are introduced (Guma, 2023). Simone (2001) therefore considers informality as a dynamic process which emerges when urban citizens attempt to access opportunities in response to shocks and trends.

Informality is thus not the problem but rather the solution to inappropriate planning (Turner, 1976). It is a widely practiced state of exception to formal rules necessary to make services and infrastructure affordable and available (Roy, 2005). This creates power-laden gray spaces (Yiftachel, 2009), within which informal practices are temporarily tolerated but never permanently legitimized, neither integrated nor eliminated (Schramm and Bize, 2023).

Digitalization processes are also often inappropriate in informality contexts (Guma, 2019; Pollio, 2024; Sarkar, 2019). Critical scholars on smart urbanism discuss how smart city programs, as main instruments of urban digitalization processes, exclude marginalized communities (Datta, 2018; Odendaal, 2006). Subsequent attempts to digitalize municipal infrastructure and services in informal contexts create states of exception. As the “modern infrastructure ideal” (Graham and Marvin, 2002) of a one-size-fits-all service delivery does not work, services delivery has become fragmented (Guma, 2019; Sarkar, 2019). Water ATMs have for instance emerged in informal

settlements alongside piped water in other urban areas (Guma, 2019; Sarkar, 2019). The delivery of water ATMs in an informality context demands a state of exception, linking formal services to informal contexts.

Extra-legal rules. Within states of exception, the interactions between civil, private, and public actors reproduce over time, whereby new and dynamic rules for social interactions emerge (Simone, 2001). These rules cater for situations not addressed by legal systems and are therefore extra-legal rather than illegal (Anyamba, 2011). Various scholars anecdotally describe how extra-legal rules emerge. Guma (2023) for example describes how two people in Nairobi lose their jobs during Covid-19 and subsequently start providing informal ride-hailing services on Uber and other platforms. They cut legal corners as they do not have ID cards. In these processes, their patterns of interaction reflect extra-legal rules, which are partly formal and informal. As another example, Sarkar (2019, 2022) describes how the government starts working with informal water providers to set up water ATMs, hardwiring informality into the government’s service delivery (Banks et al., 2020).

Disaster vulnerability. Scholars on resilience highlight that informality is likely to be risk prone due to discrimination, uncertainty associated with extra-legal rules, substandard housing, services, and infrastructure, and the likely location of housing and work on dangerous spots (Kimari, 2021; Satterthwaite et al., 2020). As the context is risk prone, households are forced to undertake resilience practices (Kimari, 2021). At the same time, attempts to digitalize resilience practices are constrained by limited skills and access to smartphones, computers, internet, and other hardware and software (Wamuyu, 2017).

Space for agency: Digital resilience practices. Agency materializes within the context of deep vulnerabilities and extra-legal rules. Scholars, especially in the field of institutional economics, have widely described the space for agency. At the bottom of the pyramid, actors have limited resources, capacities, networks, and negotiation positions, which reduce their resilience level. Their resilience practices are likely to be survival oriented (Fransen et al., 2023) and can be exploited in neoliberal markets (Banks et al., 2020). On the other extreme, Hernando de Soto (1989) argues that informality offers opportunities for entrepreneurialism outside locked-in governance systems. Such an entrepreneurial perspective enables innovative digital resilience practices through experimentation, activism and innovation (Guma 2024).

Resilience describes the capacity of systems and actors to withstand or recover from shocks (Folke, 2006). Shocks are often perceived as existential threats that pose continuous and long-term risks (Boh et al., 2023). However, in informal settlements households also face daily threats, such as income loss, fire, or illness (Fransen et al., 2024; Hati, 2025; Wyche et al., 2013). We are particularly interested in these everyday shocks, because these are commonplace in vulnerable informal settlements. As digital resilience practices are understudied at the household level, we identify four forms of resilience practices based on broader resilience theory. First, households may be forced to reduce costs by *belt tightening* after a shock, indicating a low level of resilience (Fransen et al., 2023). Second, households can engage in *maladaptive practices* which are resilient but unsustainable or harmful to others (Elmqvist et al., 2019). Third, households may adapt to shocks through incremental change by *adaptive practices* (Folke, 2006). In informal settlements, this is associated with a hustle to

survive when faced with a loss of employment, fire, illness, or other misfortune. The fourth resilience practice is *transformative*, which entails systemic change by learning from shocks. Such transformations are however rare (Folke, 2006).

Households may use digital technologies in their resilience practices. Scholars in ICT4D argue that these are potentially transformative, while opportunities for residents and firms in informal settlements have increased as the costs of digital infrastructure have reduced (Bonina et al., 2021). However, whether or not digital technologies enhance resilience is conditional. Ospina and Heeks (2010) propose seven conditions: digital technologies add to resilience if households become more robust, achieve scale, create redundancy, respond more rapidly, become more flexible, and are able to self-organize resilience and learn. These indicators are in line with Folke's (2006) system approach and Elmqvists et al.'s (2019) operationalization of resilience.

Conceptual framework

We conceptualize that informality influences digital resilience practices as a contextual factor. Its high level of vulnerability exacerbates the frequency and intensity of daily shocks and reduces options to use digital technologies. At the same time, the extra-legal rules within historically constructed states of exception condition what digital resilience practices households are likely to undertake. The resulting digital resilience practices are described based on the forms of resilience and whether conditions are met for digital technologies to contribute to resilience (Figure 1). Recurrent digital resilience practices subsequently turn into extra-legal rules, thereby reproducing informality. Table 1 operationalizes the study based on theory.

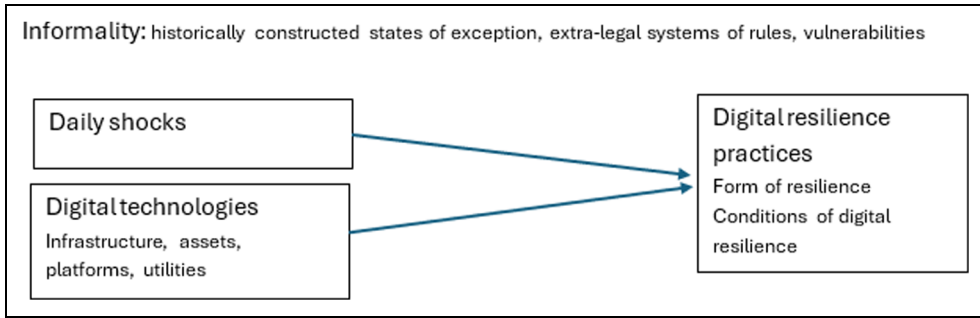


Figure 1. Conceptual framework.

Source: Authors.

Methods

The study forms part of larger community-based participatory research in Mathare, aiming to create reciprocal relationships between researchers and community-based organizations (CBOs) to co-produce knowledge. Principles include working with community researchers, sharing knowledge, holding validation workshops, and empowering CBOs through applied knowledge. The participatory approach has enabled us to appreciate the informality context as experienced by local researchers and residents. Interviews were conducted by external and community researchers, which led to questions derived from theory and daily experience.

This research is approached as a case study using mixed methods. Data is collected through 46 household interviews, two workshops, and secondary data from 10 and 12 academic articles respectively on Nairobi and Mathare. Interviews were sampled based on maximum variety in location, sex, household composition, and age. Each interview lasted about an hour and was conducted inside the house, enabling observation and privacy. Of the household sample, 56% are female, the ages ranged from 18 to 72 with a modal score of 25 to 34, while 37% lived in

tenement houses near the main road and the remaining 63% in tin shacks on small footpaths. Household composition varied, with slightly more male- than female-headed households (54%) and many alternative family structures, (grand)mothers looking after (grand)children, children looking after their parents, and friends living together.

In the first workshop, we asked 29 community leaders what shocks and stresses the settlement has faced over the last two years and what informality entails for them. In interviews, we asked respondents what shocks they had faced the last two years and how they coped with these shocks. Respondents showed the digital platforms they used on their digital assets and we discussed if and how it helped them to overcome the shocks using checklists. After the analysis, we conducted a second workshop with community leaders and respondents to validate our findings.

We have deductively coded the transcripts of interviews, observation notes, workshop minutes, and literature notes according to our operationalization, inductively adding codes for household resilience practices. We subsequently grouped the digital resilience practices for types of shocks and the characteristics of resilience practices, looking for

Table 1. Operationalization.

Concept	Sub-concepts	Indicators	Sources
Informality	Historically constructed states of exception, extra-legal systems of rules ^a , vulnerabilities	<ul style="list-style-type: none"> • Histories of informality and digitalization • Relevance of urban regulations, plans, narratives, and service. • Vulnerability of the settlement (housing, services, infrastructure) • Settlement-level digital infrastructure • Perceived shocks by households in last two years 	Academic literature
Daily shocks		<ul style="list-style-type: none"> • Household digital assets • Household use of platforms • Household use of smart utilities 	Interviews, workshops
Digital technologies		<ul style="list-style-type: none"> • Resilience activities (digital and non-digital) 	Interviews, observations, literature on Mathare, workshops
Digital resilience practices		<ul style="list-style-type: none"> • Contribution of digitalization: robustness, scalability, redundancy, rapidity, flexibility, self-organization, and learning of digital resilience practices 	Interviews, observations, workshops

^aSystems of rules are operationalized as aggregated forms of digital resilience practices. The rules are formed by and subsequently condition digital resilience practices.
Source: Authors.

established, repetitive patterns, which we conceptualize as extra-legal rules.

The relatively large number of in-depth interviews, data triangulation, working with community researchers, and the validation workshop create a relatively high level of internal validity. External validity is however low, as the sample is small and stratified. We therefore theoretically generalize to contribute to theory on digital resilience.

Findings

Informality and digital technologies in Nairobi

Nairobi was established as a railway town in 1899 and became the capital of British East Africa in 1905 (Hirst, 1994, in Anyamba, 2011). The original town was planned for European railway employees and European and Asian traders, while neglecting Africans and Asian laborers (Anyamba, 2011). Town planning during colonial time reinforced and deepened racial segregation (Schramm and Bize 2023). Myers (2015, in Sarkar, 2022) argues that urban planning continued colonial blueprints after independence in 1963. Urban planning focused on large infrastructure projects, envisioning Nairobi as a modernized “world city,” while ignoring informal settlements (Harms, 2012, in Schramm and Bize, 2023). Urban planning thereby creates states of exception, temporarily tolerating about 60% of the city’s population living in informal settlements (Gerlach, 2008) and over 70% of informal employment (Murunga et al., 2021).

At the beginning of the new millennium, Nairobi started its journey to become a center of digital technology in Africa. This included policy support for starting entrepreneurs and ICT firms and e-services (Pollio, 2024), feeding Nairobi’s world-city brand. The widespread use of digital technologies was advanced by the introduction

of MPESA in 2007, which revolutionized digital payments and related financial services (Guma, 2019), and by the introduction of cheap Chinese phones (Pollio, 2024). Pro-poor digital service delivery in informal settlements took a flight since the late 2000s, supported by among others the World Bank, UN Habitat, and Water and Sanitation for the Urban Poor (Guma, 2019). Water ATMs and metered electricity and gas were installed in informal settlements. However, while these offer cheaper access to municipal services, they are regularly vandalized by competing informal services providers and cartels. The services are not very reliable either, with reported corruption and nepotism in contracting water ATMs (Sarkar, 2022). While Nairobi thus became dubbed Africa’s Silicon Savannah, the introduction of digital technologies in the context of informality has been bumpy (Guma, 2019; Pollio, 2024; Sarkar, 2022).

Informality and digital technologies in Mathare

Mathare is the third-largest informal settlement in Nairobi, and is perceived to be one of the most unsafe settlements (Van Stapele, 2016). It is a place where “the real thugs live” (Kimari, 2021: 148). It is an old, dense, and consolidated informal settlement, with a history dating back to the 1920s (Fransen et al., 2024). Located about 5 km from the CBD, it attracts people working in the CBD and its surrounding formal settlements. The settlement includes informal apartment blocks up to seven floors high, often without water supply, drainage, or waste collection, as well as houses of makeshift material. Most households rent, with absentee landlords.

The first water ATM of Kenya was introduced in Mathare in 2015, with the international goal to provide universal access to safe water by 2030 (Sarkar, 2019). Similar e-services have been provided on a smaller

scale for electricity and cooking gas. Health services have been digitalized as well, but their platforms are hardly used. The police and the fire brigade also added digital contacts but can best be reached by phone, using personal contacts (workshop). Although e-services are potentially cheap, with water ATMs being 400% cheaper than other water kiosks, their implementation is restricted by their meagre presence, opposition from the cartels (Sarkar, 2019), and the digital divide. Water ATMs are located along major trunk water lines and are often out of use: of the 25 smart water points, only three were functional during our data collection, while 13 were taken over by community groups and no longer digital or cheap and the others were demolished by gangs to preserve their income from water. CBOs and NGOs in Mathare also offer other services, including digital community mapping (Lundine et al., 2012), digital women's empowerment programs (Githaiga and Wildermuth, 2022), and community waste management using platforms to coordinate payments (Kovacic, 2014; Mkize, 2022). The formal private sector also offers digital services, with M-Pesa as the main example, but most public services are offered by informal providers, operating as CBOs, gangs, or cartels (Guma and Wiig, 2022; Sarkar, 2019).

Household access to digital infrastructure is constrained (Wamuyu, 2017), with considerable spatial and temporal differences in Internet and electricity access. Mathare has multiple Base Transceiver Stations and Wi-Fi antennae, especially of Safaricom, but many are broken. Mabatini, a small village in Mathare, had access to Moja Wi-Fi, a private entity which offered free Internet if residents watched advertisements. However, the Wi-Fi network is no longer available, and the associated routers and antennae are dysfunctional or have been stolen. For most respondents, the cost of internet and digital assets is a key concern. Only a few

respondents own internet facilities, whereas cybercafes and vocational training institutes are sparse.

Daily shocks

All respondents have faced multiple shocks in 2022–2023; we analyze the three main reported shocks. The most-reported shock is income loss. As most people work casually, they regularly experience periods without income. This has been made worse by Covid-19, which has exhausted household assets and caused high inflation rates and governmental budget cuts (workshop). A second shock relates to unsafety, be it crime, murder, or fire. Crime and murder levels are reportedly high in Mathare, compounded by alcohol and drug abuse (MT34, MT41, workshop). This includes police killings, morbidly indicating the complex relationships of Mathare residents with government agencies (Van Stapele, 2016). The number of fires is high due to cooking practices, building materials, illegal electricity, and local conflicts (Hati, 2025). The third shock is illness, related to the unhealthy living and working environment and poor health facilities. Illnesses and accidents are not always well treated, causing long-term effects including lasting handicaps such as skin diseases and blindness.

Digital resilience practices

In their responses to shocks, households undertake a variety of actions, which are temporarily tolerated by the government (i.e. a state of exception). We find that households apply 45 different resilience practices, of which 18 (40%) are digital. Table 2 groups these for shocks and forms of resilience, whereby each group represents a stylized repetitive digital resilience practice (i.e. an emerging extra-legal rule). We add a “general resilience” category for generic

Table 2. Forms of household resilience (*digital and non-digital*).

	Forms of household resilience			Potentially transformative
	Belt tightening	Maladaptive	Adaptive	
Daily shock				
Employment and income loss	Reduce expenses	E-credit trap	E-credit and savings, online job search, casual online work, e-marketing	ICT jobs, e-learning
Credit trap		Credit trap	Credit and savings, job searches, casual work, income diversification	Learning
Unsafety	Reduce expenses	Unsafe electricity and housing	Reporting crime and fires, e-credit and savings, online job search, casual online work	E-training, safe (online) services, awareness creation
Illness	Ignore	Ignore, informal health services	Credit and savings, job searches, reinforce houses, avoid risks, community policing, fight fires, therapy	Training, awareness creation
General/ all	E-gifts and loans Gifts	E-gambling, e-criminality Gambling, criminality	E-prevention, e-health portals, e-health insurance Preventive measures, visit health facilities	Online work of Community Health Promoters (CHP) CHP, receive free medication, use better health services Online activism, e-education, e-learning Activism, education, learning

Source: Authors.

practices applied to any type of shock. The remainder of this section describes grouped digital resilience practices.

Belt-tightening digital resilience. Households apply belt-tightening practices as a last resort, when their resilience level is low. This entails that they sell their assets including smartphones (R12), reduce their number of meals (R4, 12, 20), stop using public transport (R31), or no longer visit paid-for toilets (R27). They ask for gifts and/or apply for loans, which have become almost fully digitalized (R4, 12, 20, 23, 25, 27). Digital payment has become the norm.

Belt tightening is a likely strategy when households are faced with multiple shocks and limited digital assets. Shocks may push respondents below the poverty line. Respondent 4, for instance, receives money on her dumbphone from the local church and family after she lost her job as a domestic worker when she fell ill, her son lost his job and left Nairobi, and she could no longer afford school fees or feed her two grandchildren. Her household became isolated, as her illness made it impossible to work. In her case, digital gifts replace face-to-face gifts. It adds slightly to her resilience, as it offers a more rapid response time, but otherwise does not add to resilience. She does not use other platforms as she lacks skills.

M12 is in a similar situation, being disconnected from the formal city with limited digital assets. He earns an uncertain income of about US\$1 per day transporting water within Mathare. His wife died and he looks after a handicapped child. A dumbphone allows fast and constant contact with and payment from his clients, without offering additional income, redundancy pay, or flexibility.

Other respondents describe how shocks temporarily require belt tightening but they combine it with other practices. R23 for instance performs casual works in informal

shops, but when sales are low she has no or little income and asks for digital gifts to buy food for her and her children. R25 lacks the skills and funding for digital health insurance via NHIF, leaving her more vulnerable. R27 visits richer friends in Mathare with toilets when she cannot afford the costs of community-managed toilets. Most have a dumbphone or borrow one with M-Pesa and its embedded platforms in Fuliza and M-Shwari (R4, R16).

Maladaptive digital resilience practices. Various households apply maladaptive digital resilience practices, which are short-term responses to a shock but unsustainable or reduce community resilience (Elmqvist et al., 2019). Their digital skillset is basic and access to digital assets is limited, whereby most respondents own a second-hand smartphone shared with their family.

E-credit traps are common. Micro credit enables households to smoothen income during shocks, offering funding with a rapid response time, flexibility, robustness, and abundance. However, the workshop and interviews reveal that micro credit is often used to repay interest on loans leading to credit traps. R22, a widow with a daughter and two grandchildren, notes: “taking loans from the phone is easy.” Respondents with smartphones can easily access digital lending platforms such as O-Kash, Tala, KCB M-Pesa, Branch, Fuliza, and Zenka (R25, R38). R34 reports: “It gets to the point that even with a little amount of money, it’s difficult for me to repay loans. It isn’t a nice thing to delay repaying but we do so to not let our children sleep hungry.”

Default payments may lead to blacklisting by the Credit Reference Bureau (R20, R21, R34, R36). R20 explains:

I took a loan from an app known as Tala; they were tough on me and placed me on CRB, [...] they put you in CRB where you cannot access

M-Pesa, you cannot take a loan from M-Pesa and KCB [Kenya Commercial Bank], it is like they have locked you out.

R21 is also unable to repay her loans whereas new loans are denied, noting that she does not earn enough income from laundry work, mainly lives from gifts (belt tightening), and is back to one meal a day. R34, a single mother who took a loan after her house burnt down, has sleepless nights because she cannot repay her loan.

We also find anecdotal evidence of criminal online activities such as selling drugs, but we do not study these as criminality is outside the boundary of informality. The state of exception, however, creates a space within which criminality hides and is normalized. R20, for instance, joined a digital 'merry-go-round' (a community saving group) but the local organizer ran off with the money.

Adaptive digital resilience practices. Households apply 16 adaptive resilience practices, of which half are digital. Many respondents access digital micro credit after a shock without entering credit traps, as they are aware of the risks (R24). Others search for casual work online when faced with job or income loss, often in construction. R41 and R14 use WhatsApp, TikTok, Instagram, Facebook, and YouTube to search for work. R14 notes:

I enquire about online jobs through WhatsApp since I have many entrepreneurs' contacts. I ask them to look for online jobs for me. [...] It has helped me because there was a time I worked online where I was earning when people view my status, one view was Ksh 30.

A related practice is to diversify income online. Out of the 46 respondents interviewed, 23 sometimes engage in online jobs. R41 notes: "I used to do things online like I was doing online writing and I was

promoting peoples' businesses online." A fourth adaptive practice is to strengthen informal firms through e-marketing and online buying and selling (R4, R31, R39): "Yes, yeah. I post silver cyprinid, onions, pampers, and the tailoring work, I have pictures on my phone ... I put everything together and post them on WhatsApp" (R4).

After fires, theft, or illness, digital platforms are used to spread the news or report to the authorities. Community Health Promoters digitally create awareness of health risk via WhatsApp. For six respondents, national e-health insurance reduces risks.

Adaptive digital resilience practices are commonplace and combined with non-digital practices: people extinguish fires, reinforce houses against burglaries, avoid risky places at night, volunteer for community policing, visit health facilities, and/or go into therapy. Digital resilience is a standardized practice which diversifies the hustle for survival. It contributes to resilience, as it creates redundancy, flexibility, rapid responses, and robustness and allows for self-organization. However, it has limited effects on learning and scaling, while its specific contribution to resilience varies. Most respondents own a second-hand smartphone or borrow one (R5). Some households have less access to (formal) assets, which limits their ability to adapt. Digitalization contributes less to resilience if households have reduced digital skills or access. This is associated with living in iron-sheet housing informal services and casual work (R17, R25, R27, R32, R40, R36). For instance, R40 is a single mother working as a hairdresser. She borrowed heavily after a fire destroyed her working space and a thief stole her chairs. She is still recovering but is often idle as there are not enough customers. While she does use her smartphone to look for hair designs and market her business, she more often uses it idly. For R25, limited digital literacy reduces

her digital resilience: she does not use national health insurance (NHIF) because she does not understand the digital application process. Digitalization is likely to add more to resilience if households have better digital skills and assets (R24, R26, R39). R26, a 21-year-old pregnant woman who lives with her ill mother, is more resilient to electricity outage, as she combines formal and informal electricity and gas cooking. R24 is also 21 years old and combines going to college with online work, such as buying and selling bitcoins, online contests, and offline work such as marketing for a shop. However, in all cases digital adaptability is limited by low-cost, often second-hand phones with free social media such as Facebook and WhatsApp (workshop, R24; see also Ritchie, 2022).

Transformative digital resilience practices. We identify 16 potentially transformative resilience practices, of which half are digital. They differ from adaptive strategies in enabling more learning and scaling. The most-reported practice is online collective action by Community Health Promoters (R3, 11) and CBOs (R2, R3, R11, R14, R29). Digital platforms are widely used in collective action in waste collection (Kovacic, 2014), whereby WhatsApp, Facebook, and M-Pesa are combined with the mundane technologies of barrels and carts (Mkize, 2022), community policing (Hagan et al., 2012), community mapping (Lundine et al., 2012), and for digital media and Slum TV (Githaiga and Wildermuth, 2022).

A second potentially transformative practice is to install innovate public services, such as metered gas for cooking (R26, R36) and solar energy (R15) and sawdust toilets to reduce health risks (R2, R32).

A third practice is to use digital platforms as work. R10 is a student who lives in a stone building along the main access road with formal electricity and works as a digital

photographer in Mathare. R19 has a university degree in interior design and works digitally as designer.

A fourth practice is e-learning for school, fun, or business. Often learning is adaptive rather than transformative, for instance if a hairdresser looks for new hairstyles (R40) or if it represents a search for new income opportunities (R24). However, some respondents have sustainably reduced costs or increased income by combining online and offline work (R2, R3, R11). R2 is a grandmother who runs a small firm buying and selling daily products and doing laundry. She is constantly looking for online and offline opportunities. She copes with multiple shocks, such as a daughter with a skin disease, a sister with HIV, a divorce from a drunk husband, and rising prices, by expanding her income through online marketing. R11 is another female entrepreneur who works online selling rice, underwear, and cryptocurrencies, while at the same time being a community activist managing a credit and savings scheme and designing online marketing campaigns.

Transformative digital resilience is associated with better digital access. Most respondents, however, lack the skills to use specialized platforms as well as access to computers, limiting their options (R1, 2, 14, 15). R10 and R29 are exceptions to this.

Dynamics and overlaps

The discussed digital resilience practices are not silos but form an integral part of the daily hustle for survival. Households apply generic resilience practices, such as e-learning, e-gifts, and online micro credit to cope with all kinds of shocks. They aim to create abundance, robustness, scale, rapidity, flexibility, and learning to cope with the next and yet unknown shock. General digital resilience practices diversify social networks, income, and work online by using social

media. However, households sometimes lack the resources, skills, and networks to do so and resort to belt-tightening and maladaptive practices.

We find considerable dynamics between digital resilience practices, as households use multiple practices simultaneously. R21 and R34 combine maladaptive practices (credit traps, online gambling) with belt tightening. R31 adapts to a shock through online work while saving costs by walking to school, while R1, R33, and R48 combine adaptive and maladaptive practices. Quite a few households aim to be transformative but end up being adaptive due to the multiplicity of shocks and the high level of vulnerability (R2, R3, R7, R11, R48). Transformative digital resilience often fails to meet its potential in sustainably improving a household's resilience. The line between digital resilience practices is thus blurred and porous.

Debate: Parallel extra-legal rules

The study aims to contribute to the emerging body of scholarly work on informal smart urbanism. It adds the concept of digital resilience (Ospina and Heeks, 2010; Tim and Leidner, 2023) and finds that adapting to daily shocks is at the core of digital practices in the context of informality.

The history of Nairobi and Mathare illustrates that informality is historically constructed, whereby inappropriate regulations and policies are reproduced over time (Anyamba, 2011; Guma, 2019; Sarkar, 2019; Schramm and Bize, 2023). Digitalization policies are equally inappropriate for households in the context of informality (Guma, 2019, 2023; Guma and Wiig, 2022; Poggiali, 2017; Sarkar, 2019, 2022). Inappropriate regulations and policies and associated vulnerabilities, as well as limited digital access, assets, and skills, condition and restrict the agency of households to engage in digital resilience practices.

In Mathare, nearly half of all resilience practices are digital. Digital platforms such as M-Pesa, Facebook, and WhatsApp offer formal–informal interfaces linking households to public services (Guma and Wiig, 2022; Sarkar, 2019; Van Tuijl et al., 2026), support networks (Ritchie, 2022), and international markets (Sharma and Dahlstrand, 2023). When looking for income, households in Mathare start working on digital platforms, e-market their products, and/or apply for micro credit online. Digital platforms thereby open up opportunities to become resilient but also reproduce power imbalances, enabling exploitation and maladaptive practices.

As formal policies and regulations are inappropriate, extra-legal rules of social interaction emerge (Simone, 2001). Our case study explores these for digital resilience practices of households in Mathare. Alongside generic rules of diversification and risk avoidance, we identify four parallel extra-legal groups of rules.

The main rule structuring belt tightening is that online informal social networks are used as safety nets. Informal social networks are relatively disassociated from formal services, offering access to informal grants, loans, housing, income, and services. This takes place in the context of low resilience levels and limited resources other than social networks.

For maladaptive practices, the rule is to creatively look for emergent solutions to a shock in formal and informal spheres. It bends rules for personal short-term gains at the expense of community or long-term resilience. The line between maladaptive and adaptive resilience practices is, however, thin. Online micro credit is for instance often adaptive, but households bend its rules to feed their children or pay school fees, even if they cannot afford its costs in the longer term. Cartels and gangs equally offer valuable services, but they may bend rules to

protect their turf violently and inflate prices. Community groups may destroy water ATMs and electricity connections to protect their income (Guma, 2019; Guma and Wiig, 2022; Sarkar, 2019, 2022). Parallel rules of gangs and cartels, related to for instance muscularity (Van Stapele, 2016), reinforce maladaptive behavior.

Adaptive practices similarly look for emergent solutions but are sustainable and do not harm others (Elmqvist et al., 2019). When applying for micro credit, for instance, households ensure that they can repay it. Households look for socially acceptable solutions if they can't adhere to formal regulations associated with for instance online work, e-finance, and e-services.

Finally, transformative practices are forward-looking rather than short-term responses. They aim to increase income and/or community benefits, while reducing costs in the longer term, highlighting the collective, entrepreneurial, experimental, and learning opportunities of informality (De Soto, 1989; Guma, 2024).

Conclusions

Our main conclusion is that informality influences how digital technologies affect household resilience. Households are forced to undertake digital resilience practices, as the informality context is highly vulnerable. At the same time, digital resilience practices are constrained by limited digital access, assets, and skills and by inappropriate urban policies, plans, and regulations. Within these contexts, households self-organize their digital resilience, whereby practices become standardized over time, turning into extra-legal rules which are innovative and temporarily tolerated, yet remain precarious.

We identify four parallel digital resilience practices in Mathare, whereby the influence of digitalization on resilience differs (Table 3). In belt tightening,

households receive digital gifts and apply for loans, which offer a faster response time after a shock but otherwise do not add to resilience. It primarily replaces face-to-face gifts and loans. Maladaptive practices associate with incremental, short-term improvements of household resilience at the expense of others. They illustrate that digital technologies can negatively affect community resilience. Adaptive digital resilience offers additional ways to respond quickly and flexibly to shocks. Finally, transformative practices improve household resilience over the longer term, adding learning and scalability.

We contribute to the theory on smart urbanism using informality "as a marker" (Guma, 2024). Our main contribution lies in showing how, in the context of one of Africa's digital frontier cities, households informally apply digital resilience practices. These practices are repeated and standardized, which we conceptualize as emerging extra-legal rules. The rules reflect creative and innovative appropriations of digital technologies in the daily hustle for survival.

We recommend more research on digital resilience practices in informal smart urbanism. We particularly recommend multiple case studies comparing how planning systems, states of exception, vulnerabilities, and dynamic rules influence the impact of digital technologies on resilience in different contexts. In-depth studies are also needed to describe practices and rule setting in greater detail and to explore how digital and non-digital resilience practices interact.

The above leads to two policy recommendations. In the short term, we recommend participatory planning processes to reduce vulnerabilities, prevent belt tightening, fight maladaptive practices, and support the adaptive and transformative digital resilience practices of households. We propose adaptable policy responses, which recognize, value, and support digital resilience

Table 3. Contribution of digital technologies to resilience.

Digital resilience practices	Contribution to household resilience
Belt tightening Maladaptive	Faster response time Faster, more robust, flexible, abundant, and self-organized, but community resilience reduces
Adaptive Transformative	Faster, more robust, flexible, abundant, and self-organized Faster, more robust, flexible, abundant, and self-organized, while enabling scaling and learning


Source: Authors.


practices. In the long term, the resilience of households living and working in informality requires systemic change, rethinking how urban planning, smart city programs, and ICT industries can become more appropriate for all urban residents. This does not equate to formalization processes, which may further exclude the urban poor, but rather to participatory processes aiming to reduce vulnerabilities and rethink formal rules, while supporting the innovative and creative potential of informality.

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Data availability statement

The data is not available in its present form due to privacy issues but can be made available if considered relevant.

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