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Beyond materials: The construction process in space, time and culture in the informal settlement of Mathare, Nairobi

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ABSTRACT

The informal settlements in the Global South, mostly comprising of inadequate building solutions, are growing rapidly, therefore calling for more sustainable construction interventions and upgrading strategies. Within this context, this study considers that appropriate construction strategies are capable of engaging with the local economy, affected by endemic poverty, therefore contributing to the improvement of the settlement's socio-economic and physical conditions at once.

A deeper understanding of the settlements construction process, actors, and key factors influencing material use, acceptance, and distribution, is therefore needed, and is here presented for the case of Mathare, in Nairobi. The study is based on field-based qualitative and quantitative data collection through semi-structured interviews and mapping, and through the adoption of methods as stakeholders analysis and supply chain mapping.

The following insights have emerged from the study:

- 1) different client groups have access to different building materials;
- 2) the distribution of materials inside the settlement is strictly related to stores and building sites accessibility;
- 3) the local adoption of materials is highly impacted by the availability of space both at the supplier store and on the building site;
- 4) contextual cultural factors can have a major role in the construction organization. as for the case of ethnicity influencing roles distributions in the construction sector.

The study insights are of relevance for the practice, specifically to inform project managers and policymakers involved in construction projects in the informal settlements about local material supply and demand constraints. Specifically, the study highlights the need to consider the availability of stocking space alongside the supply as well as on-site.

Finally, it shows the validity of adopting a mixed-methods approach, looking at the settlements through a socio-technical approach.

1. Introduction

The rise of urban informality corresponds to the manifestation of a problematic socio-economic condition, affecting the low-income population in the vast majority of the less developed countries (in this study referred to as Global South) (UN-HABITAT, 2016). This reality emerges from the failure of the local governments to keep up with high housing demand, especially for the low-income group, due to lack of economic resources or political will (Pugh, 1997; United, 1995). Considering the recent demographic projections, urban centers in the Global South, already struggling to provide for housing for all, will suffer the

significant additional stress of the upcoming population growth, which is likely to see the informal settlements as the solution to the housing gap (Bredenoord et al., 2010; United Nations Department, 2018).

In addition to that, according to the United Nations Center for Human Settlements and the International Labour Office, high unemployment in urban areas is one of the major problems faced by all less developed countries, affecting severely the informal settlements. In that context, they result in a setback for the transition from a temporary permanence in the informal settlements towards a more appropriate and dignified permanent housing solution in the formal city (Huang et al., 2018; Bennett and Rablen, 2015). The need for new constructions at

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scale in the context of the informal settlements can be considered as the opportunity to mobilize the local economy through tailored construction projects and strategies, resulting in local employment for housing delivery. To successfully move in this direction to engage with the local dynamics rather than disrupting them, the understanding of the socio-economic and cultural dimension of the informal city, and specifically of its construction sector, needs to be achieved. Focusing on the case study of Mathare in Nairobi, the present work tackles the exploration of the local construction practice, approached from an integrated perspective combining technical assessments with analysis touching on the social dimension of the sector, and it does so based on data collected on the field and a mixed-method approach.

As a result, this study aims to provide insights on construction process and its players in the informal city, as well as on drivers and bottlenecks impacting material uptake and use. This work furthermore investigates the connections between material adoption in the informal city and its broader socio-economic implications. To do so, it covers the multidimensional character of the built environment of the informal settlement by touching upon diverse fields of knowledge including both the engineering and the social studies domain.

1.1. Local building culture and the informal settlements

The holistic approach proposed within the present study aims to provide for the understanding of the local building culture in the informal settlement as basis for the further analysis of its construction sector. Local building culture, as defined by Caimi et al. consists in the consideration of the habitat through the lenses of the construction components (materials, techniques, structure, and shape), the construction organization (construction, maintenance, social and economic impact), design, and use(s) and its symbolic character. (Caimi and Moles, 2017). In their work, the authors consider a building culture as resulting “from the adaptation of a community to the environmental conditions of the territory in which it is established - physical, climatic, social, economic and cultural.”, therefore highlighting the multidisciplinary connections in place between the building units – or its components- and the broader environment. For this holistic and multidisciplinary perspective, this approach is of interest for the present study, which aims to contribute to the understanding of the informal settlements construction by connecting its technical and social dimensions, as will be more thoroughly explained in the Method section.

The concept of building culture, and of a social interest towards its features, has been explored in the past by Davis (2006) as he investigated the concept of building as a cultural product. In his work he unfolds the system of knowledge, rules, procedures and habits that generate the everyday building, reinforcing the concept of human-centered nature of the building process and result. Further studies have then targeted specific cultural dimensions of building and construction, as for the case of the identification of bottlenecks or drivers for the implementation of specific building technologies (Obonyo et al., 2013; Kulshreshtha et al., 2020). Furthermore, the cultural dimension is often central in reconstruction assessment, with aim of evaluating the appropriateness of the post-disaster solution and therefore the likeability of its long-term success (DuyneBarenstein, 2015; DuyneBarenstein and Pittet, 2013). Concerning the specific context of the informal city, such an approach has not been applied yet to the understanding of its local building culture, except for the study of Royden-Turner exploring the informal city through an ecosystem approach, and the work of Celentano et al. investigating the construction process in the informal settlements of Bangkok (Royden-Turner, 2012; Celentano et al., 2020).

Given the ample radius of content covered by the wording *culture*, a variety of factors can be of relevance to understanding the local building culture –or cultures-of a place, including gender norms, tribal and religious beliefs, ethnic organization, law, capabilities, and habits of groups and individuals (Tyler, 2010). On this basis, this study aims to extract

major components describing and influencing the local building culture of the informal settlement of Mathare, and insights extendable to the more broad context of the informal city worldwide.

Only by fully understanding the socio-technical dimension of the building sector, extending far beyond materials and grounded into the ramifications of the local building culture, it is, in fact, possible to draft appropriate construction strategies. With the term *appropriate strategies* (or technologies), this study refers to strategies based on the local context within its needs, capacities, and limitations comprising both technical aspects, and social ones, therefore targeting stakeholders inclusion and satisfaction through locally tailored solutions.

1.2. The informal city: buildings and materials

The definition of informal city, once referred to as *slum*, embeds some specific building characteristics, as being not complying with planning and regulations and often residing in hazardous areas (UN-Habitat, 2015a; UN-Habitat, 2003). Its physical features and local denomination change according to the cultural, geographical, economic, and legal frameworks, resulting in a variety comprising provisional shelter solutions as well as proper housing units. Such variety has been embraced under a global description set by the UN Member States in 2003, defining “a slum household as a group of individuals living under the same roof lacking one or more of the following five conditions: 1) access to improved water, 2) access to improved sanitation facilities, 3) sufficient living area – not overcrowded, 4) structural quality/durability of dwellings, and 5) security of tenure. (UN-Habitat, 2015b). These five “deficits”, embracing the variety of building types, technologies, and urban layout that can be encountered globally, are still used nowadays to measure and monitor living conditions and relative improvement in such contexts, in this paper referred to as informal cities or settlements, with no differentiation. The wide diversity of such settlements worldwide makes the description of their constructive materiality challenging, but still, some general features can be identified. The most diffuse building materials in urban informal settlements worldwide consist of iron sheet, lightweight panels (as OSB boards, gypsum boards, plywood, or polycarbonate), and prefabricated lightweight concrete blocks and bricks, the former particularly diffuse in Africa and South East Asia while the latter in the Latin American context. The richness of site-specific building declinations is enhanced by the mix of local culture and lack of resources, resulting in the unique resourceful creativity and resiliency of the informal systems, observed in various architectural studies (URBZ, 2018; Hehl and Angelil, 2011; Angelil and Malterre-Barthens, 2016; Brillembourg and Klumpner, 2012; King, 2016; King, 2017; Celentano, 2019).

The case of the settlement of Mathare assessed in the here presented study embeds all the above-listed features, as it includes a variety of building declinations and material use resulting in a mix of a more consolidated stone-based development juxtaposed to temporary-looking, and mostly iron-sheet based housing clusters. Such richness and variety of building materials and use within the settlement will be the object of data collection and analysis presented in the upcoming sessions.

1.3. The informal city: the construction practice

While the interest in the typological and incremental character of housing construction in the informal settlements is growing, resulting in consistent knowledge production, their construction process remains mostly unknown, as much less investigated. A precursory study by Lavigne and Dufresne looks into its economic dimension, focusing on the Indian case of Hyderabad (Lavigne and Dufresne, 1988). Here, the authors question the absence of research on the economy of the construction sector, listing its difficulty as just one of the factors obstructing its development together with lack of willingness of the stakeholders to disclose data potentially leading to highlight the illegality of the process.

Thirty years later, a consistent body of knowledge on the contribution of the informal sector to the construction industry has been established, recognizing the interconnection between the formal and informal urban systems (V Mitullah and Wachira, 2003; Mlinga and Wells, 2002; Wells, 2001; Lizarralde and Root, 2008). These works look at the informal labor, as “defined to include all construction workers who are employed on a casual or temporary basis without any proper form of contract, as well as those who work for themselves either alone or in small groups.” (Mitullah and Wachira, 2003). Implicitly, this applies as well to the case of the construction activities within informal settlements, as they rely on the informal labor as per earlier definition. So said, as no study so far has tackled specifically the construction process in the informal city, its process still remains mostly unexplored, and therefore in need of further work. On this basis, an initial understanding of the process and economy of the construction sector have been developed by Celentano et al. for the informal city of Bangkok (Celentano et al., 2020). The study investigated the construction of the informal city in its managerial and economic implications, combining Material Flow Analysis and Stakeholders Assessment. Their work proved the relevance of approaching the topic from an integrated perspective combining technical assessments with analysis touching on the social dimension of the sector. On this base, this work contributes to this field of knowledge, focusing on the construction practice and its supply system in the informal settlement of Mathare, Nairobi, to explore the links between construction, materials, and the broader socio-economic sphere.

1.4. The informal city: economy, supply chain, and construction process

The housing delivery sector can act as a possible engine to move towards a more inclusive and virtuous economy (United Nations, 2016; Maly, 2017; Lyons et al., 2010), as shown in the central position acquired by housing in the New Urban Agenda as well as in diverse assessments carried out worldwide (AsomaninAnaman et al., 2007; Bhalla and Edmonds, 1983; Personal et al., 2002). It is known that, while unemployment and poverty are a major local issue, the majority of informal dwellers earn their living from informal activities located in the proximity of their settlements (LeGates, 2011; UN-Habitat, 2010; Brown and McGranahan, 2016; Kudva, 2009) (LeGates, 2011; UN-Habitat, 2010; Brown and McGranahan, 2016; Kudva, 2009) (LeGates, 2011; UN-Habitat, 2010; Brown and McGranahan, 2016; Kudva, 2009). A few studies in the late Eighties touched upon the informal settlement construction process, either to set the roots for specific housing implementation plans accounting for the self-led component of the settlement development, at the time (Bhattet al., 1990), or to highlight the human-centered character of the house making process, as a value to be preserved and fostered (Turner, 1976). Authors on construction economics (Wells, 2001), (Wilson and Hillebrandt, 1975; Tan, 2002; Bon, 1992; Wells, 2007; Turin, 1978) agree on the relevance that the construction sector plays in economic growth, and propose a vision where the sector actively contributes to economic growth. Recently, methods have been developed to assess the economic flow of the construction process stages between its different stakeholders, as for the case of Ioannidou et al. assessing material and economic flow of stone including the allocation of profit along the supply chain (Ioannidou et al., 2017). Adopting a metabolic approach, which proved relevant as in the work of Royden-Turner (2012), Celentano et al. look at the informal city as a socio-technical system, focusing on the informal construction sector in the making of the informal city (Celentano et al., 2020), identifying the role of construction management in diverting or catalyzing the economy at the community level. Along with their study, as well as in the here presented work, the wording *community* is utilized to describe the ensemble of the social network of the stakeholders living in one particular area within the settlements and the physical infrastructure they inhabit and utilize, which they identify as their local hub.

These studies unveil the connection between construction choices at the building scale and their socio-economic implications on the

territorial system. A few other studies have combined informal activities and socio-economic assessments. It is the case of the application of stakeholder analysis and supply chain mapping to urban waste recyclers in India by Suthar and al. (Suthar et al., 2016). The method allowed not only to systematically assess the sector and the stakeholders involved but also to identify drivers and key-holders along the process. Sharing the same approach, the current study aims to identify and link the stakeholders involved in the construction of the informal city together with the drivers influencing its construction process and material procurement. Considering these different tensions, the objective of this work is to achieve a holistic understanding of the ongoing settlement construction from its socio-technical perspective. This enables the identification of the consequences of construction choices extending beyond the building materials while recognizing strategies for a more inclusive formal sector, capable of engaging with the relevant local stakeholders through appropriate solutions.

1.5. The context: Mathare, Nairobi

The city of Nairobi is home to 4.3 million inhabitants, and it is estimated that more than half of its population is currently sheltered in informal settlements, occupying less than 1% of its city boundaries area and less than 5% in its residential area (WangariKaranja and Makau, 2011; Mitullah, 2003; Mutisya and Yarime, 2011). This overwhelming housing gap is projected to suffer the pressure of a 50% population increase by 2025 (WangariKaranja and Makau, 2011; Mutisya and Yarime, 2011), most of which is expected to take place in its informal settlements, still threatened by evictions (OHCHR, 2018). The size of many of these settlements, locally referred to as *ghettos* or *slums*, is impressive: Kibera alone accounts for around 1.200.000 inhabitants, distributed in 550 acres (International, 2009). Second, in size, Mathare (represented in Fig. 1) stretches along the homonymous river for over 3 km, accounting for an estimate of 600.000 inhabitants (WangariKaranja and Makau, 2011). Because of its size and strategic location allowing for an easy commute to the city opportunities, Mathare is a place of a vibrant economy, both within its system and in connection with the neighboring areas. Despite the settlement extent and consolidated population, and mostly due to the flood-prone character of some areas, Mathare is still not addressed by any urbanization plan, leaving more than half of its twenty-four villages without sewage, water, or any basic service provision, therefore resulting in a diverse mix of informal and formal blocks and building development as further assessed in section 3.1. Due to the critical living conditions in the area, the housing project Mathare 4 A Slum Upgrading Program was therefore launched in 1992 by the Government of Kenya to enhance living conditions for its residents but was soon interrupted due to progressive complications (Wanjohi Supervisor, 2007; Diang, 2012; Muthoka and Malu, 2005).

According to land tenure and suitability for construction of the different plots, as well as in force of individual agreements with local chiefs, a certain level of formality has been reached, resulting in the development of four to six-story high buildings mostly located in the villages of Mathare North, Bondeni, Huruma, and Mlango Kubwa. (indicated in Fig. 2 in the next page). Still, their apparent construction formality does not often correspond to formal tenure, proper construction technique, or access to basic services. (For more thorough information on the state of the settlement in terms of land right division and infrastructure accessibility please refer to the Mathare Zonal Plan developed by Muungano Trust in collaboration with Slum Dwellers International and the University of Berkeley, California (Muungano Support Trust, 2012))

The informal part of Mathare, the object of this study, develops along the Mathare river for almost 5 Km, constituting around half of its extension, and is mostly concentrated in the villages of Mabatin, Mashimoni, Kosovo, and Nigeria. The status of apparent temporality of its dwellings does not mirror the long-term permanence of its population, most of which is born and raised in Mathare and therefore is



Fig. 1. Photo of the settlement of Mathare, Nairobi, from one of its Southern accesses, looking over the villages of No.10 and Mabatini, in the foreground, and Mathare Nord, in the background.

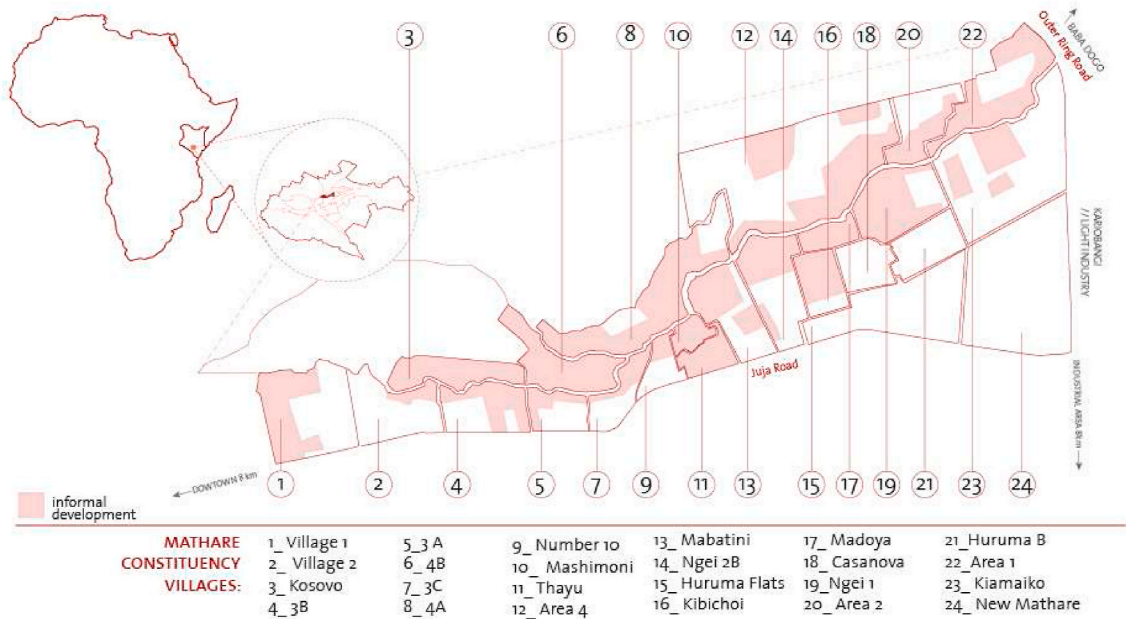


Fig. 2. Mathare settlement map including territorial localization, inner organization into villages, and an estimated indication of its informal development.

permanently settled in inadequate and unsafe building units. The discomfort of such housing conditions in the informal sections of the settlement is exacerbated by the lack or insufficient if not non-existing access to household basic service throughout their whole life. These include WASH provision (Water, Sanitation, and Sewage), safe electric supply, public lighting, mobility and accessibility to the settlement through public services, waste collection and sorting as well as medical assistance, education, and more. (For more information on settlements service provision please refer to Annex, Section 1) The frequent risk of floods due to the proximity to the river, and fires ignited by unsafe electricity connections and cooking methods, are critically boosted by

the settlement density, estimated at 185.000 inhabitants per Km2 (and resulting in around 5,4 m2 per person) (Mathare River, 2014). Besides, hazard exposure is exacerbated by and the building materials used in the informal portions of the settlement, mostly consisting of clustered single-story iron sheet houses, locally referred to as “structures” or “10 × 10” because their size measured in feet. With a great predominant of renters over structure owners (83% versus 17% according to the Mathare Zonal Plan report (Muungano Support Trust, 2012), the settlement serves the population left homeless by the lack of viable affordable housing solutions in Nairobi. Around one fourth of the residents consists of those relocated from other informal

settlements in the proximity (estimated to be at 25% of the total population), often due to forced evictions, which remain a matter of concern in Mathare as well.

Mathare has been selected as a case study for multiple reasons, as its strong economic ties and proximity to the city center, allowing the settlement to access the formal material production and supply chain and making it a typical case in the African urban scenario. Additionally, the personal contacts established by one of the authors in the settlement in 2012 and 2014 while employed on-site for a construction project played a decisive factor, as they facilitated extensive safe fieldwork for the current research and provided the study with a thick trustful network of key stakeholders within the construction sector.

1.5.1. Socio-economic settlement profile

The settlement population consists of the internal migrants looking for job opportunities provided by the city proximity, and to a first generation born in Mathare. In terms of demographics, the settlement mirrors the Kenyan prospect, being almost equally divided between men and women (Mapping No Big Deal, 2014) and is composed of over forty ethnic communities. (Muthoka and Malu, 2005), (R. of Kenya, 1995). This information is relevant as it is known that ethnicity and tribalism drive land use and market in Nairobi, and is furthermore considered a driver for violence in the region, as tragically manifested in Mathare during the 2007 election violence (Obala and Mattingly, 2014; Adino, 2010). No significant presence of foreign community is established in Mathare.

Poverty is a major endemic challenge for the local population, with the average monthly household income estimated at less than KSh 8500 (around 100 USD at the time of the survey), and is put under extreme pressure by the average household monthly expenditures are over KSh 9,100, resulting in an average monthly deficit. For this reason, the intended transient nature of the settlement (Mapping No Big Deal, 2014) often results in longer stays, becoming a permanent solution due to a lack of alternatives. The casual nature of employment in the settlement (estimated to be informal and therefore casual for 87% of the employed residents) adds on top of that the fluctuating income and therefore difficulty in saving (Muungano Support Trust, 2012). Although precise employment data are not available, a recent study targeting the youth community (age 10 to 35) reported unemployment level at 89% (Omboi, 2020). Despite that, the settlement population recognizes Mathare as a site of economic opportunities, and economic vibrancy through local entrepreneurial activities and multiple community-based organizations supporting the poverty coping mechanism through service provision. For what concerns the population composition, it is estimated that this is composed by 85% of residents below 35 years old (Mapping No Big Deal, 2014), and that around three fourths of it has a primary or secondary school degree.

2. Method

The work is based on six months of fieldwork conducted in 2018 by one of the authors, assisted by a community member, in the informal part of the settlement of Mathare and the city of Nairobi. The villages covered in depth during fieldwork were: Mabatini, Mashimoni, Kasanova, Kosovo, Mathare Nord, Mathare 4 A, Number 10. The research led to expanding the fieldwork along the supply chain of the construction sector, in the neighborhoods of Kariobangi, Industrial Area, and in the production areas connected to the research.

Data on the housing construction process were collected on the field through a mixed-method approach presented in the following section 2.1. Collected data were then analyzed, and the main building technologies present in the settlement together with information on their local use and perception are presented in section 3, Data. Collected data were also processed through the development of stakeholders analysis (Mathur et al., 2007) serving for the identification of the major needs and roles of the diverse actors related to the construction process in the

settlement. Such analysis was then associated with a stakeholder-based Supply Chain Mapping. Taking the definition of Gardner et al. with Supply Chain Mapping the authors refer to “the representation of the linkages and members of a supply chain along with some information about the overall nature of the entire map”. (Gardner and Cooper, 2003). The specific interest of mapping in the context of the study consists of material location and distribution flows. Furthermore, an integrated assessment of space consumption in correlation with material requirements on-site, based on the identified most diffuse building technologies, is finally obtained. This approach is set on the view of the city as a system and brings in the metabolic perspective from the field of Urban Metabolism, which seeks to achieve a better understanding of the relations between societies, mass and energy flow of production and consumption that shape and sustain each other, as summarized by Dijkstra et al. (Broto et al., 2012; Dijkstra et al., 2018).

2.1. Fieldwork and data collection

Fieldwork was conducted by the first author in 2018 for a total of around six months. It covered the settlement of Mathare, especially within its informally developed sections, and extended progressively to the metropolitan area of Nairobi interested by its supply chain, as Kariobangi, Baba Dogo, and Industrial Area.

Specifically, the villages interested in in-depth study were: Mabatini, Mathare Nord, and Casanova (see Fig. 2), as they proved for significant coverage of the settlement built environment variation, and were considered safe for fieldwork. Furthermore, the author's past work experience on a construction project in Mabatini allowed her to access a relevant pool of stakeholders to include in the study. Additionally, the pilot stage of the Mathare 4 A Upgrading Programme was also planned to be part of an in-depth investigation, but lack of collaboration from the residents and difficulties in finding relevant data on the program resulted in the abandonment of the idea. Outside the settlement of Mathare, the neighborhoods interested in the study were specifically: Light Industry (Kariobangi), Bab Dogo, Industrial Area. Those sites were not identified *a priori*, but emerged frequently from the supply-chain interviews and therefore were included as key sites, relevant for the study.

Fieldwork was as always conducted with the support of a resident of Mathare Nord (Pepe Henri Ochieng) with ties to the local construction sector and a previously established trustful friendship with the author. Although most of the local population is bilingual (Swahili – English) and therefore communication was not a major barrier for data collection, the author preferred to work together with Mr. Ochieng to approach the context with better awareness and more discretion. Mr. Ochieng also helped substantially in the identification of key stakeholders, and in providing access to Community Based Organizations and local gatekeepers as community leaders and landlords. He also often advised on the safety measures to be accounted for, therefore helping to select safe contexts for the study to take place.

Data collection was structured into the following main steps:

1. Observation of the building fabric of the whole settlement and identification of major building materials adopted. This phase took place on motorcycles, for a broader overview, and on foot, to access the denser sections of the settlement.
2. Mapping of local retailers, based on an aerial image and implemented by information gathered during the interviews.
3. Door-to-door interview with the residents. This was initially supported by a structured document, but it was noticed immediately that the presence of the document caused discomfort or high expectations in the residents, and was therefore abandoned in favor of a more informal conversation.
4. Interview with key local stakeholders active along the housing construction process, as local builders and contractors (mostly in-person, with the exceptions of phone calls as described in the Data

section). These were both stakeholders known to the author and her assistant due to their past construction work in Mathare with the Italian NGO Liveinslums, or stakeholders indicated by residents during their interviews.

5. In-person interview to the local retailers in Mathare, so to identify their supply chain, shop organization, distribution system, and material choice.
6. In-person interview to the construction materials retailers and producers which served the local retailers in Mathare. They were located beyond the community boundaries, specifically in Kariobangi (Light Industry), Baba Dogo, Industrial Area and within the more extended region. These interviews served to identify their own supply chain, distribution system and material choice, and their ties with the settlement of Mathare

More precise information on Data Collection can be found in [Annex, Section 2](#).

3. Data

3.1. Database: organization and content

Due to the lack of available data on the topic, the study consisted initially of the compilation of the database based on the fieldwork conducted, and is here presented organized in the following sections:

- i) Stakeholders' analysis of the construction sector stakeholders related to the supply.
- ii) Building materials in the settlement (use, culture, and distribution in the settlement)
- iii) Material supply
- iv) Construction process

Additionally, the database compiled includes maps representing the distribution of building materials and their retailers.

3.2. Stakeholder analysis

A diversity of stakeholders act along the construction supply chain in Mathare. These can be divided into the two main groups of end-users and retailers. End-users, or clients, are the final users of the construction product, being it either a building element purchased for repairs or a complete structure. They consist of structure owners, landlords, and tenants, the latter representing around 90% of the end-users in force of the very limited economic capacity of the local population at the household level, mostly unable to save enough to ever invest in a property house. Their interest in the material is limited to its impact on the rental price, as rent fluctuates according to the building material, being earth the lowest –around 1800 KSh/month- and stone the highest –from 3500KSh onwards, with KSh 110 corresponding approximately to 1 USD.

Structure owners, who do own the physical housing components but depend on the landlord agreement –if any is in place-due to their extremely weak security of tenure mostly prefer materials that can easily be disassembled and reassembled elsewhere in case of expected floods or eviction (enforced by landlords or public authorities), as iron sheet or timber.

Landlords who inherited their properties directly from the original land-owners, usually own multiple plots in neighboring alleys, resulting in a high economic capacity and local power, as reported by local tenants and material suppliers. They do not necessarily have ownership of the structures built on their plots. Where they do, their interest in materials is oriented towards the smallest investment rather than comfort, due to the rental business nature of their structures. Their own houses, when they reside in the settlement, are usually double-story, represent an exception, as their materials together with height and size act as a

status symbol to manifest their local power. According to the interviews with the residents, most of the landlords in Mathare do not reside in the settlement. This is true especially for those with the largest properties, which results in higher income due to land rental agreements and therefore enhanced economic capacity to move outside the settlement into the formal city.

The retailers that supply the end-users in Mathare are informal in the settlement, street retailers (consisting of an occupied plot without physical store), informal retailers in Light Industry, agents, formal retailers in Industrial Area, and producers. Informal retailers in Mathare are usually referred to as *hardware*, as they mostly sell hardware appliances together with a few building materials. They all reside inside the settlement, and they are often female. All of the hardware trading metal-based products as iron sheets or rebars are owned by residents belonging to the Akamba tribe. The retailers located in Kariobangi present the same ethnic characterization. Moving to the formal city, material retailers in Industrial Area show again a specific ethnic profile. For instance, the totality of timber store owners is Indian, while the ethnicity of the workers shows no pattern.

Additional stakeholders involved in the sector are agents, operating as middlemen between the informal and the formal market, advertising their work by using posters or advertising their services on public walls. They have direct contact with all the material producers, including the nearby quarry and the bricks factory, and they do not have any expenditure on stock space having no physical retail store. More precise data on the agents were not obtained during the study, as none of the contacted agents agreed to meet or to respond to questions over the phone. According to shop owners in the proximity of their contact advertisement, they never come to the settlement or are in any case unknown to them, as they work by specific commission, obtained over the phone, and their presence is at most not required.

Finally, the construction sector includes those working in the construction process on-site. The diverse workforces involved in the construction of units in the informal settlement can be distinguished as community contractors, skilled labor, slab team members, unskilled workers, and finishing labor. All these diverse figures are coordinated and selected by the contractor, known as *fundi*, and usually do not overlap as tasks and salaries are different. The term *fundi* is also utilized to describe a highly qualified worker with his network of laborers. The pronoun is used in a male form as all contractors encountered during the study, as well as workers, are male.

The construction sector shows traits of influence of ethnicity, extremely various in Mathare as more deeply described in Section 2.1 Socio-economic settlement profile and furthermore in the [Annex \(section 1\)](#), varying within roles and tasks. Most of the welders belong to the Luo tribe, while contractors are usually Kikuyus. Moreover, heavy tasks as gravel mixing or loading of materials are mostly handled by Luhyas, renowned for their strength. This fragmentation of the sector, while significant, does not seem to spark tension, but rather automatically assigns workers to specific tasks or materials.

3.3. Building materials in the settlement: use and acceptance

As mentioned in 1.5, Mathare does not present a homogeneous building fabric, but a rather diverse one including building blocks as well as iron sheet villages.

The upcoming sub-sections present detailed information on the most diffuse building materials and technologies, together with the local use and acceptance according to the interviews conducted during fieldwork (for details on the interview structure please refer to Section 2.1 Fieldwork Data Collection). In brief, interviews with residents, retailers, and landlords in the informal development of the settlement showed a stronger preference for iron sheet above the other affordable construction technologies as timber planks, earth-based solutions, or stone blocks, in virtue of its ease of transport, local purchase and modern appearance, as reported during the interviews. Iron sheet was anyway

often criticized for its lack of comfort. The material provides for no acoustic nor thermal insulating capacity, resulting in extremely hot indoor temperature over summer and an uncomfortably cold and humid environment in winter times. Its critics, mostly gravitating around thermal performance, fire resistance, and security, as described in 3.2.1, were often reported in opposition with earthen walls, heavily judged for its social image associated with poverty although often considered more comfortable. In terms of solid wall technologies, while there was a strong appreciation for their use, often economically out of reach for the most marginal population, there was an overall lack of information on its regards, especially concerning bricks and lightweight concrete blocks, which seemed like being adopted almost uniquely by NGOs.

3.3.1. Iron sheet

Iron sheet, which is locally referred to as *mabati*, is the most diffuse building material in the informal part of the settlement. It is used both for cladding and roofing, nailed to a self-standing timber frame, and usually not covered by any additional interior or exterior finishing. Its massive diffusion has led to naming one of the villages “Mabatini” as, according to the Mathare Grassroot Coalition for Housing Rights, it is composed of 95% single-story iron sheet structures.

None of the observed structures erected with such material consisted of a safe and healthy housing unit. Despite the massive diffusion of iron sheet in the settlement among those who can't afford a safer solution, many inhabitants showed concerns in terms of its capacity to protect from physical threats as fire, floods, and crime.

“When *mabati* burns you see hell on earth” added then a neighbor. “*Matope* (earth) is better for fire. But that technology is old. We don't do it anymore.” she then completed, showing mixed feelings about the material.

“*Mabati* is also bad for security as they can just cut the wall through” reported a young resident referring to the likelihood of thieves breaking in through an iron sheet wall. The resulting increased exposure to theft intrusions due to the ease of breaking through the walls can be also observed in combination with the lack of acoustic insulation. The almost absent acoustic insulation provided by this material results in an indication for potential criminals of the absence of tenants in case of silence. For this reason, some residents, and especially female tenants, sensing a higher vulnerability, prefer to keep a radio on all night at a loud volume to discourage intrusion, as well as to leave it on while away from their home-place. While this anti-theft strategy was never mentioned during interviews, the author noticed it while accompanying interviewees residents into their houses, or while spending the night in iron sheet units during fieldwork. When asking about it, the residents referred to the radio as their “anti-theft” or “security system”. In addition to this major concern of crime exposure related to the weakness of the building material and the lack of acoustic insulation provided, the author observed additional discomfort, particularly evident on rainy days. This results in a strong and persistent disturbing noise provoked by heavy rains on the iron sheet roof, making normal conversations challenging, and sums to the challenge of deep sleep made already difficult in case of the use of loud radio systems. While this information might look minor, it is important to remember that indoor comfort and proper sleep are key factor for mental health and overall wellbeing (Weimann and Oni, 2019).

The indoor comfort is furthermore exacerbated by the inadequate thermal performance of the material, resulting in unpleasant living conditions. “Here you melt. Or you freeze. And windows need to be closed because of thieves” was stated by a resident in Mabatini, unhappy about the indoor living comfort of his iron-sheet house.

Despite the extensively reported criticisms on the material, iron sheet remains one of the most utilized materials in the informal development of Mathare, and constitutes almost the total of the units in many of its villages, as will be discussed in Section 3.3 Building materials diffusion. The main referred reasons for the diffusion of iron sheets are ease of construction, speed of construction, ease of disassembly and transport in

case of eviction, economic feasibility, and availability in the settlement.

Some interviewees reported appreciating the modern image of the material, naming it as “*digital if compared to the analog* (character) of *matope* (earth) houses”.

3.3.2. Earth-based technologies

Earth, locally referred to as *matope*, is used in the settlement uniquely in single-story structures, specifically built in a simplified *wattle and daub* technology. This system consists of a lightweight timber frame erected without foundations, working as support for smaller horizontal timber elements and a humid mix of earth and fibers.

According to the senior interviewed residents and landlords, *matope* houses used to represent the significant majority of Mathare built environment together with timber houses until, around twenty years ago, a huge fire broke out through the settlement, destroying rapidly thousands of homes. Nowadays, just a small share of Mathare is still composed of earthen houses. Most of their walls are severely damaged due to low maintenance and material availability and are at times partially covered with iron sheet panels where the damage gets critical, to avoid erosion.

The reason for the discard of this material over time seems to reside in the combination of diverse causes. First, suitable soil for construction is not available anymore on-site. Furthermore, it is reported by the interviewed residents that most of the houses damaged by the fire belonged to one single owner, that found it profitable to shift to a more modern building material - iron sheet-to increase the structures rental price. Ultimately, the increased diffusion of iron sheet pushed earth out of the market, due to its image of poverty relatable to the countryside context, locally associated with the idea of poverty, where earth was a common self-building technique. Even though appreciated in that context, earthen construction seems not to be valued equally once transposed in the urban setting. Specific statements on the material adoption were brought up: “*In the village, matope is more efficient. We put four coats, and then a finishing. But here in Nairobi it's only one coat*”. This explanation is technically relevant, as earthen construction performs well thermally only if built as thick walls capable of acting as thermal mass. Due to the extreme density of the settlement, and in force of the landlords' profit-oriented strategy, the wall mass is reduced to save space and building materials. As a result, the construction provides poor thermal comfort. Despite that, the material is still appreciated by some for its comfort: “*When compared to mabati, matope was worst. It's impossible to keep it clean and rats were coming through. Said so, it is warmer than the mabati house. With mabati, the heat becomes impossible when it's hot, and the cold is just freezing cold.*” Comments on maintenance difficulty were also often provided:

“*When there are damages in matope, it is hard to get materials for repair*” commented a resident in Mabatini. Ultimately, construction time is an issue often considered by the structure owners: “*It takes too long to build with matope: time, availability of material, money, and it's old fashioned.*”

With the attempt to disrupt the local image of earth as a non-aesthetic solution to promote for a more comfortable and sustainable construction, the Italian NGO Livelinlums adopted the wattle and daub technology for the ground floor of the Why Not Academy school in Mabatini in 2012. This was used in combination with the addition of a timber frame structure and bamboo cladding for the first floor, two years later. According to the residents of the village, the community leader of Mabatini, and the construction workers involved in the project, the use of earth as a building material resulted as a winning choice, despite the initial concern of the local community. More specifically, the reported factors concurring to the local renovated interest in earth as a building material were the solidity of the construction together with the provided thermal comfort and, above all, the project's contemporary aesthetic.

Earth is also present in Mathare as processed in earth blocks (also

known as *adobe* blocks) stabilized with cement, adopted in the pilot phase of the Mathare 4 A Housing Upgrading Programme. Information about the earth blocks' use and perception was unavailable. Even though the houses built with this technique are as of today in average good conditions, the residents interviewed were not willing to respond to any question about the project and most of them were not the original beneficiaries. For these reasons, information on the material supply, building use, or construction process was not available. It is to be noticed that none of the residents recognized the material as earth or soil, and instead, they referred to it as "bricks" or "blocks".

3.3.3. Timber

Timber was in the 80s the second most diffuse building material after earth, used both for structural and cladding function. Currently, no newly built house is clad with timber boards. Beyond the drive of iron sheet affecting timber diffusion mostly for its economic competitiveness, practical issues contributed to its major local disappearance *"People stopped building in wood because Mathare was on fire, always. (...) And there is no space for it to dry. It's too dense: once it rains, it never dries. Same for matope"* commented a local retailer in village No.10, that had to adapt his offer to the demand, therefore switching his material option from timber to iron sheet.

Locally, the term *mbau* refers to timber elements (mostly eucalyptus) for the construction market, sold in poles or boards (the latter also referred to as planks). The term *mtii* instead refers to a clean tree branch or second-hand pole used to secure some shelter elements, with no load-bearing purpose.

3.3.4. Stone and concrete blocks

Stone blocks and prefabricated concrete blocks are the most used elements for the formal buildings, and structure owners and tenants refer to them both indistinctively with the terms *blocks* or *maue*, literally meaning stone. *Block* is also the term used to describe the multistory buildings in the formal area of Mathare, mostly built in in-situ cast concrete columns with stone cladding.

It is rare to find single units built with blocks or stone in the informal part of the settlement. These exceptional cases are usually owned by landlords or local chiefs, who have a much higher economic capacity than the rest of the community. Beyond that, in the informal part of the settlement blocks are used for communal buildings run by NGOs, as schools and WASH facilities.

All the interviewees commented positively on the material performance, especially in terms of fire protection, considered to be the highest threat to the inhabitants' livelihood.

3.3.5. Exceptions to the mainstream technologies

Just a minimal share of the settlement is built with alternative materials than the ones listed above. A few buildings in the informal part of Mathare are constructed with bricks, stabilized earth blocks, in-situ cast expanded polystyrene, or prefabricated boards. It is mostly the case of interventions financed and run by NGOs.

Bricks are at times used in the construction of schools and were very rarely named as possible building material during the interviews, neither by the end-users nor by the local retailers. The reason for this neglect seems to reside in the fact that their production and retail follow a private monopoly, as bricks can be uniquely bought directly from the producer, not close enough to Mathare to enter its local market. This results in a price increase in comparison to the similar prefabricated blocks or stone: *"Bricks are sold only by one person in Kyambu: it is too expensive compared to concrete block and maue, and require more mortar because they are small. It is not an option."* reflected an informal retailer from the neighboring village of Baba Dogo, highlighting how the size of building elements as well affects the economy of the construction.

In addition to the provided less diffuse building technologies in Mathare listed above, the settlement includes scattered double-story houses, built with a mixed technology composed of iron mesh used as

lost formwork filled with expanded polystyrene bound by a cement-based mix. These units are part of the unfinished housing construction program of the National Youth Programme (NYS), established nationally to engage with youths by providing them with a minimum income while improving the conditions of target settlements (Simon, 2016). All of these tens of structures are left unfinished and not used, if not as community storage. Interviewing community members on this construction technology resulted impossible, either for reported fear to speak about the program or for the rage that immediately sparked from just naming the project. One of the few community members that felt comfortable in briefly sharing an opinion, described it as *"wires and a sponge that you get when you buy a new radio"*, referring, correctly, to the expanded polystyrene used for packaging. Surprisingly, he then added that it was good that the program brought in a "new material" despite the evident miserable conditions of all the units. This shows once again how the appeal of novelty and modernity in contrast with the ongoing traditional solutions seems to be a leading driver in material acceptance.

3.4. Building materials diffusion

Information on the villages characterization according to the locally most used building technologies in Mathare described in Section 3.1 have been represented in Fig. 3. These are Iron sheet (for single or double-story units), Earth (for single-story units), and Stone and Concrete, (mostly for multi-story buildings). The other building technologies identified on-site, as Bricks, Timber, Prefabricated lightweight concrete blocks, or EPS-concrete units, are scattered rather than densely distributed in specific areas, and therefore have not been mapped individually due to the map scale. Similarly, single units built in stone in settlements characterized by the predominance of another building material do not appear on the map.

The image depicts the variety of the built environment of Mathare characterized by different predominant physical features within neighboring villages, as for the case of Kibichoi and Madoya, characterized by iron sheet low height building fabric just exposed to Casanova and Huruma, developed in multi-story stone and concrete units, locally referred to as "blocks" or "flats".

As mapped in Fig. 2, villages are characterized by the predominance of one building material. Nevertheless, individual standalone units developed with different building technologies than the village mainstream ones can be encountered. Fig. 4 displays such a case, here presented through the image of a typical street in the Mashimoni village, similar to Mabatini per building fabric, density, and material use. In the image is possible to recognize a sequence of iron sheet units on the left side of the path, as well as a stone-based unit on the right side of the image.

3.5. Material supply

In the whole settlement of Mathare, home to an estimated number fluctuating from 100.000 to over 500.000 inhabitants (Muungano Support Trust, 2012; Lines and Makau, 2017; The New York Times, 2006) a total number of nine material retailers has been identified. As displayed in Fig. 6, they usually consist of a single structure plus an open extension, allowing for increased stocking space and visibility from the road or pedestrian path. Their average size of around 22 m², corresponding to almost twice the size of a typical housing unit in the settlement (see Fig. 5), and they are mostly built as timber frame structures clad in iron sheet panels. Their internal space consists of a single room, organized with shelves so as to better stock iron sheet panels and timber poles. The illustration, together with the retailer representation, shows its usage according to stone blocks and cement bags and mixing buckets, with the addition of a small stock of iron sheet, as well as for the case of iron sheet and poles, with limited addition of cement bags.

Just two of the retailers are located in multistory buildings (respectively in Huruma and Thayu), in both cases on their ground floor.

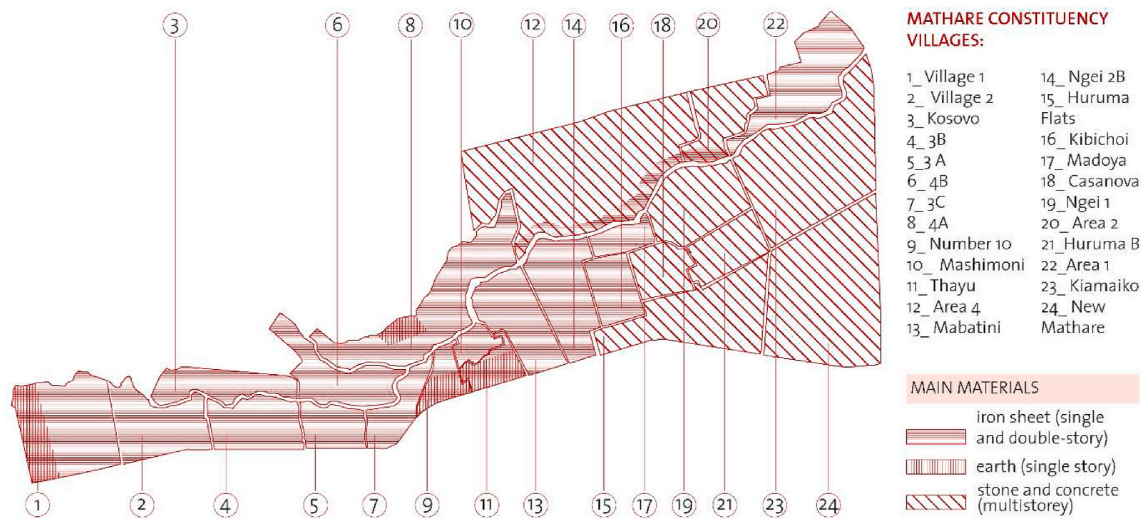


Fig. 3. Map of the main building material adoption in Mathare settlement within its subdivision into villages.



Fig. 4. One of the main streets in the village of Mashimoni, characterized by a major adoption of iron sheet except for standalone housing units built with stone blocks, timber, or earth. The image shows the lack of basic services provided to the village, here recognize din the lack of proper paving and street plan, drainage and water collection systems as well as waste collection. Some light poles are visible in the background along the main street path, while the electrical cables crossing the path consist of makeshift informal connections. WASH provision is also predominantly absent in the village.

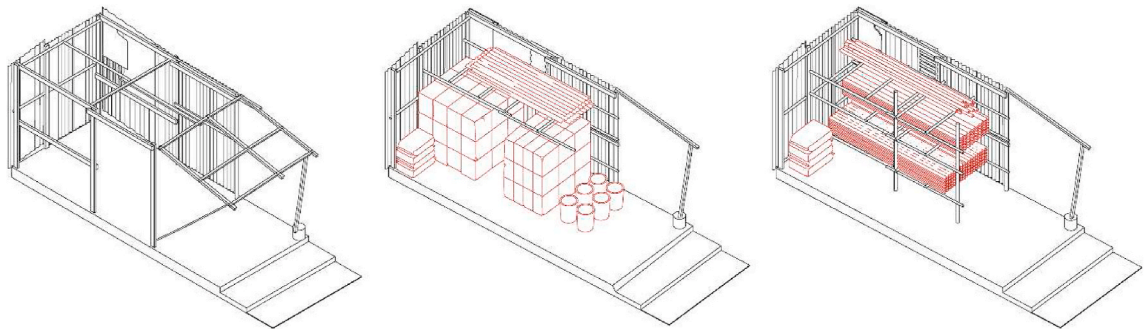


Fig. 5. Stocking of different building materials in a standard retailer store in Mathare.

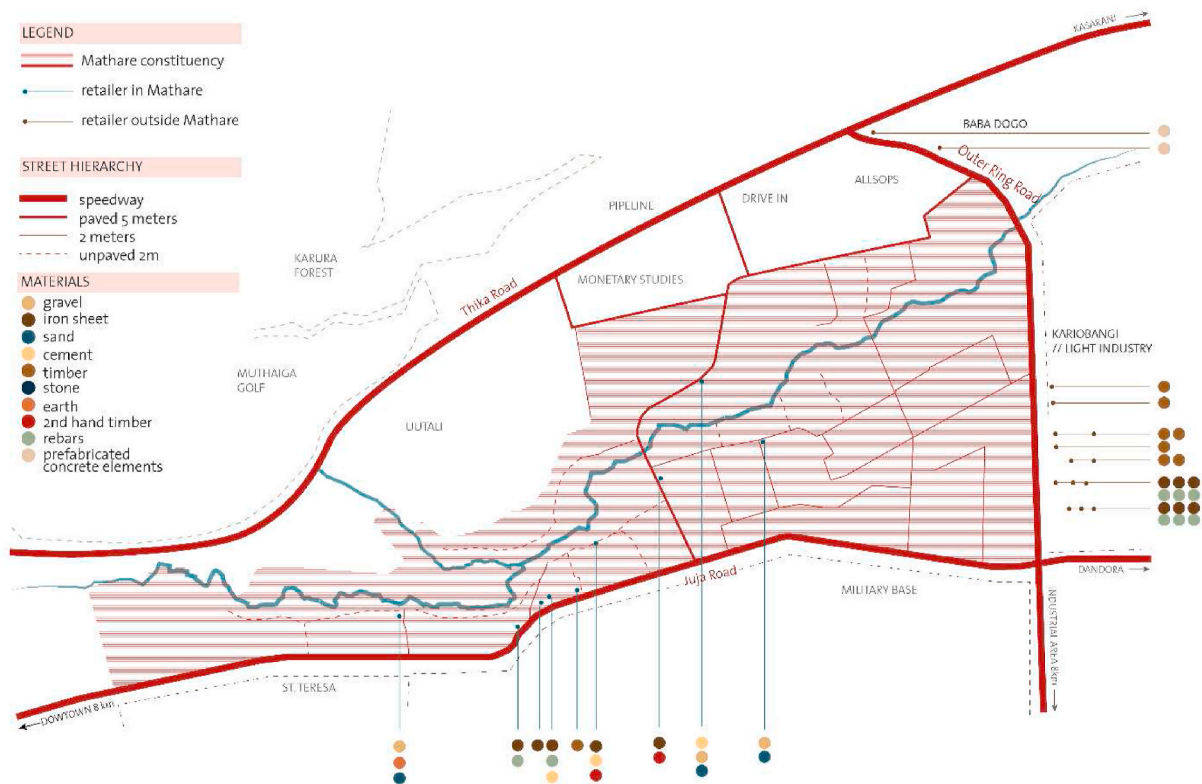


Fig. 6. Map of building material retailers in Mathare and proximities.

The map presented in Fig. 6, based on fieldwork data collection, shows the location of every retailer selling building materials in Mathare, as well as in the settlement proximity. The figure reports as well the specific materials sold presented with different colors, and the main roads accessible by car or truck, providing for potential material transport from the retailers' location to and through the settlement. The

figure displays a total of twenty-four retailers, nine of which are located within the settlement boundaries (marked in blue) and the remaining fifteen (in brown) in its close proximity, and more specifically on the Eastern border of the settlement, in the neighborhoods of Baba Dogo and Kariobangi.

The figure shows how the material stores' locations strictly depend



Fig. 7. Building materials sale along Mathare Road. For bulky materials are stone and gravel, retailers rely on the available street surface or open plots, whereas available. The stone blocks here stocked for sale are second-hand materials, collected from a nearby demolition site, and are a rarity within the local market.

on their direct access to the road, resulting in their owners' choice to settle their activities around the two major local arteries (Juja Road and Outer Ring Road). This provides for direct in-store delivery, but also enough space for storage, as the road, presents a couple of meters of buffer zone allowing for pedestrian use and marketplace. Furthermore, visibility and exposure to the public moving along these high-speed roads adds benefit to the economy of the retailers. Additionally, due to the limited size of the retailers, their location along the main roads provides for an additional benefit, allowing for the potential use of part of the pedestrian road section.

The only exceptions were recorded in two retailers taking up empty lots inside the settlement for storing building materials. Their open-air plot size, of around 80 m² in both cases, enabled them to sell sand, gravel, and earth, which require large surfaces while stocked. In rare cases, as for the one presented in the following photo (Fig. 7), stones were on sale by street retailers, and their availability resulted from local building disposal. For this reason, stone availability in the settlement, according to interviews with retailers and builders, is not only extremely rare, but also discontinuous and unpredictable, as it fully relies on the second-hand market stock (as described in Section 3.4.2).

All the other retailers, counting only on a limited space, uniquely sell iron sheet, together with small hardware elements. The timber retailers inside Mathare mainly deal with materials for furniture (see Section 3.2.3), while timber for construction is sold in 2.4 m long elements, so becoming a bulky material considering the narrow paths and the little stocking space inside the settlement. Just three of the retailers kept space for cement bags, with a maximum stock capacity of just 50 bags per store.

According to the retailers' location inside the settlement, the limited stocking space available led them to choose which material to support. It is therefore not possible to find any prefabricated concrete blocks or stone blocks inside the settlement, while they are available on the street marketplace in Baba Dogo, less than 1 km away. Despite the potential market for such materials due to their low price and high reported social perception and appreciation, retailers report that it is not convenient to invest in bulky elements, as their place for storage would get filled with one complete housing unit order, as earlier illustrated in Fig. 5.

In summary, space constraints both in terms of indoor stocking space as open-air street space usage results in a major driver for the business activities within the settlement boundary, as Mathare is characterized by an extremely dense urban fabric. This results either in the selection of non-bulky materials for sale (therefore limiting their product offer) in the case of retailers located within the settlement. For the retailers in Mathare benefitting street-space usability, as for the case of the Juja Road retailers in village Number 10, or of the two open street stores along Mathare Road inside the settlement, material offer can instead vary more and include bulky elements.

Space scarcity fits the local incremental construction process. Clients mostly order a small stock of goods, in force to their limited economic capacity. The construction therefore often takes place in small incremental steps, especially when it comes to housing renovation or expansion. This is also due to the limited availability of stocking space on the building site. As reported during the interviews with the structure owners, the first material order is immediately used to claim the plot. This land reclamation phase is a typical feature of the informal settlements affected by frequent evictions, as the evicted household is forced to seek urgently for an immediately available plot to occupy.

After this stage, the next material batches are then used to proceed with the rest of the construction. This strategy, in practice, allows the retailers to run their business mostly through custom-based orders, therefore avoiding the occupation of the store with bulky stock awaiting potential commissions. The same applies to the construction tools, often rented from the neighboring settlements to avoid the need for storage space, as stated by a local contractor active in Mabatini and Mashimoni: "We have our small tools but for the bigger ones if we need to do concrete work or bigger things, we rent in Juja or Light Industry".

Retailers in Mathare, even if complemented by the second-hand market as described in Section 3.4.2, are not able to meet the full local demand. As reported by structure owners, a consistent share of clients in Mathare, therefore, relies on the marketplace of the neighboring settlement of Kariobangi, located within walking distance from Mathare just after the local artery Outer Ring Road (please refer to Fig. 7). Locally known as Light Industry, Kariobangi is renowned locally for the strong concentration of material producers and retailers located in a radius of just a few hundred meters. Retailers in Kariobangi benefit from a wider available space, both enclosed within their properties and in terms of street use availability, and reliable electrical connection, allowing for material processing as wood cutting and welding. Material price varies between Mathare and Kariobangi, making the latter significantly advantageous and allowing saving almost 10% per purchase. We assume that such price variation is due to the additional transport required to reach the local supply in Mathare, as well as to the fact that clients residing in Mathare do not have their transportation mean and therefore more solely rely on the very local supply of Mathare for minor purchases. This probably allows the local retailers to slightly increase prices additionally, knowing that the clientele does not have many alternatives to their supply.

Beyond cost-effectiveness, Kariobangi is preferable as well in force of timber quality, definitely more suitable for construction when compared to the available stock in Mathare. Material purchase and delivery takes place either through an agent or, in order to avoid fees, in person, with the rental of a man-powered chariot for material transport. Details on material prices, dimensions, and transport can be found in the upcoming Section 3.4.1.

Availability of lightweight cement blocks, hardly used in the informal part of the settlement, has been found uniquely by an informally occupied section of the crossroad of Outer Ring Road, just on Mathare border, where the sidewalk is wide enough to provide both for space for production and drying, benefitting from great visibility supporting sales. In case of purchase, arrangement for small tracks rental is needed in combination with the use of man-powered chariot once paths in Mathare become too narrow for trucks circulation.

3.5.1. Material transport and price variations

Kariobangi represents the biggest material supply in town for the low-income population. The neighborhood hosts a significant number of material processing activities as woodworking and welding workshops, which owned it the informal name of *Light Industry*. Material price varies between Mathare and Kariobangi, making the latter significantly advantageous. This can be seen in the market value of a single iron sheet element (250 cm × 80 cm, gauge 30), fluctuating from 700 KSh per element when purchased in Kariobangi to 750 KSh when purchased in Mathare. For an estimated use of 24 elements to clad a single unit, corresponds to a non-negligible increase of 1.200 KSh over a total cost of 18.000 KSh, making Kariobangi the preferable market for the purchase of materials for a complete structure. The same price fluctuation applies to timber, with the additional issue of the significant quality decrease, as commented by a local landlord. Clients from Mathare often purchase goods from Kariobangi through an agent, which takes care of delivery as well. When they cannot afford to involve one, they would rent a man-powered chariot (locally called *mkokoteni*) for around 100KSh per day to move lightweight materials as timber elements or iron sheet from Kariobangi to the site in Mathare. Just rarely customers would rent a small truck, when in need of moving heavy or bulky materials, to get the stock as close as possible to the building site, completing just the final transport through the narrow paths carrying it on wheelbarrows. Additionally, the production and sale of lightweight cement blocks have been found uniquely by an informally occupied section of the crossroad of Outer Ring Road, just on Mathare's border, where the sidewalk is wide enough to provide both for space for production and drying, benefitting from great visibility.

3.5.2. Disposal and the second-hand market

The supply in Mathare moves along an almost circular flow, where materials, at the end of their use, are almost immediately utilized by another user, either through a second-hand resale or through a direct handover in exchange for in-kind contribution or just for free.

As for most of the goods marketed in the informal settlements, construction materials as well go through multiple cycles before being disposed of. This practice is due to multiple reasons, as reported in interviews with structure tenants and material suppliers, the first being the lack of local resources and the need for affordable solutions available at hand. The second-hand market trades all of the building materials encountered in the study within the settlement boundaries, except for earth, and it is organized in a way so that there is no intermediary between the end-user of a cycle and the new client. Taking into example the testimony of a contractor, the soil removed while digging the foundations is then “resold to those who need it to fill a land or make it flat. They walk around and look for soil, so as they see us setting up construction, they’d let us know they need it. And we’d sell it cheap because otherwise, we have to find another solution on our own”. This ends up being a convenient

mechanism for all.

Similar statements were given by structure owners or occupants for what concerns cladding and structural materials. The second-hand market works through a mouth-to-mouth advertisement, and only supplies a minimal part of the material needed for construction as anyway most of the time the structure owners would move their full structure to the next plot if materials allow for it. This market so is mostly oriented for repairs or additions. For instance, when disassembling an iron sheet structure it is mentioned that “*mabati gets smaller*”, hindering the fact that some elements end up being too damaged to be reused. As a consequence, a small amount of supplementary material is needed to complete the newly settled unit.

When recycling is not a possibility anymore, then down-cycling is always considered before final disposal. For instance, where timber elements are too ruined for being used as building elements, they are sold as cooking firewood in the community, being competitive with coal.

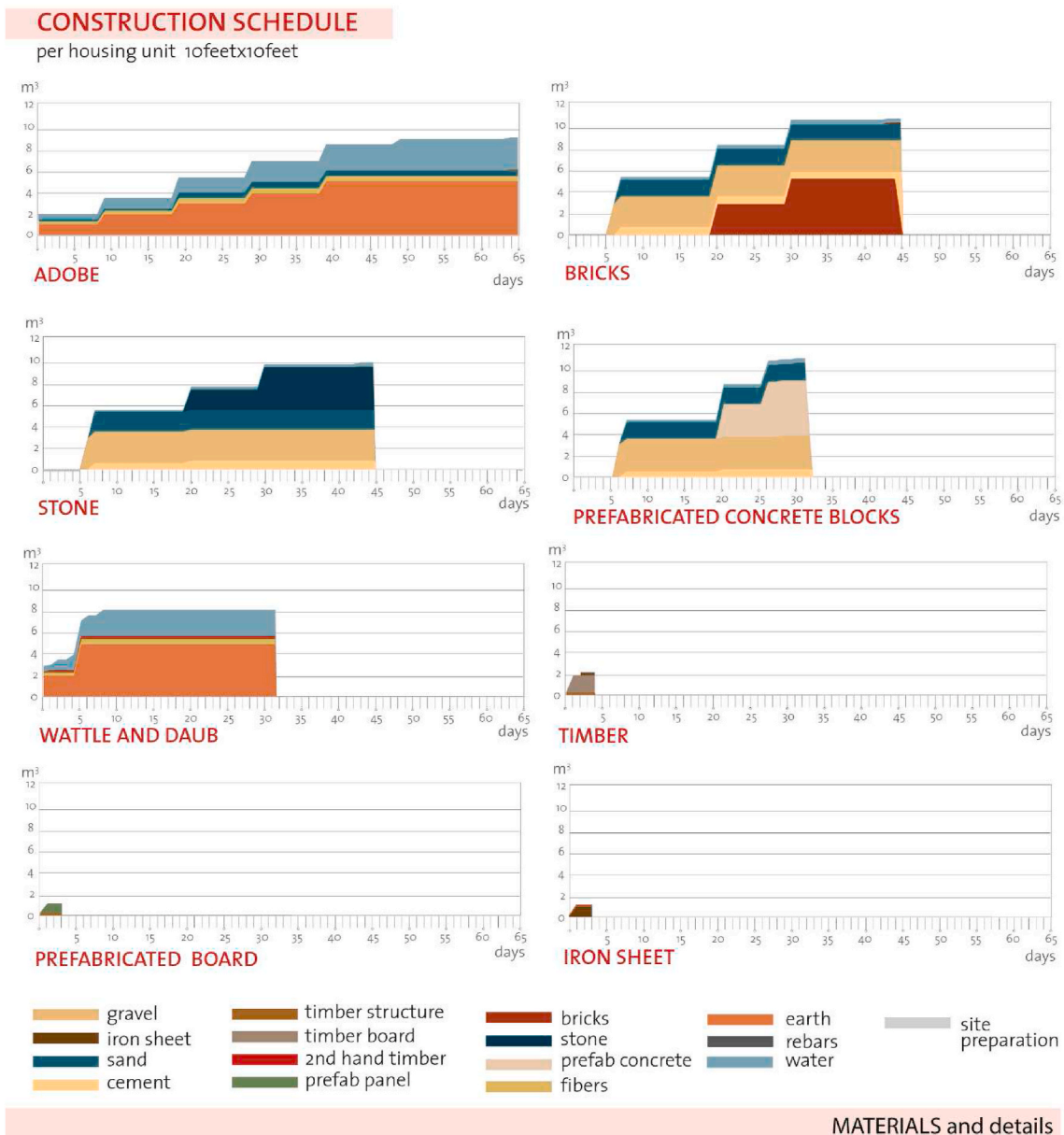


Fig. 8. Comparative informal construction schedule of different building technologies per standard housing unit in Mathare.

3.6. The construction process

The settlement undergoes continuous transformations, both in terms of maintenance and new construction, usually carried out respectively by the tenants and the landlords. New constructions are developed either as re-constructions after fire outbreaks or eviction or as incremental extensions, nowadays mostly vertical due to the lack of available space.

The diverse workforces involved in the construction of units in the informal settlement, described in Section 3.1 Stakeholders analysis, can be distinguished as community contractors, skilled labor, slab team members, unskilled workers, and finishing labor.

Labor price varies according to the skill level of the worker, the complexity of the construction, and the eventual involvement of a contractor within the construction, not required in the case of a simple technology as an iron sheet and timber. Construction time as well fluctuates according to the unit type, but is on average set for around 5.5 working days for simple technologies (iron sheet, timber) and 11 days for stone, with foundations. More details on the construction process organization and cost breakdown can be found in the Annex (section 3).

Data on the diverse building techniques have been organized to obtain a bill of quantities per each technology implemented in the settlement, corresponding to one built unit of 10×10 feet. Such dimension is based on the local reference to informal built units as “ten by ten”, hinting at their average size throughout the informal development of Mathare. The technologies considered are adobe, bricks, stone, prefabricated concrete blocks, wattle and daub, timber, iron sheet, and prefabricated boards. According to the interviews with local construction workers and further research, a construction schedule per each technology has been developed and is presented in Fig. 8.

The assessment considers the amount of material delivered (space) measured in m³ and indicated on the vertical axis, and the time of delivery (time), measured in working days along the horizontal axis.

Construction time includes: site preparation, accounted for technologies requiring foundations (and therefore displayed in the case of Brick, Stone and Prefabricated Concrete Blocks), drying time, and scattered deliveries as per local practice. The schedule is based on interviews conducted on the field, and therefore report data from the local building practices. It so does not necessarily represent a correct building process, as for the case of concrete mix proportion or drying time which have been taken from the interviews from local workers rather than from literature on optimal and safe construction practice.

4. Results

4.1. Comparative spatial assessment

A comparative assessment of the required stocking space on-site for a reference housing unit of 10 by 10 feet is represented in Fig. 9, where construction materials spatial stock requirement is presented based on the eight available local building technologies (adobe, bricks, stone, prefabricated blocks, wattle and daub, timber, prefabricated board, and iron sheet).

The available space on-site is illustrated by the dotted cube corresponding to the reference unit volume, as it was observed that often no extra space is available for on-site storage due to the settlement high density characterized by 60 cm to 1 m wide inner paths. Some materials as gravel and sand cannot be piled, just as elements that need to dry on-site, as adobe bricks. Therefore, the material stock is expressed in a combination of m² and m³, considering the actual stocking requirement of the diverse technologies.

The figure shows the significant impact that the technological choice has on on-site logistics due to space availability. Low-volume technologies as iron sheet, prefabricated board, and timber manage to comprise the material stock within the unit boundaries. On the contrary, those including foundations or massive walls as blocks or stone necessarily require a much larger surface for on-site material storage. The same applies to technologies requiring on-site production as adobe bricks, posing the additional bottleneck of production and drying space, making it the most surface-consuming technology among the ones assessed.

The figure reveals the relevance of considering in-situ stock capacity when selecting a building technology in the context of urban informal settlements, as it does impact the construction process. Specifically, it shows that such a feature becomes key even for a single building unit development, as technologies requiring significant on-site space can compromise the feasibility of the construction.

4.2. Stakeholders based supply chain

Data on material distribution and production was related to the stakeholders and combined in Fig. 10 along their construction supply chain. The stakeholders are divided between end-users and retailers. End-users are listed vertically, and comprise of residents of the informal settlement, NGOs operative in Mathare, and formal entities as private subjects in the city of Nairobi or public institutions), Retailers are listed horizontally, and located from left to right in the illustration in order of proximity from Mathare. The circles associated with the stakeholders vary in size according to the stakeholders' individual space availability.

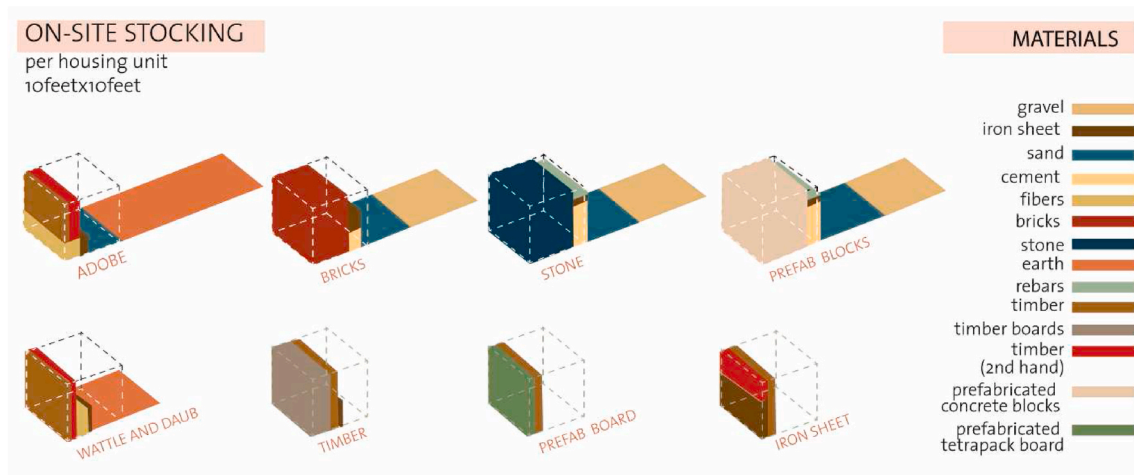


Fig. 9. Comparative spatial assessment of the material stock on-site for a housing unit of 10×10 feet in the informal settlement of Mathare, Nairobi.

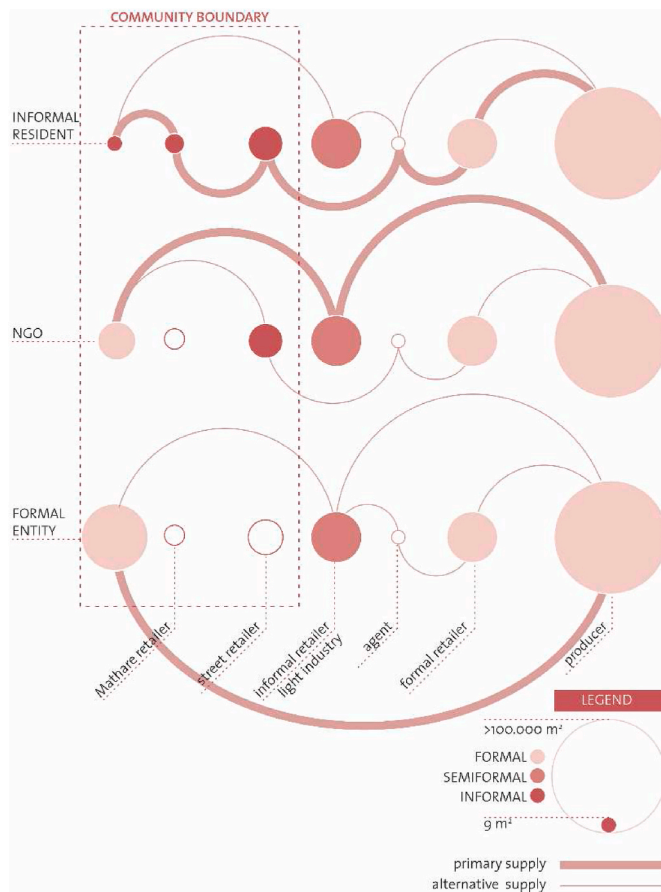


Fig. 10. Stakeholders mapping along the building materials supply chain in the informal settlement of Mathare, Nairobi.

Fig. 10 indicates how the three end-users interact differently with the stakeholders along the supply chain. Specifically, it reveals how only informal residents strongly rely on the local market. NGOs and Formal entities instead, capable of handling bigger stock in force of their economic capacity and physical space availability, mostly reach out directly to the stakeholders working in synergy with the formal market, outside of the settlement.

Furthermore, a stakeholders-based supply of the individual building materials has been represented in Fig. 11.

The material supply is indicated in different colors according to the building materials. The diverse stakeholders are indicated with icons positioned along the individual supply chains as described by the legend. The locations of the stakeholders in relation to the informal settlement of Mathare are indicated by their horizontal position. Specifically, they are positioned on the left side of the figure when within the informal settlement of Mathare. As their distance with the settlement increases, the icons position in the figure shift progressively to the right, moving first through its semi-formal context (characterized by a mix of formal habitat and informal market), then to the formal city of Nairobi, and finally extending to the region, located more than 10 km away from the settlement.

The figure shows how the different end-users (informal-dweller, NGO, and formal dweller) have access to a different supply of materials, and even to different materials. It is the case of bricks, accessed by NGOs operating in Mathare but never included by the informal supply.

This can be explained by the economic capacity that NGOs have, enabling them to consider the market beyond the immediate boundaries of the settlement by investing in more expensive transport as for the case of truck rental or, where necessary, multiple trips of man-powered chariots inside the settlement. Especially for the case of their capacity

in investing in the rental of vehicles capable of moving big quantities of material, this also results in the NGOs capacity to directly reach the producer whereas necessary, as for the case of bricks or stone. The case of stone, which almost entirely depends on direct pick up at the production site with the only exception of second-hand stone resold in the settlement in case of units removal or demolishing, therefore results in the exclusion of informal clients from its supply.

4.3. Ethnic fragmentation of the sector

Ethnic heterogeneity in the local construction sector influences the market fragmentation along the material supply chain, where specific building materials were handled and commercialized by certain tribes or nationalities, as indicated in Section 3.1 according to the diverse building materials. It is the case of timber, marketed mainly by Luos in Mathare while uniquely traded by Indians, and still physically processed by locals of diverse ethnic origin when moving outside the settlement. Similarly, when it comes to Iron and steel, the marketplace in Mathare is lead by Akambas while the welding and setting in place are run by Luos, who also take care of woodwork. Kikhuyus finally cover the contracting roles.

For these reasons, and in force to these materials compartmentation, the full material handling and construction of a house often involves more than one single ethnic group, due to their skills, knowledge compartmentation, creating a mutual dependency.

To complement this finding, and put in perspective a more global discourse, the additional literature review has been conducted. It emerged that multiple studies have approached the topic of the economic role of ethnic fragmentation (Alesina and La Ferrara, 2005; Collier, 2001). Economy and ethnic fragmentation have been correlated by Easterly and Levine already in 1997 for the broad case of the African context. In their work, they identify ethnic division as an impacting factor in Africa's growth tragedy (Easterly et al., 1997). Our result proposes a different but complementary view on the topic, positioning ethnic fragmentation not as an element of limitation or acceleration of the economy, but rather as a driving factor to be considered when intervening on market and supply modifications.

5. Discussion

The presented work shows the relevance of instigating the construction process of the informal settlements to achieve a more thorough understanding of their specific building culture, setting basis for more informed decisions for project managers and policy makers. The results show the relevance of adopting a mixed-methods approach to assess the current construction process of the informal city, by integrating methods as Supply Chain Mapping and Stakeholders Analysis. This approach enables the identification of local building practices and the codification of the construction sector of the informal city in a stakeholder-based and mapped way. Drivers and bottlenecks of material choice and implementation are therefore identified. This achievement is a key factor for the development of more appropriate informal settlements upgrading programs, that could be tailored around these identified system dynamics to more strategically engage with the local economy and its stakeholders. This approach to material selection, more aware of its economic ramifications, aims to achieve the double-folded benefit of boosting the local economy while facilitating the engagement of residents and stakeholders in the project development and execution phase. Moreover, it can support acceptance in the project development and handover. As a result, the chance of engaging with the informal economy while addressing the challenge of an urban transition towards sustainable development becomes an achievable and controllable target.

The technical assessment, looking at stocking space both on-site and along the supply chain, is complemented by the interviews conducted highlighted the major impact that material stock has on technological choice and availability on the market. This result is presented in Fig. 12.

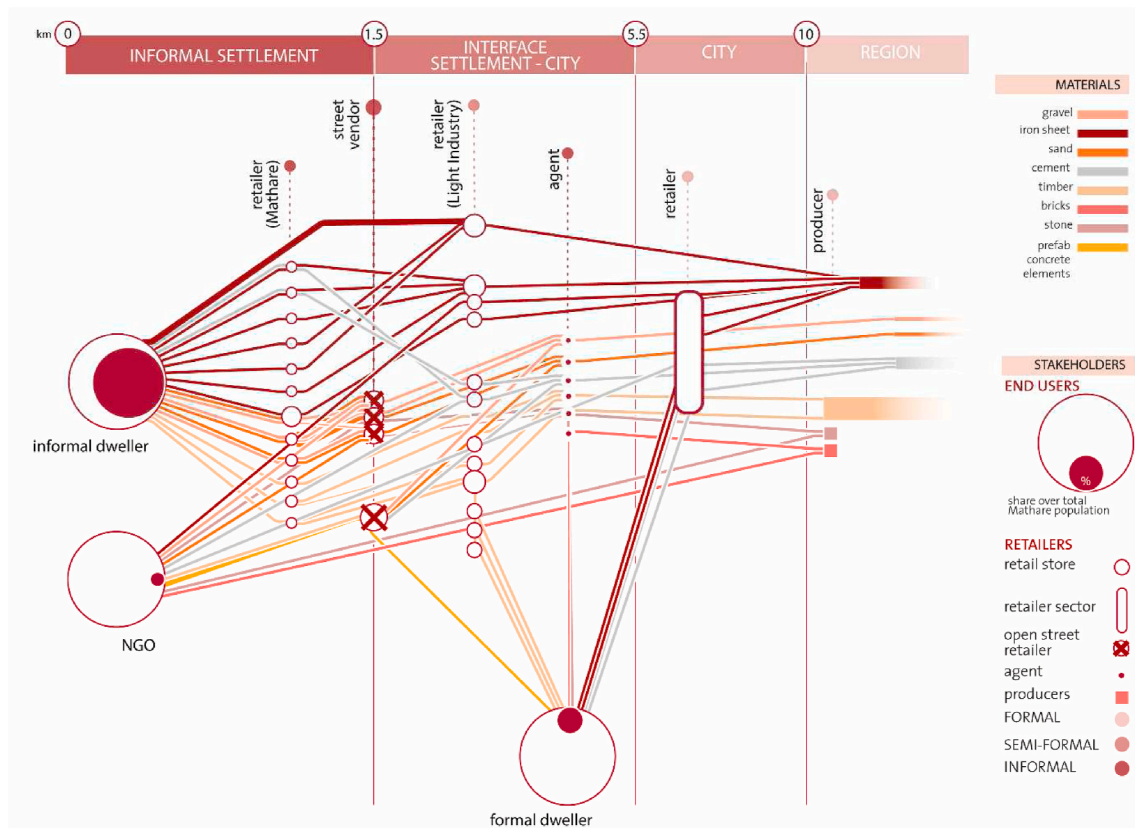


Fig. 11. Stakeholder based supply chain mapping for the construction sector of the informal settlement of Mathare, Nairobi.



Fig. 12. Socio-technical integrated assessment of building technologies for the settlement of Mathare.

This finding could be extended to the majority of urban informal settlements presenting the same challenges of inner density and limited access and mobility within the settlement, or where retailers size and on-site stocking space are all extremely limited. In addition to that, the illustrated assessment shows how social and technical drivers play a role in the distribution of materials inside the settlements.

The comparative diagram considers the eight-building technologies assessing their adoption preference by the informal community of Mathare based on the following socio-technical criteria: construction time (as per actual time needed to complete the unit construction according to the local practice); stocking space (as resulting from the assessment presented in Fig. 9), feasibility (indicating the economic viability of the selected technology as perceived by residents),

availability in the proximity (regarding the availability of the material within the local supply, presented in the previous figures); and social acceptance (as of likelihood of the selected technology based on the local building culture and perception, resulting from interviews). The assessment also includes the distribution of the building technologies throughout the formal and informal end-users, represented in the two concentric circles. These show how the first purchase mainly stone, blocks, and iron sheet while the latter relying almost uniquely on iron sheet. The combination of such information confirms that stocking space becomes the discriminating factor, being iron sheet the most diffuse building technology despite competing against other affordable and available technologies, still much less diffuse.

These findings can be extended to dense urban informal settlements

globally, where material adoption and distribution are likely to suffer the same bottlenecks due to stocking space and settlements accessibility identified in the present study for the case of Mathare. Although testing of these insights on diverse case studies would be at this point needed to prove the validity of the presented approach, these findings can be read as operative indications for project managers and policymakers. Specifically, they could support the achievement of a grounded approach to construction interventions in the informal settlements, aiming to engage with the local informal practice, which can so become an active and inclusive agent of change. This approach goes beyond materials and touching onto the socio-economic dimension provides relevant insights for the practitioners, as successful implementation of alternative building technologies at scale needs to fulfill the local demand and market in terms of social acceptance, economic profile, and usability, fitting within the existing dynamics. Awareness of job distribution in relation to ethnicity might be required by NGOs and public institutions to avoid diverting the market away from one social group and in favor of another, unintentionally. While the relevance of ethnicity can be specific for the case of Mathare, a broader indication of the need of exploring the socio-cultural dimension of the construction practice can anyway be extracted for more global reasoning.

In parallel, local material producers could make use of this finding to engage with the relevant stakeholders when introducing a new technology in the settlement market, so to avoid disrupting job distribution and to consider the social group who'd most be affected, or interested, by the introduction of a new building solution.

Moreover, understanding the significant relevance of stocking requirements along the supply can be of use for material developers while designing products targeting the informal context.

Beyond these considerations for the practice, the study provided insights on the everyday dynamic of the construction in the informal city and proved the relevance of adopting an integrated socio-technical approach for the assessment of the informal city. It showed that choices made at the building level have an impact reaching the territorial scale, and might hinder the capacity of a technology to be adopted locally.

6. Conclusions

This study applied a mixed-method approach to the assessment of the built environment of the informal settlement of Mathare to understand its construction process, to identify the key stakeholders directing its supply chain, and the social and technical drivers influencing the decision on material choice.

From the study, based on direct data collection on the field, the

following statement arose:

- different final end-users (clients) in Mathare have access to different building materials
- the distribution of materials inside the settlement is strictly related to the store accessibility
- the adoption of materials inside the settlement is highly impacted by the availability of space both at the supplier store and on the building site
- ethnic fragmentation characterizes the distribution of roles in the construction sector.

These statements can be extended to the broader case of dense urban informal settlements affected by scarce mobility and accessibility, and highlight how the identification of appropriate building technology for the specific context of the informal city is tied to a degree of complexity going beyond pure feasibility, availability, and suitability for a self-building process, as often considered. Especially for the case of informal urban intervention, an appropriate solution necessarily needs to take into account its space consumption and requirement, along with its supply as well as on-site.

Such findings allow for practitioners to provide for a more grounded approach while implementing construction projects and material developments for the informal context, capable of engaging with the local economy, supply, and flows. These findings can support decision-making for a more inclusive project management, and for the implementation of alternative sustainable technologies at scale. Such an approach supports a global inclusive development, where the informal city actively participates to the formal local economic capacity, engaging virtuously with it rather than being left behind.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

1 Socio-economic settlement profile

Even though there is no available large-scale assessment on the ethnic profile of the whole settlement, data is available for the ethnic composition of Mathare 4 A, which was found to be heterogeneous with 50.8% Luo community forming the largest group; followed by 16.6% Kamba; 15.6% Kikuyu and then 10.3% Luhya. Other ethnic groups also live in Mathare 4 A but are insignificant in number.

According to the Mathare Zonal Plan report, the settlement residents suffer significantly of the following deprivations:

- sanitation; with only 17% of residents having access to in-home toilet and only 29% relying on a public toilet located within 30 m from their home, resulting in additional concerns as health and hygienic conditions, as well as sexual crime exposure;
- water access, with 90% of residents not served by in-home piped water, and water availability being unreliable, unsafe and subject of price spike;
- mobility and accessibility, limited within and between the villages, due to slopes, dangerous river crossing, human waste and garbage impeding proper circulation and absence of a sufficient number of motorable roads, making emergency vehicles access almost impossible;
- access to electricity, inadequate in number (serving only 9% of the residents through a safe metered connection, and 68% relying on informal connections to the grid and 22% having no access at all) and responsible of the major local threat of fire hazard due to makeshift connections (Muungano Support Trust, 2012).

2 Fieldwork and Data Collection

The listed data collections steps, more in details, provided for the following information:

1. Observation of the settlement fabric and identification of major building materials adopted

This phase took place first touring the settlement, whereas possible, on a motorcycle to get a major breakdown of the wards characterization by building fabric, and map it. Then, the observation continued on foot, wards by ward and in particular in the viallges listed. Photos were taken during this stage of the study. Although professional cameras were brought on the field, the author finally preferred to work mainly with her smartphone camera, as less intrusive, with the exception of a few residents' portraits acquired later on during the study.

2. Mapping of identified local retailers

During the first settlement overview, the location of the construction retailers in the settlement was mapped, as well as the street-sale of building materials. Mapping in the settlement was developed by hand, based on a printed aerial image. At times, interviewee were asked to indicate their suppliers on the same map.

3. Door-to-door interview to the local residents

A total of eighty residents was interviewed, selected according to their housing construction, and their presence in the proximity of the house facilitating an initial information, or as they were direct contacts of the author or of her assistant.

This step was initially conceived as a semi-structured interview, conducted on the base of a printed document. It was immediately noticed that the presence of a physical document or paper as support for the interview made the residents feel uncomfortable, and more reluctant to participate to the interview. They reported lack of trust on surveys, as they often were interested of survey from international agencies and the local municipality which resulted in no improvement of their housing conditions. Some of them also tended to associate the document with some business-related action, and therefore expected a monetary compensation for the collaboration. In other cases they expected an immediate improvement of the settlement conditions, which was not planned to be associated with the study. For all of these reasons, none of the interviews was supported by any written document or checklist, and just rarely notes could be taken at the time of the interview. Recordings were not possible either.

The interview provided with data necessary to proceed with.

- a) mapping of their supply chain related to the unit construction, both inside and outside the settlement boundary;
 - b) identification of drivers and bottlenecks in material adoption;
 - c) identification of the local building techniques and key stakeholders active along the construction and supply process
4. Interview with key local stakeholders active along the housing construction process, as local builders and contractors

This interview served the purpose of identify the roles of the different stakeholders and their knowledge on material purchase, use and preference in the context of the settlement of Mathare.

5. Interview to the local retailers in Mathare

These interviews focused on the observation of their material stock and understanding of the drivers leading to the selected choice and market offer. Further more they covered question enabling the identification of their own supply chain and distribution system.

A total of nine retailers in the settlement have been interviews, which.to the authors knowledge-correspond to all of them.

6. Interview to the construction materials retailers located beyond the community boundaries, so to identify their own supply chain, distribution system and material choice, and their ties with the settlement of Mathare

Construction retailers in the settlements of Baba Dogo, Light Industry (Kariobangi) and Industrial Area, as well as producers located in the metropolitan area of Nairobi, were also interested by the study, so to identify the diverse flows of materials from the producers or main distributors to the settlement, and eventual factors influencing such flows.

Interviews included a couple of dozens of local retailers located outside Mathre, as well as brick producers and stone workers by the regional quarry.

3 Construction expenditure breakdown

The diverse workforces involved in the construction of units in the informal settlement can be distinguished as: community contractor, skilled labor, slab team member, unskilled workers and finishing labor. All these diverse figures are coordinated and selected by the contractor, or fundi, and usually do not overlap as tasks and salaries are different. For simple consturctions, as iron sheet units, a contractor might not be involved.

For skilled workers or those performing fine tasks like plastering, the salary is on average 1.500 KSh/day. A regular mason, unskilled, would receive around 500 to 600 KSh/day. Foundations quotation depends on depth, as it is quoted per meter of ground dug, and 1 cubic foot corresponds to 50KSh. The contractor would negotiate a total price with the structure owner, saving per se the margin left from labor and materials' cost. At times though contractors set a daily fee of 1.500 KSh/day, distributing then the rest to the workers.

The following table ([Table 1](#)), based on data collected through interviews with the main contractor of Mabatini, shows an average breakdown of the fees between material cost, contractor cost and labor cost as well as usual construction time and the number of people employed according to the most requested building technologies: iron sheet, timber and stone.

Table 1
Construction time and fees per building technique

10 × 10 feet	Community contractor (fundi) fee (KSH)	Material cost (KSH)	Labor cost (KSH)	Construction time (days)	Number of people (n)
Iron sheet No foundations	50000	200000	50000	5.5	10
Timber + iron sheet roof No foundations	50000	250000–300000	50000	5.5	10
Stone Concrete and stone foundations	100000	500000	100000	11	10–15

During interviews with different workers, it emerged that the estimated time is not to be intended for formal employment. Working days are in Mathare hardly consequent, making an average week consisting of 2–3 working days according to availability of the employees and space for stocking and delivery, for an average total number of working days per month of around 12 to 15.

It is the case, at times, that no contractor is involved, and a less expensive team of unskilled workers is employed for simple construction (as for the case of iron sheet units). Also in case of repair, the technology that the most fuels local retailers, contractors are almost never involved. Finally, it is frequent that NGOs operating on the territory introduce their own contacts, or reach out to city distributors, accessing a different slice of the market and supply.

While building sites are run by men, it is common to see women employed for infrastructure work. This is likely to happen as infrastructure servicing is mostly provided by NGOs, often promoting women empowerment projects. Due to the highly centered local patriarchal perception, the presence of women on a building site is in fact not well seen by the community.

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