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ECONOMIA CIRCOLARE NEI PAESI IN VIA DI SVILUPPO
Pratiche di edilizia sostenibile in Kenya

CIRCULAR ECONOMY IN DEVELOPING COUNTRIES
Sustainable construction practices in Kenya

Cinzia Talamo, Christian Jonathan, Nazly Atta, Giancarlo Paganin

Abstract

L'articolo esplora le pratiche di Economia Circolare nel settore delle costruzioni in Africa, e in particolare in Kenya, indagando come le pratiche di riuso di prodotti edilizi possano portare a benefici economici, ambientali e sociali. Sebbene l'Economia Circolare sia ancora un argomento nuovo nella gran parte dei Paesi africani, alcune situazioni possono suscitare l'interesse del settore: i crescenti investimenti in edilizia, l'aumento di rifiuti da costruzione e demolizione e la presenza significativa di attività informali che riutilizzano prodotti edilizi rivelano opportunità per sviluppare appropriate strategie di circolarità. Si propone un approccio di 'circolarità per l'accessibilità economica' come leva strategica per contrastare la povertà, esplorando alcuni cambiamenti di paradigma: da flussi di materiali lineari a circolari; da catene di fornitura destrutturate a reti imprenditoriali; da insediamenti informali ad alloggi a prezzi accessibili.

The article explores Circular Economy practices in the construction sector in Africa and, in particular, in Kenya, investigating how practices of reuse of construction products can lead to economic, environmental and social benefits. Although the Circular Economy is still a new topic in most African countries, some conditions can stimulate the interest of the sector: the growing investments in construction, the increase of construction and demolition waste and the significant presence of informal activities that reuse construction products reveal opportunities to develop appropriate circularity strategies. A 'circularity for affordability' approach is proposed as a strategic lever to fight poverty, exploring the following paradigm shifts: from linear to circular material flows; from unstructured supply chains to entrepreneurial networks; from informal settlements to affordable housing.

Keywords

economia circolare, settore edile, rifiuti da costruzione e demolizione, paesi in via di sviluppo, sviluppo sostenibile

circular economy, construction sector, construction and demolition waste, developing countries, sustainable development

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Sebbene l'Economia Circolare sia ancora un argomento relativamente nuovo nella maggior parte dei Paesi africani, alcune condizioni possono suscitare l'interesse degli operatori del settore delle costruzioni (Muriithi and Ngare, 2023; Turing, 2021). Fenomeni come i crescenti investimenti nel settore edile, la crescente quantità di rifiuti da costruzione e demolizione e la significativa presenza di attività informali di riutilizzo di prodotti edilizi lasciano intravedere opportunità per sostenere l'imprenditoria locale, sviluppare strategie di circolarità e contrastare la povertà. In Africa il settore edile rappresenta un'area prioritaria, caratterizzato da un'elevata produzione di rifiuti e da un intenso utilizzo di risorse. L'aumento della produzione di rifiuti da costruzione e demolizione è determinato dall'aumento delle attività edilizie, legato alla crescita della popolazione – che secondo previsioni raggiungerà 2,4 miliardi di persone entro il 2050 (Rademaekers et alii, 2020) – e alla conseguente crescente domanda di alloggi.

In tutta l'Africa si prevede che i rifiuti edili raggiungeranno 516 milioni di tonnellate annue entro il 2050, di cui oltre il 90% sarà conferito in discariche incontrollate (Footprints Africa, 2022). Attualmente diverse associazioni, come l'African Circular Economy Alliance, stanno promuovendo sperimentazioni circolari e sviluppando campagne per aumentare la consapevolezza tra gli stakeholder del settore edile finalizzate a coinvolgerli nella sperimentazione di pratiche circolari. Tra i Paesi africani il Kenya merita particolare attenzione considerando da un lato il suo tasso di sviluppo e la continua crescita nel settore delle costruzioni (KNBS, 2022), dall'altro i conseguenti elevati volumi di rifiuti da costruzione e demolizione prodotti (ClimateKIC, 2024; GRID-Arendal, 2021; Karcher et alii, 2020).

Inoltre il Kenya rappresenta potenzialmente un favorevole terreno di sperimentazione di pratiche di Economia Circolare in considerazione dei numerosi insediamenti informali e delle crescenti pratiche di riuso che coinvolgono venditori di materiali edilizi di seconda mano e artigiani locali (Jonathan, 2023). Queste condizioni se considerate alla luce di strategie di circolarità e secondo una prospettiva Triple Bottom Line (che tiene conto delle diverse dimensioni della sostenibilità, ovvero sociale, ambientale ed economica) potrebbero rappresentare opportunità per una transizione da pratiche informali ad attività formali e per la realizzazione di alloggi 'a prezzi accessibili' per fasce di popolazione a basso reddito.

Obiettivi | Sulla base di questa premessa l'articolo propone una visione di 'circolarità per l'accessibilità economica' come contributo alla lotta alla povertà, basata su alcuni obiettivi chiave: 1) supportare la transizione delle attuali pratiche di Economia Circolare da informali a formali, coinvolgendo i mercati di seconda mano già esistenti attraverso la definizione di metodi semplificati per catalogare e valutare le prestazioni residue di prodotti di seconda mano; 2) contribuire alla riduzione dei costi di costruzione attraverso la fornitura di prodotti usati da installare direttamente negli edifici o tramite interfacce adattabili e la definizione di modelli tecno-tipologici progettati per la costruzione facilitata e per il disassemblaggio, basati sulle capacità manifatturiere e costruttive delle risorse locali; 3) rafforzare e consolidare l'imprenditorialità locale, attivando nuove relazioni di filiera capaci di coinvolgere e integrare artigiani per la rimanifattura e il ricondizionamento di prodotti usati, rivenditori che acquistano e vendono prodotti di seconda mano, microimprese di costruzione e autocostruttori, facilitatori come ONG, soggetti pubblici, Università, start up locali, ecc.

La valutazione di quanto le strategie di economia circolare, basate sul riuso di prodotti edilizi e su modelli tecno-tipologici orientati alla facilità realizzativa e al disassemblaggio, possano concorrere all'abbassamento dei costi di costruzione è sicuramente resa difficoltosa dalla esiguità di dati tipica di molti contesti africani e delle pratiche informali. Per questa ragione è fondamentale l'indagine sul campo e il coinvolgimento di varie categorie di stakeholder locali al fine di individuare criteri e dati per la comparazione di soluzioni costruttive alternative e di possibili strategie di circolarità. In questa direzione l'articolo riporta parte dei risultati di una ricerca dottorale, attualmente in corso, volta a coinvolgere e mettere in relazione stakeholder locali tra cui due Università di Nairobi, a indagare le potenzialità per strategie circolari e a sperimentare attraverso casi pilota soluzioni tecno-tipologiche basate su una visione di 'circolarità per l'accessibilità economica'.

Metodologia | La ricerca ha seguito un approccio metodologico, che integra riflessioni teoriche, indagini sul campo e sperimentazione progettuale, articolato in tre fasi principali: analisi del contesto, coinvolgimento degli stakeholder locali e sperimentazione su casi studio. In particolare la ricerca ha sviluppato i seguenti passaggi:
1) individuazione di condizioni favorevoli alla diffusione dell'economia circolare nel settore delle costruzioni in Kenya;
2) costruzione di una rete di stakeholder locali, con coinvolgimento attivo di professionisti, accademici, ONG, imprese edili e rivenditori di materiali di riuso operanti nell'area di Nairobi, attraverso attività di osservazione sul campo, interviste e tavoli di lavoro;
3) sviluppo e confronto tecnico di quattro soluzioni tecno-tipologiche per moduli abitativi – due lineari che assumono elementi costruttivi tipici della produzione locale e due alternative circolari proposte – valutandone la fattibilità costruttiva, la circolarità e l'accessibilità economica; le quattro soluzioni sono state valutate economicamente mediante un'analisi dei costi e attraverso la valutazione dell'accessibilità rispetto alle condizioni reddituali nel caso studio del Quartiere di Kibera a Nairobi (Kenya).

Il paper è strutturato in più paragrafi: i primi due riportano gli esiti di un'approfondita analisi della letteratura finalizzata a comprendere l'attuale stato dell'arte nell'applicazione dei principi di economia circolare al settore delle costruzioni africano e, in particolare, al contesto kenyota. I paragrafi terzo e quarto individuano e analizzano soluzioni tecnologiche tradizionalmente impiegate in Kenya per proporre soluzioni alternative circolari; tali soluzioni vengono inoltre analizzate in termini di costi di costruzione, comparando i costi delle soluzioni lineari e circolari per stimare il potenziale risparmio economico, valutato anche in termini di 'accessibilità economica' nel quinto paragrafo.

Economia Circolare e settore delle costruzioni nei Paesi africani | Le esperienze di economia circolare in Africa testimoniano di un crescente interesse, nonostante la diversità di approcci dei vari contesti locali e il fatto che le iniziative nel settore edilizio richiedano ancora attenzione e impegno (Rademaekers et alii, 2020; Desmond and Asamba, 2019; Mhlanga, Haupt and Loggia, 2022).

Secondo il rapporto pubblicato dalla Footprints Africa (2022) circa le iniziative di sostenibilità ambientale e gestione rifiuti nei Paesi africani, quelli del continente orientale – in particolare Ruanda, Kenya e Uganda – primeggiano con iniziative puntuali per i settori edilizio e manifatturiero (Rademaekers et alii, 2020). Come affermato da Anthony Nyong, Direttore del Climate Change and Green Growth presso la African Development Bank (AfDB, 2020): «[…] For African countries, the circular economy model offers concrete means to deliver on their Paris Agreement and Sustainable Development Goal […] with positive impact on job creation and resource optimization».

Questo implica sfruttare i vantaggi dell'economia circolare a livello ambientale (incoraggiare il riutilizzo e il riciclo di materiali locali, riducendo così lo smaltimento dei rifiuti), sociale (creare posti di lavoro) ed economico (sviluppare nuove aree di business per gli stakeholder locali). Per quanto riguarda molte delle recenti esperienze di Economia Circolare in Africa, importanti attori (Tab. 1) sono le Agenzie internazionali, Associazioni e Organizzazioni non Governative che stanno svolgendo un ruolo chiave nelle campagne di sensibilizzazione per le politiche governative a supporto della transizione circolare.

Una spinta a ricercare strategie appropriate per una transizione circolare nei contesti africani è sicuramente legata al fenomeno della crescita demografica, poiché il settore delle costruzioni è fortemente sollecitato dalla domanda di alloggi e dai conseguenti fenomeni di urbanizzazione ed espansione edilizia incontrollata. Una tale crescente richiesta abitativa implica l'acuirsi di fenomeni quali la deforestazione, l'erosione dovuta alle attività minerarie, utilizzo di materie prime, emissioni di carbonio in atmosfera, produzione di rifiuti, ecc. In questo senso l'Economia Circolare può rappresentare un'alternativa sostenibile laddove si riescano a individuare nuove possibili strategie di riutilizzo, rilavorazione e riciclo di materiali e prodotti usati (Rademaekers et alii, 2020), come anche evidenziato da Ellen MacArthur Foundation (EMF, 2021) che menziona tra le strategie prioritarie a sostegno della transizione circolare:
– l'approvvigionamento di materiali e componenti edilizi locali e recuperati; il riuso nei Paesi Africani è in realtà già assai praticato, seppure in modo spontaneo e non organizzato secondo logiche di filiera, specie negli insediamenti informali e nelle pratiche di autocostruzioni e dove ad esempio le lamiere grecate vengono riutilizzate molteplici volte e impiegate come elementi di copertura o partizioni interne di alloggi;
– il perseguimento di approcci innovativi come la 'progettazione per la decostruzione' e la 'progettazione per il disassemblaggio' (Di Virgilio, 2023), assumendo modularità e flessibilità (Manni and Valzano, 2023) come requisiti di progetto e promuovendo componenti assemblati a secco e prefabbricati (Chen, Feng and Garcia de Soto, 2022).

Ellen MacArthur Foundation sottolinea come le più efficaci azioni per adottare la circolarità nel contesto africano si collocano nella fase di progettazione di edifici e infrastrutture. Ripensare il progetto

Organisation	Description of the initivatives
The African Circular Economy Facility (ACEF) [1]	Negotiations between the African Development Bank (ADB), the Government of Finland, the Finnish Innovation Fund Sitra, and the Nordic Development Fund were initiated at the 2019 World Circular Economy Forum in Helsinki, Finland. The result is a strategic partnership in a five years programmme (2021-2025) that aims to support the diffusion of circular economy practices across the continent's member countries.
The African Circular Economy Alliance (ACEA) [2]	ACEA was established during the 23rd United Nations Conference of Parties (COP23) by the Governments of South Africa, Nigeria, and Rwanda. The mission is to spur Africa's transition to Circular Economy at the country, regional, and continental levels by operating as a collaborative platform to coordinate and link the various initiatives on the continent. The ACEA main intervention pillars include policy advisory, leadership and advocacy, as well as projects and business scale-up.
The African Circular Economy Network (ACEN) [3]	Born on the belief that Africa could strive through a Circular Economy (Lemille, 2019), ACEN is a partnership with the African Development Bank initiatives. The network envisions building an African Economy that generates well-being and prosperity through the pool of Circular Economy experts across the continent and strategic relationships aimed at supporting Africa.
African Footprints	The agency created a summary of initiatives across the continent. East African Countries like Rwanda, Kenya, and Uganda seem to be driving in this regard, covering sectors including construction and manufacturing (Footprints Africa, 2022).

Tab. 1 | Main Organisations involved in Circular Economy initiatives in Africa (credit: the Authors, 2025).

verso soluzioni modulari, a secco e reversibili può facilitare l'integrazione di prodotti di riuso e di materie prime seconde, con un impatto positivo in termini di riduzione dei costi di costruzione e di creazione di nuove opportunità di lavoro (rivendita di prodotti e materiali di riuso). Rispetto a questa visione molteplici sono oggi gli operatori del settore delle costruzioni in Africa a mostrare interesse e a condurre sperimentazioni verso pratiche di riciclo, seguite da riutilizzo e rigenerazione (Tab. 2).

Potenzialità dell'economia circolare nel settore edile keniota | Tra i Paesi africani il Kenya merita una particolare attenzione considerando il suo tasso di sviluppo e le iniziative di economia circolare esistenti (GRID-Arendal, 2021; Karcher et alii, 2020). Lo scenario economico in Kenya presenta opportunità per l'applicazione di strategie di economia circolare (da rifiuto a risorsa) nel settore delle costruzioni, aprendo a nuove opportunità di business volte alla rivitalizzazione dell'economia locale.

Uno studio di Karcher et alii (2020) stima che le attività di economia circolare in Kenya entro il 2030 possano contribuire alla crescita economica dello 0,5%: le attività di economia circolare possono apportare benefici sociali e combattere la povertà con un aumento stimato dello 0,15% dell'occupazione (Karcher et alii, 2020). Inoltre la 'Big Four Agenda' (Netherlands Enterprise Agency, 2021) keniota ha promosso negli anni iniziative circolari (Tab. 3) volte da un lato a ridurre la generazione di rifiuti nel settore delle costruzioni, dall'altro a garantire alloggi economicamente accessibili anche alle fasce più fragili di popolazione. Tali obiettivi sono condivisi anche dalla 'Kenya Vision 2030' che mira a supportare il Kenya a divenire un «[…] newly industrializing, middle-income country providing high-quality of life to all its citizens by 2030 in a clean and secure environment» (Netherlands Enterprise Agency, 2021, p. 7).

Tuttavia, nonostante queste premesse le attuali applicazioni di economia circolare, in particolare quelle legate al riutilizzo e al remanufacturing, nel settore delle costruzioni keniota sono perlopiù sperimentali, non ancora strutturate e consolidate. Come mostrato in Tabella 4 le sperimentazioni circolari più consolidate riguardano il riciclo di rifiuti in plastica per produrre elementi di finitura (ad esempio pavimentazioni); accanto a queste iniziative le attività informali – come l'autocostruzione con rifiuti da costruzione e demolizione, la vendita di materiali e prodotti di seconda mano e la rilavorazione di componenti usati – sono molto frequenti, come emerso dall'indagine sul campo condotta con il coinvolgimento di ONG, professionisti e accademici kenyoti.

Attualmente è difficile quantificare l'entità di queste attività informali; tuttavia, se opportunamente organizzate secondo una visione strategica, potrebbero rientrare in logiche di filiera, con possibili miglioramenti nella qualità edilizia e abitativa, conseguendo benefici economici e ambientali (Sibanda, Mhlanga and Munuhwa, 2025). La ricerca, di cui questo articolo riporta alcuni esiti, esplora le possibilità di perseguire una visione di 'circolarità per l'accessibilità economica' con il fondamentale supporto di stakeholder locali quali professionisti, imprese di costruzione, ONG, Università, produttori, rivenditori di materiali e prodotti di seconda mano e utenti finali.

Proposta di soluzioni tecnologiche con prodotti da riuso per il contesto kenyota | Rispetto alle indagini condotte la ricerca si è orientata alla definizione di modelli tecno-tipologici caratterizzati da soluzioni facilmente assemblabili e disassemblabili, realizzabili con risorse locali e con mezzi d'opera semplici (autocostruzione e/o imprese artigianali), in grado di utilizzare elementi edilizi di seconda mano: l'obiettivo è ridurre i costi di costruzione e contribuire a limitare l'impatto ambientale delle attività edilizie. Le soluzioni sviluppate, che si basano quindi sulla fornitura di prodotti riutilizzati da installare direttamente negli edifici o integrabili nel sistema edilizio tramite interfacce adattabili, sono state definite nei loro aspetti costruttivi e di processo con il supporto degli stakeholder, anche per valutare la fattibilità realizzativa rispetto a prodotti e maestranze locali e il possibile coinvolgimento dei rivenditori locali, che attualmente commerciano prodotti di seconda mano nei mercati dell'usato.

La sperimentazione parte da due soluzioni abitative tradizionali comunemente utilizzate in Kenya: la prima realizzata con pareti portanti in blocchi di pietra locale tagliata e partizioni interne, la seconda con telaio strutturale in calcestruzzo armato e tamponamenti in blocchi di terra stabilizzata più partizioni interne.

Queste soluzioni costruttive sono caratterizzate dai materiali da costruzione più comunemente utilizzati in Kenya: secondo Kariuki, Mugwima e Kaluli (2015), pietra naturale e blocchi di terra rappresentano circa il 57% dei materiali per pareti, mentre le lamiere zincate ne costituiscono circa il 27%. Questi materiali sono preferiti per la loro disponibilità, convenienza e prestazioni termiche adatte al contesto. Per quanto riguarda il sistema strutturale il calcestruzzo armato rimane il materiale da costruzione più utilizzato grazie alla sua resistenza e durabilità (Okumu, Oyawa and Shitote, 2016). La tipologia di queste soluzioni tradizionali rappresenta circa l'80% degli edifici residenziali in Kenya (Kenya Green Building Society and GreenThumb, 2023) che spesso impiegano tecnologie costruttive semplici per soddisfare esigenze di economicità.

Nella prima fase di lavoro queste soluzioni costruttive tradizionali vengono confrontate con due soluzioni alternative – realizzate adottando materiali diversi – orientate ad approcci circolari e al 'design-for-disassembly', con processi di costruzione e decostruzione semplificati (Fig. 1).

Nella seconda fase di lavoro per ciascuna delle quattro soluzioni tecno-tipologiche viene effettuato un confronto – prevedendo l'inserimento di elementi da riuso nelle pareti esterne – tra 'approccio lineare' (caratterizzato dalla fornitura di nuovi materiali e prodotti per la realizzazione di pareti non portanti) e 'approccio circolare' (caratterizzato dalla fornitura di materiali e prodotti di seconda mano derivati da mercati secondari locali).

Nella terza fase di lavoro viene valutata l'accessibilità economica delle soluzioni alternative proposte con fornitura di materiali e prodotti di riuso attraverso una analisi economica comparativa tra costi di costruzione e reddito medio in contesti di insediamento informale caratterizzati da attività costruttive artigianali o di autocostruzione per il contesto di Kibera, uno slum della Città di Nairobi in Kenya.

L'analisi delle soluzioni tecnologiche e delle tecniche di costruzione prevalentemente utilizzate in Kenya è stata supportata dal dialogo attivo con una

Countries	Promoter	Circular Economy Practices/Initiatives	Description/goals	Year	Source
Cote d'Ivoire	UNICEF	A partnership between UNICEF and Concepts Plastics to build 500 classrooms for 25,000 children using recycled plastics collected from around Abidjan. Provision of income in the formalised recycling market to women. A similar project has been accomplished in Colombia.	The bricks are made from 100% recycled plastics which are 40% cheaper and 20% lighter and last longer than conventional building materials; they are also waterproof and designed to resist wind. Similar activities are also ongoing in Ghana.	2019	Rademaekers et alii, 2020
Egypt	Egyptian Government	Green Economy Strategy for recycling, resource efficiency, use of local sandstone, use of secondary materials.	To boost the role of the industrial sector towards recycling of materials and limiting the quantity of raw materials extraction.	2018	Mahmoud et alii, 2020
Ghana	Non-Governmental Organizations	Circular Economy policies to enforce standards for new and renovated buildings characterized by low energy and use of recycled materials.	Circular Economy for addressing the issue of high cost of building and reduce raw material extraction through recycling and reuse of secondary materials.	2015	Hemkhaus et alii, 2020
Kenya	National Construction Authority (NCA) Kenyan Green Building Society (KGBS)	Banning of single-use plastic, sustainable waste management. Production of interlocking Stabilized Soil Blocks (ISSB), and plastic block and pavements.	Banning non-biodegradable materials will boost the construction sector to reduce its impact on the environment. Use of plastic waste to produce plastic block and pavement.	2020	Karcher et alii, 2020
Morocco	Moroccan Green Building Society	Proposal for integrating construction and demolition waste within stakeholders' value chain.	The effort is towards the achievement of a more sustainable system in the construction sector.	2018	Diaco et alii, 2020 Rademaekers et alii, 2020
Nigeria	The Nigerian Government	Informal Waste Management. Waste minimisation face the rapid urbanisation across the country.	The Solid waste management initiative provides opportunity for Circularity in the construction sector.	2017	Potgieter et alii, 2020
Senegal	Global Environmental Facility (GEF) United Nation Development Programme (UNDP)	Diamniado Eco pavilion in a futuristic City construction as a sample using Compressed Earth Bricks (CEB). Provision of a regulatory framework that should allow recovery of demolition and construction waste.	Eco-construction involving the use of compressed earth bricks in an innovative way.	2018	Bonnaire et alii, 2020
South Africa	Arup, South Africa	Re-use of construction and demolition wastes due to the rising cost of virgin materials. The Centre for Regenerative Design and Collaboration (CRDC) converts disposed plastic products to blocks called EcoArena used for constructing low-cost houses. Digiyard, a material exchange platform launched by Arup in Cape Town, to reduce construction waste. The platform, made for a web and mobile application, allows the data gathering and sharing about materials that can be exchanged.	Second-hand material market in South Africa through informal waste collectors provide for reusable construction and demolition scraps, avoiding landfill. Digiyard: A Material exchange digital platform, for South Africa (Re-use, Recycle).	2018	Potgieter et alii, 2020
Rwanda	Strawtec building solution, Rwanda	Green building rating system for boosting the use of sustainable materials and recycled materials and enhancing environmental performance. Strawtec Business Solution is a building construction company replacing conventional cement walls with wheat and rice straws of high quality.	The use of recycled materials to reduce the extraction of virgin materials. Eliminating the burning of straw that can be sold by the farmers for producing Strawtec walls as a means of income.	2015	Rademaekers et alii, 2020
Uganda	Local design Company	Local Works: A multi-disciplinary design collaborative, based in Kampala Uganda. They are specialised in ecological architecture in East Africa. The company experiments with low-carbon materials such as eucalyptus sisal and earth in their projects.	Construction with Low-Carbon Materials: from the design stage they ensure minimum wastage during construction.	2013	Rademaekers et alii, 2020
Zambia	Copperbelt University, Zambia Leeds University, UK University of Witwatersrand, South Africa	A cost-benefit of using copper tailing as a partial replacement of elements in concrete production.	With the abundance of copper tailings in the Copperbelt province of Zambia, the use of a concrete mixture could increase circularity in the construction sector. This also produces a maximum compressive strength value.	2009	Muleya et alii, 2020 Mhlanga et alii, 2022

Tab. 2 | Circular Economy initiatives in the construction sector of African countries (credit: the Authors, 2025).

rete di stakeholder locali che operano principalmente a Nairobi, tra cui architetti, imprese, produttori, rivenditori, utenti, Centri di ricerca e Università. La prima soluzione tradizionale (Fig. 2) identificata è realizzata in blocchi di pietra tagliati presso la cava, per i quali l'impatto prevalente è legato all'estrazione massiccia di materie prime. La seconda soluzione tradizionale (Fig. 3) identificata è realizzata integrando una struttura a telaio in calcestruzzo armato con una chiusura in blocchi di terreno stabilizzato, difficili da recuperare in fase di dismissione perché collegati da giunti di malta cementizia.

A partire da questi sistemi costruttivi tradizionali sono state individuate due possibili soluzioni alternative più orientate alla circolarità del progetto e alla facilità di disassemblaggio, secondo i criteri di: massimo impiego di materiali e prodotti da costruzione disponibili sul mercato locale; facilità di costruzione; facilità di disassemblaggio grazie a collegamenti reversibili; presenza di interfacce adattabili per consentire la sostituzione di pareti non portanti realizzate con materiali e prodotti nuovi con pareti non portanti realizzate con prodotti e materiali da riuso.

La prima soluzione alternativa in sostituzione dei blocchi tagliati in pietra è rappresentata dai Twist Block (Fig. 4), innovativi blocchi a incastro che, prodotti localmente e realizzati con una miscela di calcestruzzo, non richiedendo giunti in malta cementizia possono assicurare un'agevole disassemblabilità. La sezione, considerata come adeguata a integrare elementi circolari nella chiusura esterna, in questo caso è stata assunta – secondo le indicazioni di progettisti e costruttori locali – pari a 1,8 x 1,9 metri, per consentire una percentuale maggiore di elementi circolari pur mantenendo la stabilità strutturale. La seconda soluzione alternativa in sostituzione dei blocchi di terreno stabilizzato è rappresentata dai blocchi a incastro di terreno stabilizzato (Fig. 5), facili da disassemblare, perché collegati senza la necessità di giunti in malta cementizia.

La Tabella 5 riporta l'analisi condotta sulle quattro soluzioni alternative per un modello abitativo di 3 x 4 metri, comprensiva del costo di realizzazione desunto da computo metrico estimativo redatto con il coinvolgimento attivo delle imprese edili locali: la soluzione con blocchi twist è caratterizzata da un costo di costruzione inferiore rispetto alla soluzione tradizionale con blocchi tagliati in pietra, anche nel caso della tipologia con telaio in calcestruzzo armato e mattoni a incastro in terra stabilizzata il costo di costruzione è leggermente inferiore alla soluzione tradizionale con telaio in calcestruzzo armato e mattoni in terra stabilizzata.

Il modello tecno-tipologico con materiali e prodotti di riuso | Al fine di valutare la fattibilità delle soluzioni abitative circolari proposte e la relativa riduzione dei costi complessivi di costruzione in linea con la visione di circolarità, per semplicità è stata sviluppata un'analisi comparativa confrontando uno scenario di base (caso lineare: soluzioni tecno-tipologiche realizzate con nuovi materiali e prodotti) e uno scenario circolare (soluzioni tecno-tipologiche realizzate parzialmente con prodotti di seconda mano / riutilizzati provenienti da mercati secondari e da attività con costruzione e demolizione). I criteri e i principi guida seguiti per delineare soluzioni alternative circolari con prodotti di riuso sono stati la disponibilità sui mercati secondari locali, la propensione alla realizzazione di pareti non portanti, la facilità di montaggio e/o costruzione e la facilità di integrazione con sistemi costruttivi esistenti.

La preferenza per i materiali utilizzati nelle soluzioni alternative è inoltre legata ad attributi quali le loro prestazioni termiche, la facilità di lavorazione, il processo di produzione, la riciclabilità e la riutilizzabilità; si ritiene che questi attributi siano adatti al contesto keniota e facilitino il successivo utilizzo dei materiali circolari smontabili. La Tabella 6, con attributi tratti da Kenya Green Building Society and GreenThumb (2023), Kariuki, Mugwima e Kaluli (2015) e Okumu, Oyawa e Shitote (2016), fornisce una panoramica delle caratteristiche dei materiali di rivestimento alternativi.

Lo studio dei modelli tecno-tipologici ha guardato in primo luogo alla possibilità di sostituire una porzione delimitata degli elementi edilizi non portanti con omologhi recuperati dal mercato dei materiali edili di seconda mano (Fig. 6); per la tipologia dei blocchi tagliati in pietra, nella quale le pareti sono portanti, la porzione di parete da sostituire è stata dimensionata con una apertura di 1,2 x 1,9 metri sulla muratura in modo tale da evitare la diminuzione di capacità portante della parete.

Questa 'opportunità di sostituzione', ampiamente discussa con le aziende edili locali e i rivenditori locali di prodotti di 'seconda mano', ha portato alla definizione di approcci tecnologici di costruzione con smontaggio e montaggio attraverso l'utilizzo di giunti a secco per consentire una facile aggiornabilità dei prodotti recuperati, tra cui compensati di seconda mano, lamiere metalliche, ecc. I materiali e i prodotti circolari per pareti ed elementi edilizi non portanti sono descritti nella Tabella 7, con evidenza di costi e fonti correlate; questi prodotti circolari ed elementi di muratura consentono di ottenere un costo di costruzione inferiore, che varia anche quando applicato al diverso sistema edilizio.

La modifica degli elementi per ciascuno dei modelli tipologici viene descritta nella Tabella 8. Per ciascuna soluzione la stima dei costi degli elementi portanti e non portanti è stata effettuata con il supporto degli stakeholder locali, partendo da un computo metrico estimativo per lo scenario tradizionale (caso lineare) e quindi calcolando il computo metrico estimativo per il caso circolare per il quale sono state considerate influenti le caratteristiche di smontaggio, i materiali circolari non portanti, la porzione dimensionale dei materiali non portanti e l'origine dei materiali non portanti: in questo modo è stato possibile calcolare il costo della costruzione delle porzioni circolari alternative non portanti e stimare la riduzione dei costi di costruzione rispetto al caso tradizionale.

In seguito verrà discussa la valutazione della 'circolarità per l'accessibilità economica' menzionata in precedenza, adottando come riferimento un approccio progettuale incrementale e adatto a integrare elementi da riuso eprendendo in esame il costo di costruzione per la tipologia scelta. La progettazione incrementale della residenza ben si adatta al particolare contesto economico in quanto permette di aumentare nel tempo la superficie degli alloggi in base alla progressiva disponibilità di risorse.

Valutazione dell'accessibilità economica dei modelli tecno-tipologici proposti per il contesto keniota | Al fine di valutare l'accessibilità a prezzi

Year	Politcies
2017	**Plastic Carrier Bag Ban** Ban of use of the disposal PET bottles in Karura Forest by the Ministry of Environment and Forestry. Other areas include the National Reserve and Game Parks, a move aimed at conserving and protecting animals and nature within the ecosystem.
	Establishment of the PET task force A partnership between Kenya Association of Manufacturers KAM, the Ministry of Environment and Forestry, and the National Environmental Management Authority (NEMA). The task force's purpose is to have both the private sector and government support each other in the management of waste PET bottles.
2018	**Framework of Cooperation (FOC)** Private Sector (Kenyan Association of Manufacturers) and National Environmental Management Authority on PET plastic.
2020	**Revised National Building Code** Ministry of Transport, Infrastructure, Housing & Urban Development and the Ministry of Lands & Physical Planning. The new code represents a considerable improvement to the previous building code of 1968. Part XX Disaster Risk Management Section 23, sub-section 3 states – 'While carrying out the demolition, priority shall be given to reduce, reuse wastage, and recycle materials salvaged from demolition'.
	Business Plan Model based on EPR (Extended Producer Responsibilities) Kenya Association of Manufacturers in collaboration with the Ministry of Environmental and Forestry and Sustainable Inclusive Business developed a Business Plan Model for Kenya considering the current draft regulations for the EPR.
2021	**Business Plan Model based on EPR (Extended Producer Responsibilities)** Kenya Association of Manufacturers in collaboration with the Ministry of Environmental and Forestry and Sustainable Inclusive Business developed a Business Plan Model for Kenya considering the current draft regulations for the EPR.

Tab. 3 | Policies and regulations to support the Circular Economy in Kenya (source: Netherlands Enterprise Agency, 2021).

contenuti delle soluzioni alternative proposte con fornitura di materiali e prodotti di riuso è stata condotta un'ulteriore analisi economica per ciascuna proposta prendendo quale campo di applicazione il contesto socio-economico di Kibera, un insediamento informale di Nairobi in Kenya. A titolo esemplificativo si riporta di seguito l'analisi sviluppata per il caso della 'soluzione alternativa 1' realizzata con i Twist Block. Il modello tecno-tipologico è stato concepito con uno schema modulare incrementale (Fig. 7) per facilitarne lo smontaggio. L'analisi è finalizzata a verificare l'accessibilità economica dell'unità abitativa considerando le entrate economiche dei residenti della classe di reddito più bassa di Kibera.

Le unità abitative tipiche di Kibera, come quelle di altri insediamenti informali di Nairobi, sono caratterizzate da una superficie media di non più di 11 metri quadrati per singola famiglia. La proposta di modulo abitativo denominata Disassembling Incremental Circular Modular House (DICMH) è configurata come un modulo realizzato con elementi Twist Block, facile da smontare, che consente una maggiore possibilità di integrazione con materiali circolari. Il progetto prevede un piano terra e un piano superiore con scala, cucina e servizi igienici (per una superficie di 48 metri quadrati) rifiniti con materiali e prodotti circolari, mentre le parti incrementali di altri 48 metri quadrati sono pianificate per essere completate con materiali e prodotti circolari recuperati dagli abitanti. La DICHM, che sarà abitata da quattro famiglie, offre un livello di accessibilità alla proprietà con mutuo entro 8 anni, con rata costante inferiore al 30% del reddito familiare medio (Tab. 9) e al canone mensile di affitto degli intervistati residenti a Kibera.

In Figura 8 si riporta la descrizione del DICMH con i moduli base di partenza (scale, servizi igienici e cucina), mentre gli spazi abitativi possono essere incrementati con i muri esterni non portanti che prevedono le aperture che saranno completate con gli elementi realizzati con materiali da riuso. Questo approccio si fonda su studi sulla modularità e sui sistemi adattivi (Manni and Valzano, 2023) e prevede un sistema strutturale che consente di aggiornare facilmente gli elementi circolari non portanti all'interno del sistema adattivo.

Gli elementi circolari per il completamento dei moduli incrementali dovrebbero seguire le caratteristiche e le tecniche costruttive degli elementi circolari non portanti dei moduli base. Queste caratteristiche, come menzionato in precedenza, includono materiali di seconda mano di provenienza locale, facili da montare e smontare per consentire futuri aggiornamenti, facili da lavorare per artigiani e proprietari di case e in grado di fornire un livello adeguato di capacità termica per il contesto keniota. Questa facilità di costruzione dei moduli incrementali per i proprietari delle abitazioni fa riferimento all'approccio dell'autocostruzione che deve essere semplice ed economico (Di Virgilio, 2023): la filiera locale degli elementi circolari è molto importante per realizzare una rete di materiali circolari a basso impatto economico (Gaddi and Mastrolonardo, 2024).

Conclusioni | Nel continente africano il tema generale della sostenibilità si apre a molte chiavi di lettura, una delle quali riguarda il rapporto tra strategie di circolarità e accessibilità alle abitazioni per fasce di popolazione a basso reddito. Il Kenya dimostra una progressiva presa di coscienza dei notevoli problemi ambientali e un crescente interesse per i temi della circolarità: la Città di Nairobi si presta ad essere un osservatorio rappresentativo di molte realtà africane caratterizzate da un elevato tasso di crescita demografica, una forte domanda abitativa e una grande presenza di insediamenti informali caratterizzati dalla mancanza di riferimenti normativi, dalla assenza di qualità tecnica e architettonica, dalla presenza di numerose piccole imprese artigiane e di iniziative di autocostruzione nelle quali, in modo non strutturato, si sviluppano pratiche spontanee di economia circolare attraverso il riuso di materiali e componenti edilizi di seconda mano.

In un tale contesto appropriate strategie di circolarità possono aprire a molte opportunità nella direzione di fornire criteri organizzativi alle attività edilizie e alle già presenti offerte di prodotti edilizi da riuso. Le azioni si dovrebbero concentrare su più fronti: approcci edilizi fondati sul riuso di materiali e componenti utilizzabili direttamente o grazie ad opportune interfacce; individuazione di tecniche costruttive a secco, reversibili, disassemblabili e di facile esecuzione.

Come dimostrato dall'osservazione sul campo e dal caso pilota è possibile ottenere risparmi su costi e tempi di costruzione e allo stesso tempo incrementare la qualità di progetto e di processo attraverso azioni coordinate quali: la progettazione di moduli abitativi ripetibili e definiti in base a capacità

Name	Business focus & products	Circular economy approach	Objectives	Source
Gjenge makers	From plastic waste to paving blocks, tiles and manhole covers	Recycling of plastic waste	Gjenge's aim is to address the need for sustainable and affordable alternative construction materials in Kenya and Africa by recycling plastics to produce plastic paving blocks, plastic paving tiles, and plastic manhole covers.	gjenge.co.ke
Green Pavers Kenya	From plastic waste to paving, fence posts and solar tiles	Recycling of plastic waste	Green Pavers, a social enterprise that creates durable and affordable building components, participates in providing low-cost building products to low-income people by recycling plastic waste into building components, i.e. paving tiles.	Okutoyi, 2021
Ecopost Limited Kenya	Recycling waste plastic to manufacture eco-friendly plastic fencing profiles	Recycling of plastic waste	Ecopost recycles waste plastic to manufacture into profiles with application in fencing, road signage and outdoor furniture.	ecopost.co.ke
Corec Limited Kenya	Recycling waste plastic to manufacture roofing tiles, paving tiles, etc.	Recycling of plastic waste	COREC produces high quality and durable resin bonded roofing tiles, Manhole Covers, Plastic lumber Planks and Fencing poles / posts.	netfund.go.ke
Endelevu.africa Kenya	Digital Marketplace. People can donate and sell reclaimed building materials	Digital sharing of materials	Endelevu promotes sharing by providing a digital platform. Crowdfunding for under-resourced social construction projects, crowd-sourcing an empowered workforce to design and construct the funded community projects, and exchanging reclaimed construction materials and products.	endelevu.africa Footprints Africa, 2022
Myco Tile Kenya	Construction material from Fungi	Rethink, Remanufacture	MycoTile offers cheaper alternative to traditional building materials. It uses a carbon negative process to bond agricultural with mushroom mycelium to manufacture building products, e.g. suspended ceiling panels.	Footprints Africa, 2022

Tab. 4 | Circular Economy materials and products in the construction sector in Kenya (credit: the Authors, 2025).

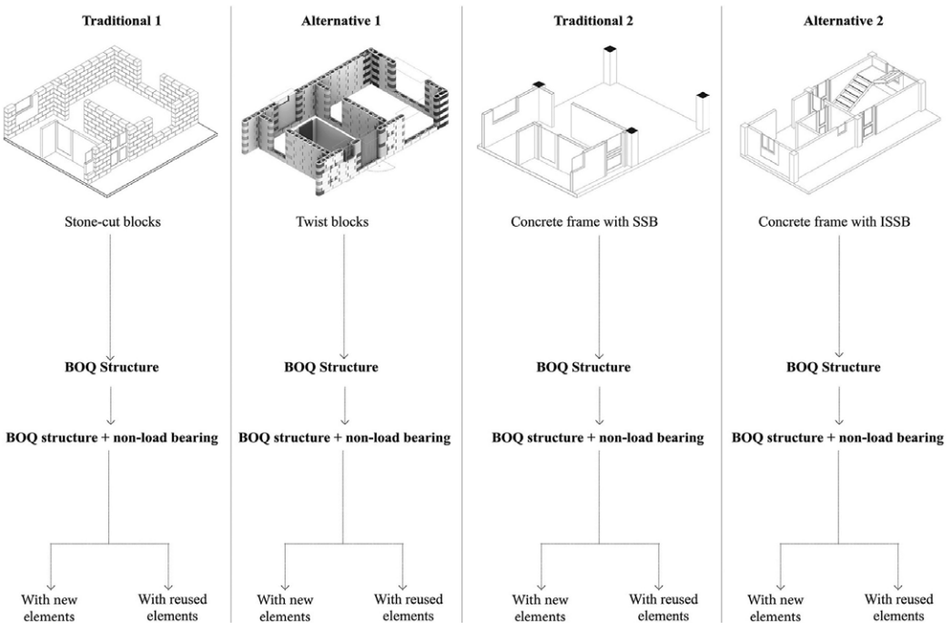


Fig. 1 | Outline of the methodology (credit: the Authors, 2025).

produttive, prodotti e tecniche locali; l'individuazione dei prodotti di seconda mano facilmente reperibili in loco; il coinvolgimento di molteplici stakeholder pubblici e privati di filiera. In questo senso strategie coordinate di circolarità dimostrano di avere, oltre agli evidenti vantaggi ambientali, le potenzialità per la creazione di nuove opportunità per micro-imprese (costruzione, manifattura di prodotti, vendita diretta o con azioni di ri-manifattura di prodotti usati) e per start up locali, ma anche per cooperare alla transizione da approcci informali a formali nella realizzazione di insediamenti per fasce a basso reddito della popolazione.

Gli esiti della sperimentazione hanno evidenziato che i benefici ambientali e economici (espressi in termini di 'circolarità per l'accessibilità economica'), conseguiti nel caso studio attraverso l'impiego di soluzioni tecnologiche circolari e l'applicazione di pratiche di riuso, sono percentualmente rilevanti rispetto alle tradizionali soluzioni 'lineari'.

Nonostante questi vantaggi è possibile osservare alcune criticità, principalmente riferibili alla disponibilità e all'attendibilità dei dati. Gli step di lavoro per lo sviluppo della sperimentazione sono stati parzialmente condizionati dalla scarsa disponibilità di dati e informazioni, tra cui dati tecnici dei prodotti, costi della manodopera, costi dei prodotti di recupero rivenduti nei mercati 'second-hand', ecc. In questo senso il supporto degli stakeholder locali è stato di primaria importanza e ha posto le basi per la definizione di un approccio strutturato alla gestione delle informazioni, basato sul principio di gradualità, che faciliterà i prossimi step di lavoro verso l'integrazione di valutazioni ambientali, economiche e sociali.

La sperimentazione condotta e l'approccio metodologico proposto rappresentano possibili strumenti per promuovere e valutare soluzioni costruttive circolari in termini economici e ambientali in contesti dinamici e fragili, quali i Paesi in via di sviluppo, spesso caratterizzati da realtà sociali, politiche ed economiche incerte e dal crescente fenomeno dell'urbanizzazione che comportano l'impossibilità per le fasce più svantaggiate della popolazione di accedere ad alloggi adeguati a prezzi accessibili.

Although the Circular Economy is still a relatively new topic in most African countries, some conditions may raise the interest of construction sector actors (Muriithi and Ngare, 2023; Turing, 2021). Phenomena such as increasing investments in the construction sector, the growing amount of construction and demolition waste and the significant presence of informal activities for the reuse of construction products suggest opportunities to support local entrepreneurship, develop circularity strategies and fight poverty. In Africa, the construction sector is a priority area characterised by high waste generation and intensive use of resources. The increase in construction and demolition waste generation is driven by the growth of construction activities, linked to the population growth – forecast to reach 2.4 billion people by 2050 (Rademaekers et alii, 2020) – and the resulting growing demand for housing.

Across Africa, construction waste will reach 516 million tonnes annually by 2050, of which over 90% is going to uncontrolled landfills (Footprints Africa, 2022). Several associations, such as the African Circular Economy Alliance, promote circular experiments and develop awareness-raising campaigns among construction sector stakeholders to involve them in experimenting with circular practices. Among African countries, Kenya deserves particular attention considering, on the one hand, its rate of development and the continuous growth of the construction sector (KNBS, 2022), and on the other hand, the resulting high volumes of produced construction and demolition waste (ClimateKIC, 2024; GRID-Arendal, 2021; Karcher et alii, 2020).

Moreover, Kenya potentially represents a favourable testing ground for Circular Economy practices, given the many informal settlements and the growing reuse practices involving second-hand building material sellers and local artisans (Jonathan, 2023). These conditions, if considered in the light of circularity strategies and according to a Triple Bottom Line perspective (which takes into account the different dimensions of sustainability, namely social, environmental and economic), could represent an opportunity for shifting from informal activities to formal practices and for the creation of 'affordable' housing for the low-income population.

Objectives | Based on this premise, the article proposes a vision of 'circularity for affordability' as a strategy to the fight against poverty, based on some key objectives: 1) supporting the transition of current Circular Economy practices from informal to formal by pushing the involvement of existing second-hand markets through the definition of simplified methods to catalogue and evaluate the residual performance of second-hand products; 2) contributing to the reduction of construction costs through the supply of used products to be installed directly in buildings or through adaptable interfaces and the definition of techno-typological models designed for easiness of construction and disassembly, based on the manufacturing and construction capabilities of local resources; 3) strengthening and consolidating local entrepreneurship, activating new supply chain relationships capable of involving and integrating artisans for the remanufacturing and reconditioning of used products, retailers who buy and sell second-hand products, construction micro-enterprises and self-builders, facilitators such as NGOs, public bodies, Universities, local start-ups, etc.

Evaluating how circular economy strategies, based on the reuse of building products and techno-typological models oriented towards ease of construction and disassembly, can contribute to the reduction of construction costs is certainly made difficult by the scarcity of data typical of many African contexts and informal practices. For this reason, involving various categories of local stakeholders and on-field investigations is essential to identify criteria and data for comparing alternative construction solutions and possible circularity strategies. In this direction, the article reports part of the results of doctoral research, currently underway, aimed at involving and connecting local stakeholders, including two Universities of Nairobi, to investigate the potential for circular strategies and to experiment through pilot cases techno-typological solutions based on a vision of 'circularity for affordability'.

Methodology | The research followed a methodological approach integrating theoretical reflections, field investigations, and design experimentation. It consists of three main phases: context analysis, involvement of local stakeholders, and experimentation on case studies. In particular, the research developed the following steps:
1) identification of favourable conditions for the diffusion of the circular economy in the construction sector in Kenya;
2) construction of a network of local stakeholders, with the active involvement of professionals, academics, NGOs, construction companies and retailers of reused materials operating in the Nairobi area, through field observation activities, interviews and working groups;
3) development and technical comparison of four techno-typological solutions for housing modules – two linear ones that assume typical construction

elements of local production and two proposed circular alternatives – evaluating their construction feasibility, circularity and economic accessibility; the four solutions are economically analysed through a cost assessment and the affordability concerning income conditions in the case study of the Kibera District in Nairobi (Kenya).

The paper consists of several paragraphs; the first two report the results of an in-depth literature analysis aimed at understanding the current state of the art in applying circular economy principles to the African construction sector, particularly the Kenyan context. The third and fourth paragraphs identify and analyse technological solutions traditionally used in Kenya to propose alternative circular solutions; these solutions are also analysed in terms of construction costs, comparing the costs of linear and circular solutions to estimate the potential economic savings, also evaluated in terms of 'affordability' in the fifth paragraph.

Circular Economy and the construction sector in African Countries | The experiences of circular economy in Africa show a growing interest despite the diversity of approaches in the various local contexts and the fact that initiatives in the construction sector still require attention and commitment (Rademaekers et alii, 2020; Desmond and Asamba, 2019; Mhlanga, Haupt and Loggia, 2022).

According to the report published by Footprints Africa (2022) on environmental sustainability and waste management initiatives in African countries, those of the eastern continent – in particular Rwanda, Kenya and Uganda – lead the way with specific initiatives for the construction and manufacturing sectors (Rademaekers et alii, 2020). As stated by Anthony Nyong, Director of Climate Change and Green Growth at the African Development Bank (AfDB, 2020): «[…] For African countries, the circular economy model offers concrete means to deliver on their Paris Agreement and Sustainable Development Goal […] with positive impact on job creation and resource optimization».

It implies exploiting the benefits of the circular economy at the environmental (encouraging the reuse and recycling of local materials, thus reducing waste disposal), social (creating jobs) and economic (developing new business areas for local stakeholders) levels. Regarding many recent experiences of Circular Economy in Africa, important actors (Tab. 1) are International Agencies, Associations and Non-Governmental Organisations that play key roles in raising awareness of the circular economy within government policies.

The drive to seek appropriate strategies for a circular transition in African contexts undoubtedly ties in with population growth. The construction sector receives a strong stimulus from the demand for housing, which results in urbanisation and uncontrolled building expansion. Such a growing demand for housing implies worsening phenomena such as deforestation, erosion due to mining activities, use of raw materials, carbon emissions into the atmosphere, waste production, etc. In this sense, the Circular Economy can represent a sustainable alternative in which to identify possible new strategies for the reuse, reprocessing and recycling of used materials and products (Rademaekers et alii, 2020), as also highlighted by the Ellen MacArthur Foundation (EMF, 2021) which mentions among the 'priority strategies' to support the circular transition: – the supply of locally recovered building materials and components; the reuse in African countries is already widely practised, albeit spontaneously and not organised according to supply chain logics, especially in informal settlements and self-construction practices, where, for example, corrugated sheets are reused multiple times and employed as roofing elements or internal partitions of housing; – the pursuit of innovative approaches such as 'design for deconstruction' and 'design for disassembly' (Di Virgilio, 2023), assuming modularity and flexibility (Manni and Valzano, 2023) as design requirements and promoting dry-assembled and prefabricated components (Chen, Feng and Garcia de Soto, 2022).

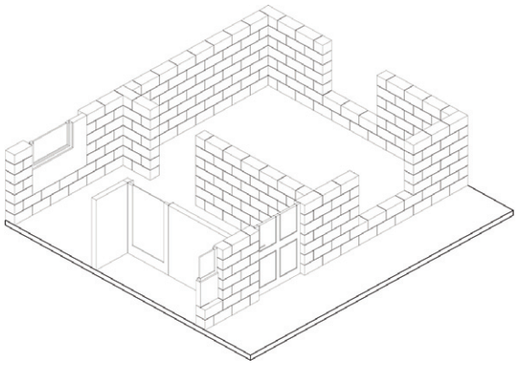
The Ellen MacArthur Foundation highlights how the most effective actions to promote circularity in Africa focus on the design phase of buildings and infrastructure. Rethinking the project towards modular, dry and reversible solutions can facilitate the integration of reused products and secondary raw materials, positively reducing construction costs and creating new job opportunities (resale of reused products and materials). Concerning this vision, many operators in the African construction sector are now showing interest and conducting experiments towards recycling practices, followed by reuse and regeneration (Tab. 2).

The potential of circular economy in the Kenyan construction sector | Among African countries, Kenya deserves special attention considering its rate of development and existing circular economy initiatives (GRID-Arendal, 2021; Karcher et alii, 2020). The economic scenario in Kenya presents opportunities for applying circular economy strategies (from waste to resource) in the construction sector, opening up new business opportunities to revitalise the local economy.

A study by Karcher et alii (2020) estimates that circular economy activities in Kenya can contribute to economic growth by 0.5% by 2030: circular economy activities can bring social benefits and fight poverty with an estimated increase of 0.15% in employment (Karcher et alii, 2020). Furthermore, the Kenyan 'Big Four Agenda' (Netherlands Enterprise Agency, 2021) has promoted circular initiatives over the years (Tab. 3) aimed, on the one hand, at reducing waste generation in the construction sector, on the other, at ensuring affordable housing even for the most vulnerable sections of the population. These objectives are also shared by the 'Kenya Vision 2030', which aims to support Kenya in becoming a «[…] newly industrializing, middle-income country providing high-quality of life to all its citizens by 2030 in a clean and secure environment» (Netherlands Enterprise Agency, 2021, p. 7).

However, despite these premises, current circular economy applications, particularly those related to reuse and remanufacturing, in the Kenyan construction sector are still purely experimental and not yet structured and consolidated. As shown in Table 4, the most consolidated circular experimentations concern the recycling of plastic waste to produce finishing elements (for example, for flooring); alongside these initiatives, informal activities – such as self-construction with construction and demolition waste, the sale of second-hand materials and products and the reworking of used components – are widespread, as emerged from the field survey conducted with the involvement of Kenyan NGOs, professionals and academics.

It is currently difficult to quantify the extent of these informal activities; however, if appropriately



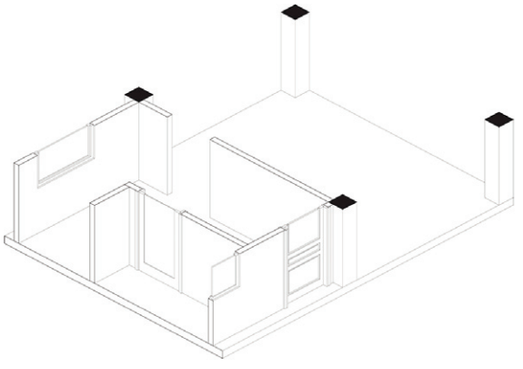


Fig. 2 | Traditional solution 1: load-bearing walls in stone-cut blocks (credit: the Authors, 2025).

Fig. 3 | Traditional solution 2: reinforced concrete frame structure with stabilised soil blocks (credit: the Authors, 2025).

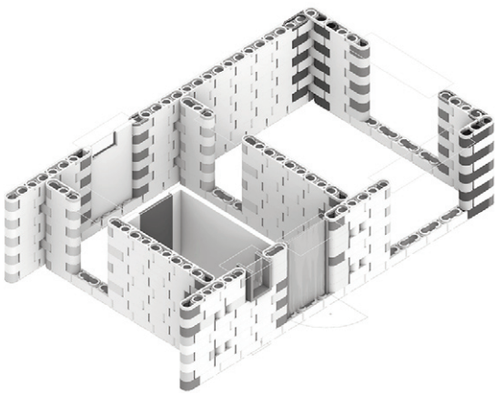


Fig. 4 | Alternative solution 1: load-bearing masonry in Twist Block (credit: the Authors, 2025).

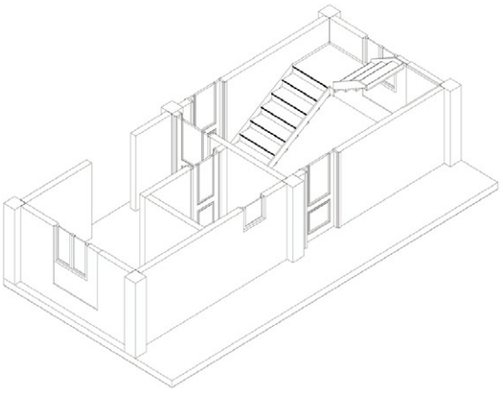


Fig. 5 | Alternative solution 2: reinforced concrete frame structure with interlocking stabilised soil blocks (credit: the Authors, 2025).

Typology model dimensions	The modular typology measures internally three 3 x 4 metres with 12 square metres of internal floor area			
	TRADITIONAL LOAD BEARING SOLUTION	**ALTERNATIVE LOAD BEARING SOLUTION**	**TRADITIONAL NON-LOAD BEARING SOLUTION**	**ALTERNATIVE NON-LOAD BEARING SOLUTION**
	Stone-cut blocks typology	Twist blocks typology	Reinforced concrete frame with Stabilised Soil Bricks typology (SSB)	Reinforced concrete frame with interlocking Stabilised Soil Bricks typology (ISSB)
	LOAD BEARING ELEMENTS			
Key features	Stone-cut blocks are quarry stone materials, although it is the most common used wall material in Kenya, it presents more environmental challenges since it involves more resource extraction.	Twist blocks are innovative blocks made from concrete mixture to specific mix ratio of sand, aggregate and cement.	Concrete frame of column and beams with stabilised soil bricks made from available soil materials.	Concrete frame of column and beams with stabilised soil bricks made from available soil materials.
Disassembling factors	Stone-cut are solid blocks, laid with cement mortar joints, therefore, they are not easily to disassembly.	Twist blocks are interlocking blocks that does not required extra material for joints so therefore they are easy to disassembly.	Concrete frame remains the load bearing structural parts while stabilised soil bricks are the filler wall materials (non-load bearing walls) which requires mortar joints; therefore, the solution is not easy to disassembly.	Concrete frame remains the load bearing structural parts while interlocking stabilised soil bricks are the filler wall materials which requires no mortar joints, therefore can be easily disassembled.
CONSTRUCTION COSTS (estimates from bill of quantities received by local construction companies)				
Structural cost per square metre (without non-load bearing elements)	118.25 USD	112.74 USD	111.32 USD	111.32 USD
Conventional cost per square metre with (new) non-load bearing elements	186.81 USD	180.00 USD	204.55 USD	200.95 USD

Tab. 5 | Characteristics of the four technological-typological solutions (credit: the Authors, 2025).

Product	Dimension	Production process	Thermal capacities	Recyclability	Reusability
Stone cut blocks	Natural stone-cut blocksare usually of width 20 cm, height 20 cm and length 40 cm.	Stone cuts are obtained from quarries, cut into required sizes with machine. Stone cut blocks walls are laid with enabling cement mortar joints.	The thermal mass of a 20 cm thick natural stone-cut block plastered on one side is 367,800 J/M^2K although it has high transmittance (U-value) 2.86 W/m^2k, the high thermal mass improves its efficiency, making it suitable for the Kenyan context.	Demolished stone blocks can be crushed and used as foundation hardcore rubble or other purposes.	Though not easily recoverable, stone cut blocks can be recovered and reused. Stone cut blocks are not ideal for disassembling.
Twist blocks	Twistblocks measures 24.5 cm width, 17.5 cm height and 55.0 cm length.	Twist blocks are produced from a mix of concrete aggregates, mix to a specified ratio, compacted in a mould and allowed to cure. Twist blocks walls are interlocking blocks laid without mortar joints.	The thermal capacity of Twistblocks can be attributed to a lightweight 20 cm concrete block plastered on one side with a thermal mass of 135,600 J/M^2K and Thermal transmittance (U-Value) of 0.81 W/m^2k, making Twistblocks more thermal efficient with its larger thermal mass.	Twistblocks can be crushed into concrete aggregates and can be made from crushed concrete.	Twistblocks can be disassembled and reused elsewhere.
Concrete frame	Size of concrete frame columns and beams varies based on structural specifications.	Concrete beams and columns production depends on the required mix. Comprising of coarse aggregates, sand, cement and water.	Concrete frame of columns and beams are of good thermal capacity in Kenya, considering the thermal mass.	Concrete frame, columns and beams can be recycled and used for foundation backfilling, often recovered after demolition, as a form of downcycling. Crushed concrete aggregates can also be used to manufacture new concrete products.	
Interlocking Stabilised Soil Blocks (ISSB) and Stabilised Soil Blocks (SSB)	ISSB measures length 140 mm, width 220 mm, and height of 110 mm. SSB measures length 120 mm, width 50 mm, and height of 40 mm.	Soil blocks are produced with soil and cement binders, compacted in moulds and cured under sun. Only SSB requires mortar joints for walling as ISSB walls are interlocking blocks.	Soil bocks can be equivalent to a 300 mm thick rammed earth bricks plastered on both sides have a U-value of 2.08 W/m^2k and thermal mass of 547,800 J/M^2K, making suitable for the Kenyan context.	Soil blocks can be crushed and recycled to re-make soil blocks or other soil products.	Interlocking Stabilised Soil Blocks (ISSB) can be easily dismantled and reused. While Stabilized Soil Blocks (SSB) are not easily dismantlable but are reusable when recovered.
Galvanised corrugated iron sheet for external wall portion	The wooden frame is of 75 mm x 50 mm timber studs, while the galvanised iron sheets measure 0.8 metres width and 2 to 3 metres in length.	Galvanised corrugated sheets are nailed to wooden wood frames, mostly produced on site by local craftsmen.	Galvanized corrugated iron sheets is below the thermal capacity of stone cut blocks with U-value of 3.34 W/m^2K and thermal mass of 10,300 J/M^2K. However, its thermal capacity can be improved with interior lining of plywood or marine boards.	Galvanised corrugated roofing sheets can be recycled and used to produce other products.	Corrugated roofing sheets are reusable and can be sold in the second-hand market. Timber stud frames are also reusable and can be sold in the local second-hand markets. Both corrugated iron sheets and timber stud walls can be easily disassembled.
Timber frame wall with lining boards for interior partitions	The wooden frame is of 75 mm x 50 mm timber studs, while the lining board thickness will vary depends on whether its plywood, gypsum or marine boards.	Timber frame wall are produced locally on site, with lining boards nailed to the timber frames.	Timber frame with gypsum board lining has a U-value of 1.66 W/m^2K and thermal mass of 22,700 J/M^2K. They are ideal for interior partitions with no exposure to the external weather.	Timber can be recycled but often due to lack of enabling technologies they are often burnt to create energy.	Wood products can be reused and repurposed to make new products as a form of upcycling.

Tab. 6 | Attributes of the materials constituting the alternative solutions (credit: the Authors, 2025).

	External non load-bearing portion	Internal non load bearing portion	Doors	Windows	Fixture / fittings	Floor finish
Description	Repurposed second-hand timber frame of width 75 mm x 100 mm, with metal sheets on the exterior, plywood boards on the interior, and painted.	Repurposed second-hand timber frame of width 75 mm x 100 mm, with plywood boards on both side and painted.	Second-hand external metal doors. Second-hand internal wooden doors.	Second-hand metal casement windows	Second-hand sanitary fittings. Second-hand wooden kitchen top.	Use of broken tiles or second-hand 30 x 30 cm tiles.
Cost /cost per sqm	11.61 USD per square metre.	10.38 USD per square metre.	Almost 50% lower than the cost of new.	Almost 50% lower than the cost of new	More than 50% lower than the cost of new	More than 50% lower than the cost of new.
Source	Local craftsmen in Kibera and Toi-market.	Local craftsmen in Kibera and Toi-market.	Toi-market Nairobi.	Toi-market Nairobi.	Toi-market Nairobi.	Toi-market Nairobi.

Tab. 7 | Attributes of the proposed non-load-bearing circular elements (credit: the Authors, 2025).

Fig. 6 | Integration of circular materials and photos of second-hand products from a local market (credit: the Authors, 2025).

Attributes/ model typology	Stone-cut blocks typology	Twist blocks typology	Concrete frame with stabilised soil bricks typology (SSB)	Concrete frame with interlocking stabilised soil bricks typology (ISSB)
Typology model dimensions (3x4 metres, 12sqm)	The modular typology measures internally three (3) X four (4) metres with twelve (12) square metres of internal floor area.			
	Non-load bearing material			
Dimensional portion/ attributes of external wall non-load bearing circular elements	Portion of 1.2 metres by 1.9 metres. Timber frame of width 75 mm x 100 mm, with metal sheets on the exterior and plywood boards on the interior.	Portion of 1.8 metres by 1.9 metres. Timber frame of width 75 mm x 10 0mm, with metal sheets on the exterior and plywood boards on the interior.	Portion of 1.2 metres by 1.9 metres. Timber frame of width 75 mm x 100 mm, with metal sheets on the exterior and plywood boards on the interior.	1.2 metres by 1.9 metres. Timber frame of width 75 mm x 100 mm, with metal sheets on the exterior and plywood boards on the interior.
Source of non-load bearing circular elements	The circular materials and products are obtainable from local second-hand markets in Nairobi, coming from construction and demolition activities. Repurposed by local craftsmen into the building system, using dry joints.			
	CONSTRUCTION COSTS (estimates from bill of quantities received by local construction companies)			
Structural cost per square metre without non-load bearing elements	118.25 USD	112.74 USD	111.32 USD	111.32 USD
Conventional cost per square metre with new non-load bearing elements	186.81 USD	180.00 USD	204.55 USD	200.95 USD
Conventional cost per square metre with new non-load bearing elements	142.94 USD	135.02 USD	164.75 USD	161.22 USD
Cost reduction difference introducing circular materials for all non-loading elements	23%	25%	19%	20%

Tab. 8 | Comparative analysis of techno-typological models: linear case, with new non-load-bearing elements; circular case, with second-hand load-bearing elements (credit: the Authors, 2025).

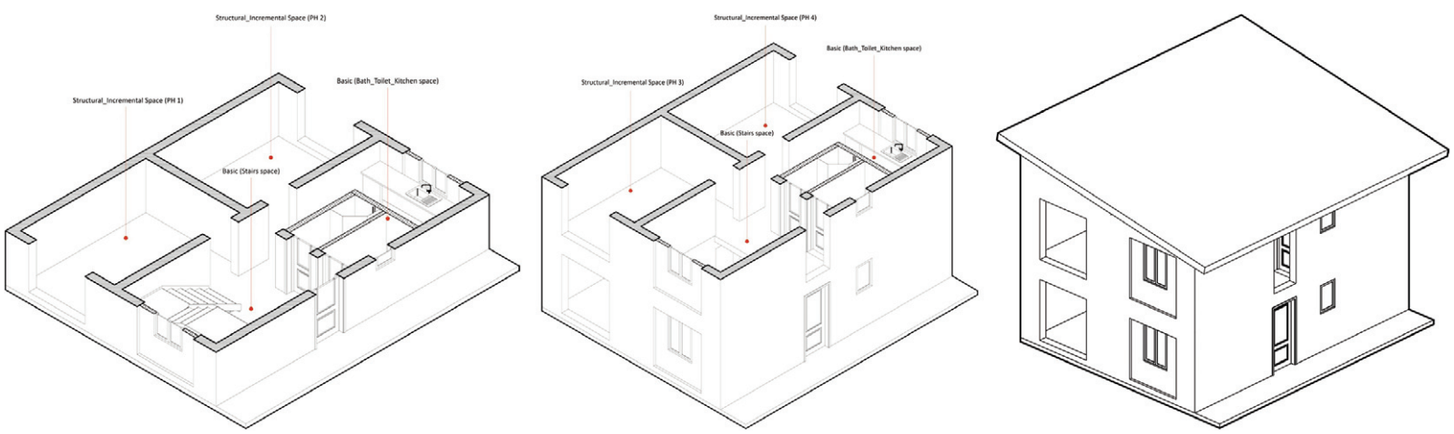


Fig. 7 | Schematic illustration of the proposed DICHM showing the completed and incremental spaces (credit: the Authors, 2025).

organised according to a strategic vision, they could integrate supply chain logic with possible improvements in building and housing quality, achieving economic and environmental benefits (Sibanda, Mhlanga and Munuhwa, 2025). The research, of which this article reports some results, explores the possibilities of pursuing a 'circularity for affordability' vision with the fundamental support of local stakeholders such as professionals, construction companies, NGOs, Universities, manufacturers, retailers of second-hand materials and products and end-users.

Proposal of technological solutions with reusable products for the Kenyan context | Concerning the investigations conducted, the research was oriented towards the definition of techno-typological models characterised by easily assembled and disassembled solutions, achievable with local resources and with simple means of work (self-construction and/or artisanal companies), able to integrate second-hand building elements: the objective is to reduce construction costs and contribute to limiting the environmental impact of building activities. The solutions developed are, therefore, based on the supply of reused products to be installed directly in buildings or integrated into the building system through adaptable interfaces. These solutions are defined in their construction and process aspects, with the support of stakeholders, to evaluate the feasibility of implementation for local products and workers and the possible involvement of local retailers who currently sell second-hand products in second-hand markets.

The experimentation starts from two traditional housing solutions commonly employed in Kenya: the first made with load-bearing walls in blocks of local cut stone and internal partitions, the second with a structural frame in reinforced concrete and infills in stabilised-earth blocks, plus internal partitions. These construction solutions feature Kenya's most commonly used building materials: according to Kariuki, Mugwima and Kaluli (2015), natural stone and earth blocks represent about 57% of wall materials, while galvanised sheets constitute about 27%. These materials gain preference due to their availability, cost-effectiveness, and thermal performance, which are appropriate to the context. As for the structural system, reinforced concrete remains the most used building material due to its resistance and durability (Okumu, Oyawa and Shitote, 2016). The typology of these traditional solutions represents about 80% of residential buildings in Kenya (Kenya Green Building Society and GreenThumb, 2023) that often employ simple construction technologies to meet the need for cost-effectiveness.

In the first phase of the work, these traditional construction solutions are compared with two alternative solutions – realised using different materials – oriented towards circular approaches and 'design-for-disassembly', with simplified construction and deconstruction processes (Fig. 1).

In the second work phase for each of the four techno-typological solutions a comparison is made – with the integration of reused elements in the external walls – between the 'linear approach' case (characterised by the supply of new materials and products for the construction of non-load-bearing walls) and the 'circular approach' case (characterised by the supply of second-hand materials and products supplied by local secondary markets).

In the third work phase, the economic accessibility of the proposed alternative solutions with the supply of reused materials and products obtains an evaluation through a comparative economic analysis between construction costs and average income in informal settlement contexts characterised by artisanal or self-construction construction activities for the context of Kibera, a slum in the City of Nairobi in Kenya.

The analysis of technological solutions and construction techniques mainly used in Kenya supports an active dialogue with a network of local stakeholders in Nairobi, including architects, companies, manufacturers, retailers, users, research centres and Universities. The first traditional solution identified (Fig. 2) is quarry-cut stone blocks, mainly from the massive extraction of raw materials. The second identified traditional solution (Fig. 3) is integrating a reinforced concrete frame structure with a stabilised earth block closure, which is difficult to recover during demolition because cement mortar joints connect them.

Starting from these traditional construction systems, two possible alternative solutions – more oriented to project circularity of ease of disassembly – were identified, according to the criteria of: maximum use of materials and construction products available on the local market; ease of construction; ease of disassembly thanks to reversible connections; presence of adaptable interfaces to allow the replacement of non-load-bearing walls made with new materials and products with non-load-bearing walls made with reused products and materials.

The first alternative solution to replace the stone-cut blocks is the Twist Blocks (Fig. 4), innovative interlocking blocks produced locally, made from a concrete mixture with special mixing ratios. These do not require cement mortar joints and can ensure easy disassembly. The section, considered adequate to integrate circular elements in the external closure, in this case was assumed – according to the indications of local designers and builders – equal to 1.8 x 1.9 metres, to allow a greater percentage of circular elements while maintaining structural stability. The second alternative solution to replace stabilised soil blocks consists of interlocking blocks of stabilised soil (Fig. 5). Interlocking stabilised earth blocks are easy to dismantle because no cement mortar joints exist.

Table 5 reports the analysis conducted on the four alternative solutions for a 3 x 4 metres housing model, including the construction cost derived from the bill of quantities estimated with the active involvement of local construction companies. While the solution with twist blocks is characterised by a lower construction cost than the traditional solution with cut stone blocks, in the case of the typology with a reinforced concrete frame and interlocking stabilised earth bricks, the construction cost is slightly lower than the traditional solution with a reinforced concrete frame and stabilised earth bricks.

The techno-typological model with reused materials and products | To assess the feasibility of the proposed circular housing solutions and the related reduction in overall construction costs in line with the vision of circularity, for simplicity, a comparative analysis was developed by comparing a baseline scenario (linear case: techno-typological solutions made with new materials and products) and a circular scenario (techno-typological solutions partially made with second-hand / reused products from secondary markets and construction and demolition activities). The criteria and guiding principles followed to outline alternative circular solutions with reused products were the availability on local secondary markets, the propensity to create non-load-bearing walls, the ease of assembly and/or construction and the ease of integration with existing construction systems.

The preference for materials used in alternative solutions also relates to their thermal performance, ease of processing, production process, recyclability and reusability; these attributes are suitable for the Kenyan context and facilitate the subsequent use of demountable circular materials. Table 6, with attributes from Kenya Green Building Society and GreenThumb (2023), Kariuki, Mugwima, and Kaluli (2015), and Okumu, Oyawa, and Shitote (2016), provides an overview of the characteristics of alternative cladding materials.

The study of the techno-typological models focused first on the possibility of replacing a limited portion of the non-load-bearing building elements with equivalents recovered from the second-hand building materials market (Fig. 6); for the cut stone block type, where the walls are load-bearing, the portion of the wall requiring replacement was sized with a 1.2 x 1.9 metres opening in the masonry to avoid a decrease in the load-bearing capacity of the wall.

This 'replacement opportunity', widely discussed with local construction companies and local 'second-hand' product dealers, led to the definition of technological approaches for construction with dismantling and assembly through the use of dry joints to allow easy upgradability of the recovered products, including second-hand plywood, metal sheets, etc. The circular materials and products for non-load-bearing walls and building elements are in Table 7, with evidence of costs and related sources. These circular products and masonry elements allow for a lower construction cost, which varies when applied to different building systems.

The change of elements for each model is in Table 8. For each solution, the cost estimate of the load-bearing and non-load-bearing elements was carried out with the support of local stakeholders, starting from a cost estimate for the traditional scenario (linear case) and then calculating the cost estimate for the circular case for which the dismantling characteristics, the non-load-bearing circular materials, the dimensional portion of the non-load-bearing materials and the origin of the non-load-bearing materials were considered influential: in this way it was possible to calculate the cost of building the alternative non-load-bearing circular portions and estimate the reduction in construction costs compared to the traditional case.

In the following paragraph, the assessment of the above-mentioned 'circularity for affordability' will be discussed by adopting an incremental design approach suitable for integrating reuse elements, considering the construction cost for the adopted typology. Incremental residential design is well suited to the particular economic context, as it increases housing space over time as resources become available.

Assessment of the affordability of the proposed techno-typological models for the Kenyan context | In order to assess the affordability of the pro-

posed alternative solutions with the supply of reused materials and products, a further economic analysis was conducted for each proposal, taking as its field of application the socio-economic context of Kibera, an informal settlement in Nairobi, Kenya. For example, the analysis developed for the 'alternative solution 1' case realised with Twist Blocks is below. The techno-typological model features an incremental, modular scheme (Fig. 7) to facilitate dismantling. The analysis is aimed at verifying the affordability of the housing unit, considering the economic income of the residents of the lowest income class in Kibera.

Kibera's typical housing units, like other informal settlements in Nairobi, are characterised by an average surface area of no more than 11 sqm per single-family home. The proposed housing module, Disassembling Incremental Circular Modular House (DICMH), is configured as a module made with Twist Block elements, easy to disassemble, allowing for a greater possibility of inserting circular materials and being more economical. The project includes a ground floor and an upper floor with a staircase, a kitchen and toilets (for a surface area of 48 sqm) finished with circular materials and products. In comparison, the incremental parts of another 48 sqm with circular materials and products recovered by the inhabitants provide for completion. The DICHM, which four families will inhabit, offers accessibility to ownership with a mortgage within 8 years with a constant instalment lower than 30% of the average family income (Tab. 9) and the monthly rent of the interviewees residing in Kibera.

Figure 8 describes the DICMH with the basic starting modules (stairs, toilets and kitchen). Living spaces increase with non-load-bearing external walls, which include openings supplemented by elements made of reused materials. This approach relies on studies on modularity and adaptive systems (Manni and Valzano, 2023). It provides a structural system that allows for easy updating of the circular, non-load-bearing elements within the adaptive system.

The circular elements for completing the incremental modules should follow the characteristics and construction techniques of the circular non-load-bearing elements of the basic modules. These characteristics, as mentioned above, include locally sourced second-hand materials that are easy to assemble and disassemble to allow for future upgrades, easy to work with for artisans and homeowners and able to provide an adequate level of thermal capacity for the Kenyan context. This ease of construction of incremental modules for homeowners refers to the self-construction approach, which must be simple and economical (Di Virgilio, 2023): the local supply chain of circular elements is fundamental to create a network of circular materials with low economic impact (Gaddi and Mastrolonardo, 2024).

Conclusions | In the African continent, the general theme of sustainability opens to many interpretations, one of which concerns the relationship between circularity strategies and accessibility to housing for low-income population groups. Kenya demonstrates a progressive awareness of the significant environmental problems and a growing interest in circularity issues: the City of Nairobi lends itself to being a representative observatory of many African realities characterised by a high rate of population growth, a strong housing demand and a significant presence of informal settlements characterised by the lack of regulatory references, the absence of technical and architectural quality, the presence of several small artisan businesses and self-construction initiatives in which, in an unstructured way, spontaneous practices of circular economy emerge through the reuse of second-hand building materials and components.

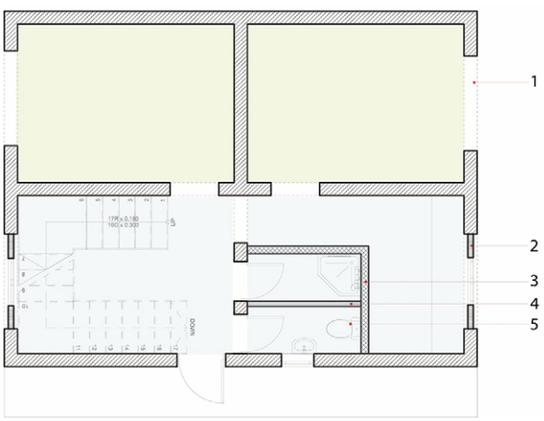
In such a context, appropriate circularity strategies can open many opportunities to provide organisational criteria for building activities and the existing offers of reused building products. Actions should focus on several fronts: building approaches based on reusing materials and components that can be used directly or through appropriate interfaces; identification of dry, reversible, disassembled and easy-to-execute construction techniques.

As demonstrated by field observation and the pilot case, it is possible to obtain savings on construction costs and times and, at the same time, increase the quality of the project and process through coordinated actions such as: the design of repeatable housing modules defined based on local production capacities, products and techniques; the identification of second-hand products readily available on-site; the involvement of multiple public and private stakeholders in the supply chain. In this sense, coordinated circularity strategies demonstrate that, in addition to the obvious environmental advantages, they have the potential to create new opportunities for micro-enterprises (construction, manufacturing of products, sales of new or remanufactured products) and for local start-ups, but also to cooperate in the transition from informal to formal approaches in the construction of settlements for low-income groups of the population.

The experimentation results have highlighted that the environmental and economic benefits (expressed in terms of 'circularity for affordability') achieved in the case study through circular technological solutions and the application of reuse practices are

Income class	Lower income class	Total internal square metre	96 sqm
Mortgage option	8 years	Total cost of construction [C]	11,892.49 USD
Monthly income [A]	70.13 USD	Required cost of construction per household	2,973.12 USD
Average household income (AVI) [B]	105.19 USD	Monthly remittance per household (30% of AVI)	31.56 USD
Number of households	4	Year of remittance per household	8
Development level	Basic (48 sqm) and Structure (48 sqm): Basic (Toilet + Kitchen + Stairs) and Structure (of 4 incremental spaces)		

A) Source: Average monthly income of interviewed Kibera residents and questionnaire respondents for Kibera residents.
B) Average household income (AVI) is equivalent to 1.5 of monthly income.
C) The total cost of construction (96 sqm) 11,892.49 USD is equivalent to cost of 48 sqm twist block structural modules (5,411.56 USD) plus construction cost of completed modules with circular elements (6,480.93 USD).



Incremental module spaces, characterised by the structural elements, to be completed with retrived circular elements.

Basic starting modules of stairs, toiletries and kitchen space. with circular non-load bearing walling portion and elements.

1- 1.8 x 1.9 meters portion on the external wall for circular, second-hand materials, adopted to the opening, and easy to be disassembled.

2- Repurposed second-hand timber frame of width 75mm X 100mm, with metal sheets on the exterior, plywood boards on the interior and painted. Frame to accomodate wooden windows, for easy assembling and disassembling.

3 & 4 - Repurposed second-hand timber frame of width 75mm X 100mm, with plywood boards or marine boards on both side and painted with oil paint.

5 - Other second-hand circular elements including sanitary wares, windows, doors and kitchen cabinets.

Tab. 9 | Affordability of the DICHM unit with Twist Block compared to the average income in informal settlement and self-build contexts (credit: the Authors, 2025).

Fig. 8 | DICHM's starting and incremental modules (credit: the Authors, 2025).

percentage-wise relevant compared to traditional 'linear' solutions.

Despite these advantages, it is possible to observe some critical issues, mainly related to the availability and reliability of the data. The work steps for the development of the experiment are partially subject to the poor availability of data and information, including technical data of the products, labour costs, costs of recovered products resold in second-hand markets, etc. In this sense, the support of local stakeholders was of primary importance and laid the foundations for the definition of a structured approach to information management, based on the principle of graduality, which will facilitate the following work steps towards integrating environmental, economic and social assessments.

The conducted experiment and the proposed methodological approach represent possible tools to promote and evaluate circular construction solutions in economic and environmental terms in dynamic and fragile contexts, such as developing countries, often characterised by uncertain social, political and economic realities and by the growing phenomenon of urbanisation that make it impossible for the most disadvantaged segments of the population to access adequate housing at affordable prices.

Notes

1) For more information, see the webpage: afdb.org/en/documents/africa-circular-economy-facility-enabler-circular-transition-africa [Accessed 15 April 2025].

2) For more information, see the webpage: aceaafrica.org [Accessed 15 April 2025].

3) For more information, see the webpage: acen.africa/ [Accessed 15 April 2025].

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