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Eco-friendly Architecture in Developing African Countries: Design and Self-construction of a Playground in Kenya

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ABSTRACT

Developing countries can seize the opportunity to direct their development by freeing themselves from the mistakes of already developed countries and rooting it towards environmental, economic, and social sustainability. The research has identified a method described in phases that becomes the guarantor of an eco-friendly architecture, which starts from the resources of the territory, enhances them, and returns cyclical processes to the territory that becomes the driving force of development. An initial phase of acquisition of knowledge about the territory is followed by an analysis of its criticalities and potential. Based on these results, the definition of the harvest map (tangible and intangible resources) is conducted, which also includes related construction solutions and the analysis of compatibility with the current production system, to improve it. This method was applied to a case study in Kenya, through the construction of a playground in the external area of a school located in an area adjacent to Makongeni Village, Malindi, Kenya. The playground was built with local wood and waste tires, involving the teachers and students both in the design and construction phases. Eco-friendly architecture can become a driving force for sustainable development. The development of a production system based on local resources makes it possible to produce jobs, with an increase in the well-being of the population, specializing local companies and workers to the detriment of foreign companies and imported materials. The use of products from local supply chains reduces the cost of construction, favoring greater access to primary goods such as a home or services (such as the playground of the case study) otherwise available to few. The self-construction had the role both of raising awareness of the value of waste and training users (mainly school teachers) for the future maintenance of the playground.

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1. Introduction

"The biggest threat to our planet is the belief that someone else will save it." (Robert Swan). The countries defined as "developed" are currently paying the price for the unsustainability of their development and are constantly looking for economic models that not only direct the present and the future toward the protection of the environment and the elimination of inequalities in society but also to rebalance the imbalance created by the choices of the past. In fact, as Joan Martínez Alier's school of ecological economics [1] states, no real compensation is possible when it comes to irreproducible and irreplaceable goods. On the one hand, Latouche's theory of happy degrowth [2] mainly pushes toward a reduction in the consumption of resources and an increase in the durability of goods, on the other hand, Cradle To Cradle (C2C) [3] focuses on the type of resources to be used, not by limiting the quantity of use, but by defining the characteristics of the resources to be used to allow a re-release into the environment of excess production without environmental damage. ensuring the correct balance between eco-cycles and techno-cycles [4].

The protocols and actions aimed at finding agreements at the international level (from Kyoto in 1997 to Dubai in 2023) [5], together with the often disregarded objectives, demonstrate the difficulty in changing the development process when it is now rooted in industrial structures and infrastructures and the daily choices of society.

Developing countries, on the other hand, are a "blank sheet of paper" and can seize the opportunity to direct their development by freeing themselves from the errors of the models of already developed countries and rooting it toward environmental, economic, and social sustainability. It follows the importance of takingctions that are not only punctual, but that have a virtuous effect both locally and globally, according to the principle of "think global, act local" [6].

Construction is one of the leading sectors of a country's economy [7], also considering that the construction of services, structures, and infrastructures functional to the development of the territory requires the involvement of this sector. It therefore becomes a crucial sector also for this development to be sustainable. Suffice it to say that in the world construction is responsible for about 40% of energy consumption, 25% of water consumption, 40% of resource depletion, and 50% of the waste produced [8], involving other sectors such as production, transport, etc.

The eco-friendly architecture consists of defining building processes (and related products) that protect the environment ("eco") and eliminate inequalities with the weaker classes ("friendly" or "solidarity"). In this way, the three dimensions of sustainable development can be involved: environmental, economic, and social. To achieve this goal, some studies underline the need to identify local ethical and/or ecological supply chains that therefore have direct and indirect effects on the territory [9-12], while other studies intend to create virtuous models that can be reproduced in the territory through examples of sustainable architecture [13-16]. At the same time, the idea of architecture is developed that starts from the materials available in the territory and arrives at the architectural project through networks or online databases [17-19] and using materials with passports [20, 21]. To ensure social sustainability, some studies emphasize the importance, especially in developing countries, of the involvement of the local population under the coordination of a technician/architect, which, in addition to benefits in economic terms (of considerable importance in the case of low-cost projects), fosters the training of the population and a sense of ownership of the project implemented in the community, helping its maintenance in the future [22–25].

The research presented in this paper combines these different approaches in a single method, which allows the interaction between local resources that are not only material but also intangible, a production system based on circular economies, and finds expression in the eco-solidarity architecture project.

2. Method

The research has therefore identified a method described in phases that becomes the guarantor of an eco-friendly architecture (Fig. **1**), which starts from the resources of the territory, enhances them, and returns to the territory cyclical processes that become the driving force of development [26].

In developing countries, traditional architecture is, often, passed down orally among those working in the sector. The first step is therefore to scientifically codify traditional architecture both from a typological and technological point of view. Traditional architecture is based on local resources, the ways of which have been assessed over the centuries. This phase makes it possible to identify material resources, i.e. materials with greater availability in the territory, and intangible resources, i.e. the construction knowledge linked to these materials. The subsequent typological and technological analysis of traditional architecture allows the identification of the strengths and limitations of these construction systems, some to be enhanced and others to be solved. The improvement of the critical issues found in traditional architecture, also through innovative techniques or technologies borrowed from developed countries, allows the use of traditional construction systems even in contexts in which over the last twenty years they have been overtaken by systems deriving from developed countries, sometimes apparently more durable and representing a status symbol.

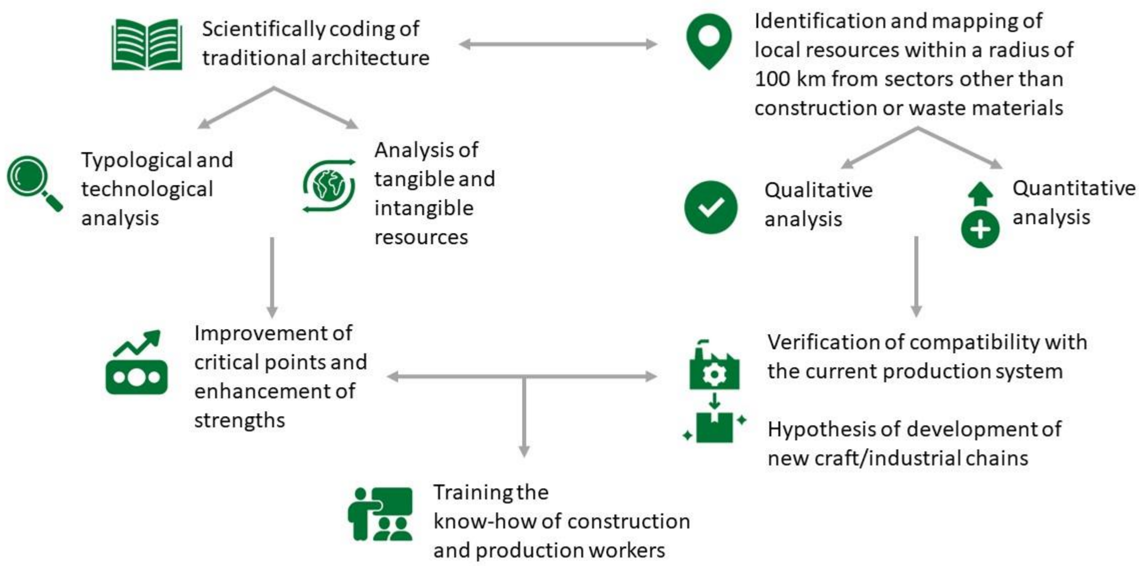

Figure 1: Flowchart of the method for an eco-friendly architecture.

At the same time, it is necessary to identify and map the local resources present in the territory and not necessarily linked to traditional architecture. Think of the presence of materials from other sectors or waste materials. The latter are present in large quantities in a state of abandonment in developing countries as there are often no structured end-of-life supply chains and waste is disposed of by voluntary accumulation by the population and combustion, with serious consequences on the health of living beings and with the pollution of air, water and soil and the impoverishment of resources, that could be reinserted into other life cycles [27].

Once the local resources within a radius of 100 km [28] have been mapped (whether they derive from traditional architecture or other sectors), the quantities of the same must be identified to verify their compatibility with the development of an artisanal or industrial production system. Once the quantitatively compatible resources have been identified, the compatibility of the current production system with their transformation needs to be assessed. The system will be compatible with traditional resources, but it may not be compatible if product or process innovations are applied to these resources. It is necessary to evaluate whether the current production system can transform the identified resources or needs to be implemented. The implementation can be structural and manifests itself in the need to introduce functional machinery for a more efficient production or to move from an artisanal system to an industrial and/or theoretical one and manifests itself in the need to train the "know-how" of operators in the sector. Training can also take place through temporary support to foreign operators in the sector, but functional to the independence of the trained people. In a developing country with low economic resources to invest, especially at the beginning of the process, the initial development of low-tech supply chains in which few production processes and low labor specialization are required is preferable. With the implementation of the initial low-tech supply chains, through the reinvestment of part of the revenues, it will also be possible to trigger high-tech supply chains, without prejudice to the link with the territory.

The methodology described was applied to a case study in Kenya, through the construction of a playground in the external area of a school located in an area adjacent to Makongeni Village, Malindi, Kenya.

3. Results and Discussion

The research required an initial phase of acquisition of knowledge about the area, followed by an analysis of its criticalities and potential. Based on these results, a phase of definition of the harvest map was conducted, which also included related construction systems and an analysis of compatibility with the current production system with local resources. The aim was to identify possible actions to improve the system.

3.1. Analysis of the Territorial Context

Kenya is classified as a lower-middle-income country, with an average annual economic growth of 4.8% [29]. The leading sectors of the economy are agriculture, manufacturing, and tourism. In 2019, tourism accounted for 9% of GDP and employed 1.5 million people. Despite a negative period during the COVID-19 pandemic, in 2022 the revenue generated by this sector returned to 2019 levels [30].

Tourism development requires the creation of dedicated services and infrastructure, which become a driving force for the construction industry. However, construction is altering the landscape without proper control of the architectural forms, with negative consequences on the visual appearance of the area. In addition, new constructions mainly adopt Western materials and techniques, especially concrete and steel (such as reinforced concrete structures, concrete block infills, and corrugated sheet metal roofs). Construction companies, although they often involve local labor, are predominantly run by individuals of European or Asian descent, and therefore apply their construction knowledge for logistical and economic reasons. Western materials, such as concrete and steel, have advantages in terms of durability, require less maintenance in the short term, and withstand the elements well. In addition, building systems based on these materials enable the construction of high-density buildings.

The disadvantages related to the thermo-hygrometric conditions of such construction systems in a tropical climate are considered of minor importance and are overcome using appropriate plant systems by construction companies. In contrast, Kenya's traditional building systems, based on materials such as raw earth, wood, and leaves, require constant maintenance and are compatible with low-density construction. Building with Western materials is seen by the local population as a sign of progress and is also more expensive since it involves the prevalent use of imported materials. As a result, the construction of buildings out of traditional materials such as mud is reserved for the less affluent social classes who cannot afford to use Western materials.

However, this process is unsustainable in the long term from an environmental, social, and economic point of view. Building systems based on materials such as concrete and steel have a significant environmental impact: they are irreversible and cause permanent land consumption, use non-renewable resources, and result in a high energy cost and impact on the environment during production, transport, installation, and disposal. On the contrary, building systems linked to tradition and local materials in Kenya, such as raw earth, wood, and foliage, are local zero-kilometre resources, renewable and easily reintegrated into the environment, with a significantly lower environmental impact [31].

Moreover, these traditional construction systems have thermal and humidifying characteristics that, especially in a tropical climate, allow the control of the environment without the need for complex plant systems [32, 33].

From a cultural point of view, the adoption of Western techniques and technologies risks leading to the progressive loss of traditional Kenyan construction knowledge. Economically, investment in foreign operators in the construction sector impoverishes the local economy and relegates local operators to a marginal role.

In addition, even though the territory has a high natural value, the environment is only partially preserved for tourism purposes.

The reuse of waste materials is not widespread on a cultural level and occurs only out of economic necessity, as in slums, and not out of a genuine concern for environmental protection. This means that this virtuous practice is also associated with the most disadvantaged classes.

The knowledge acquisition phase involved a geographical area stretching from the Watamu coast to the Savannah area at the entrance to Tsavo East Park, with a local radius of about 100 kilometers. The understanding of the culture and resources of the territory was obtained through field inspections aimed at mapping resources, both local and considered discarded, and documenting the construction characteristics. Meetings with operators in the sector have made it possible to identify foreign companies that use Western materials in the territory, or local artisans who build, usually for the most disadvantaged groups, using traditional systems and transmitting their techniques from generation to generation orally.

The traditional building culture in this context is based on the construction of buildings that mainly use raw clay earth, wood, and *makuti* palm roofs (Fig. **2**). The structures can have a rectangular plan with a double-pitched roof or a circular plan with a gabled roof. The most common traditional construction method is the torchis, a self-supporting system that uses wood as a structural trellis and a mixture with a variation in grain size consisting of raw clay earth, stones, water, and natural plant fibers to fill the walls. The walls are finished with raw earth plaster.

The foundations and the connection of the walls to the ground are made using stones or baked bricks bound with cement mortar, to mitigate the problems related to soil moisture in contact with the raw earth and wood walls [34]. Roofs, traditionally, are built with a gabled structure, with main and secondary wooden beams, often of casuarina or cedar, with a slope between 80% and 100%, protruding from the walls [35]. These features allow rainwater to drain quickly before it enters the building and protect the raw earth walls. Air and water tightness is ensured by *makuti*, which consists of dried leaves of coconut palm (*Cocos nucifera*), a species common in the region. These leaves are intertwined with wooden elements stacked in a staggered manner and bound with plant fibers [36].

Figure 2: Building system based on raw earth, timber, and makuti roofs. Construction steps and installation of makuti and construction process of a typical housing.

The production system related to traditional construction systems takes place in an artisanal dimension. Soil with a high clay component is easy to find in any area of the geographical surroundings considered. There are no specific processing areas, the earth is kneaded, worked, and possibly formed directly on-site. The wood and leaves used to make the *makuti* come from species of plants that are widely distributed and easily available, except for the restricted areas intended for parks. The wood and leaves are not subjected to specific treatments. Therefore, the operations related to them (cutting for wood and drying and weaving for leaves) can be carried out in an area adjacent to the place of supply or directly on site. The fixtures are also handcrafted with a local wooden frame and imported glass. There is no industrial system tied to traditional resources and non-traditional materials such as steel, cement, and plastic are imported.

In addition, the analysis of the territorial context has shown a wide availability of numerous waste materials that can be reused in the construction sector. In particular, plastic and glass bottles, car tires, empty plastic cement bags, and empty polypropylene or jute rice bags are easily available at low cost (Fig. **3**). In the area, the Watamu Marine Association [37] which recovers and stores waste materials including plastic and glass bottles, facilitating their supply for potential operators in the construction sector.

The analysis of traditional architecture made it possible to identify both the weaknesses and the potential of this construction system. One of the main weaknesses is the risk of fire associated with wooden and *makuti* roofing, which is traditionally not treated with fireproof materials. This risk is particularly high during the period between October and March, when hot, dry winds occur, and rainfall is scarce. During the rainy season, on the other hand, raw earth walls are exposed to the risk of degradation if they are not properly protected by the roof overhang or plastered, as contact with water can turn raw earth into mud. In general, this system requires constant maintenance of the clay plaster and periodic replacement of the leaves that make up the *makuti*, usually every 5 years [38].

Another limitation of the traditional torchis system is its inability to create spaces with large spans and multiple floors. However, from a climatic point of view, this system can provide thermo-hygrometric comfort to interior spaces thanks to the thermal inertia and breathability of the raw earth walls, as well as the ventilation favored by the possibility of opening the *makuti* roof.

Figure 3: Locally available waste materials, such as glass bottles and plastic containers, aluminum cans, empty cement and rice bags, and tires.

The availability of raw earth with a high clay content and the expertise of local workers in using it represents significant resources. These conditions make it possible to experiment with alternative construction techniques to the traditional torchis, such as adobe or pisè (present to a lesser extent in the region). By separating the structural part from the load-bearing part, it is possible to obtain spaces with greater spans and heights, expanding the possibilities of using local materials in construction and promoting the development of the skills of local operators. In addition, raw earth can be combined with waste materials identified in the area to facilitate their reuse through construction techniques that take into account the specific characteristics and performance of each recovered component [39]. Empty bags of cement and rice, for example, can be reused to build walls using the earthbag technique. These bags, being waterproof, can also be used as coatings for roofing and foundations. Machine tires can be reused after being filled with pressed earth for the construction of walls or point foundations. In addition, plastic bottles filled with pressed earth or empty glass bottles can be integrated into the making of prefabricated walls or bricks. To increase the durability of raw earth walls, it is possible to stabilize them with lime (Fig. **4**).

Figure 4: Adobe construction technique using locally available earth about 50 meters from the construction site and bricks or walls made by reusing plastic or glass bottles and raw earth or cement.

3.2. Design and Self-Construction of the Playground

Once analyzed the territorial context and identified quantitatively and qualitatively the resources present, the needs related to the playground project were analyzed. The primary school is located in an area adjacent to Makongeni Village in a non-urbanized context and with the presence of rural villages in the surroundings and is attended by children with poor economic possibilities. The school buildings, in a poor state of maintenance, were built partly with stones and cement and partly with the traditional torchis system. The outdoor area is not paved and the presence of waste (mainly plastic) is evident due to the absence of a structured separate waste collection system. The construction of a playground aims to transform the outdoor space into an area for collective use, involving the school's teachers and students in the design (Fig. **5**) and construction process (Fig. **6**).

Figure 5: Drawings illustrating how school children envisioned the playground.

Figure 6: Aerial view of the area before construction (left-above), during construction (left-below) and after construction (right).

The school is not equipped with a water network and the water comes from cisterns for the recovery of rainwater, which makes it a limited and scarce commodity during certain periods of the year. For this reason, although we have found in the analysis phase the prevalence of raw earth systems in the local tradition, the use of dry systems is to be preferred for the construction of the playground. Any water for the construction of wet systems should be transported from neighboring areas using tanks. In addition, it would require the specialization of those who make it, excluding the choice of self-construction of the playground.

The choice was therefore directed towards dry systems with easy-to-make connections (by nailing or tying). The materials used are mainly two: local wood and waste tires. In this way, it was also possible to raise awareness among the community of the value of waste and the importance of the second life cycle of materials, in a context in which, as already highlighted, there is no virtuous form of end-of-life. Even the simple action of cleaning up the area from waste to be able to equip it with a playground turned out to be an awareness-raising action, reinforced by the reuse of waste elements in the project. The presence of easy-to-make components and local and waste materials will also favor the future maintenance of the playground in a context where the scarce economic resources available are functional for survival and cannot be used for other purposes. The concept of the project, shared with the teachers and children, was to reproduce the animals of the savannah and transform them into games. The wooden elements (rectangular section) were sanded down to prevent splinters from injuring children when using the playground. Given the presence of the rainy season, the wooden elements, after being cut, were treated with a preservative brush treatment. The wooden elements and tires have been painted also to provide a chromatic element of visual recognition in a context characterized by the red of the clayey earth. The connections between the wooden elements were made by nailing, and the connections between the wooden elements and the tires were made using ropes of plant origin. All assembly and preparation were done with hand tools (hammer, hand saw, brush, etc.). Children and teachers actively participated in the realization by identifying the location of the playground games by preparing the materials and by painting the components (Fig. **7**).

4. Conclusions

Eco-friendly architecture is a driving force for sustainable development that, starting from the enhancement of local tangible and intangible resources, leads to the creation of circular local economies, solving the problems currently being solved in already developed countries during the development phase of the country. Knowing the resources of the territory and their potential makes it possible to enhance and "requalify" local construction knowledge [40] currently relegated to being used by the weaker social groups, to innovate it through techniques and technologies that also provide for the integration of waste materials and to analyze the economic investments

Figure 7: Photos of the construction of the playground: collection of plastic materials and cleaning of the area, unloading and preparation of materials (cutting and preservative treatments), assembly of playground equipment, and painting.

linked to growing tourism on the development of sustainable local supply chains [41]. The harvest map of resources (tangible and intangible) and the verification of compatibility with the production system allow the creation of a dynamic database referring to the specific territory analyzed, the starting point of eco-solidarity projects. This database provides information on materials, products, techniques, and technologies that can be used in a sustainable architecture project, information that should however be systematized with the specific cases of each project that want to be realized. In fact, in the self-construction project of the playground, only two materials and one construction technique were used among all those identified. Regardless of the specific use made in the project described, the database remains a tool available to operators in the sector in the specific territory between the coastal strip of Watamu and the savannah at the entrance to the Tsavo East park, functional to trigger cyclical and virtuous local supply chains and to produce the specialization of workers and companies over time. The development of a production system based on local resources makes it possible to produce jobs, with an increase in the well-being of the population, and generate cycles based on local resources, specializing local companies and workers to the detriment of foreign companies, and imported materials. The use of products deriving from local supply chains generates virtuous economies and, by limiting the impact of transport, reduces the cost of creating eco-friendly architecture, promoting greater access to primary goods such as a home or services, such as the playground in the example described, otherwise available to few. The self-construction had the role both of raising awareness of the value of waste and of training users (mainly school teachers) for the future maintenance of the playground. The awareness-raising action has had the effect of triggering voluntary mechanisms for the collection of waste in the area, preventing it from remaining abandoned, with environmental consequences and degradation of collective spaces.

Conflicts of Interest

The author declares no conflict of interest.

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References

[1] Alier MJ. Ecologia dei poveri. Editoriale Jaca Book; 2009.

[2] Latouche S. La scommessa della decrescita. Feltrinelli Editore; 2014.

[3] Braungart M, McDonough W. Cradle to cradle. Random House; 2009.

[4] Ayres RU. Industrial metabolism. Technology and Environment, Washington D.C: National Academy Press; 1989, p. 23-49.

[5] UNFCC. Available from: https://unfccc.int/process-and-meetings/conferences/past-conferences/past-conferences-overview (accessed on October 20, 2023).

[6] Bauman Z. Liquid modernity. John Wiley & Sons; 2013.

[7] Stone P. Building economy. 3rd ed. NY, USA: Routledge; 1983.

[8] UNEP. Available from: https://www.unep.org/publications-data (accessed on October 10, 2023).

[9] SchlegelmilchBB, Öberseder M. Etica nelle supply chains globali 2007. https://doi.org/10.4468/2007.2.03schlegelmilch.oberseder

[10] Fritz MMC. A supply chain view of sustainability management. Cleaner Production Letters 2022; 3. https://doi.org/10.1016/j.clpl.2022.100023

[11] New S. The ethical supply chain. In: New S, Westbrook R, Ed., Understanding Supply Chains: Concepts, Critiques, and Futures. Oxford University Press; 2004, p. 253–80. https://doi.org/10.1093/oso/9780199259328.003.0011

[12] Simangunsong E, Hendry LC, Stevenson M. Managing supply chain uncertainty with emerging ethical issues. Int J Oper Prod Manag. 2016; 36: 1272-307. https://doi.org/10.1108/IJOPM-12-2014-0599

[13] Bennetts H, Radford A, Williamson T. Understanding sustainable architecture. Taylor & Francis; 2003. https://doi.org/10.4324/9780203217290

[14] Guy S, Farmer G. Reinterpreting sustainable architecture: The place of technology. J Archit Edu. 2001; 54: 140-8. https://doi.org/10.1162/10464880152632451

[15] Iyengar K. Sustainable architectural design. Routledge; 2015. https://doi.org/10.4324/9781315758473

[16] Lewis P, Tsurumaki M, Lewis D. Manual of biogenic house sections. USA: Oro Editions; 2022.

[17] ENEA. What is Industrial Symbiosis? Available from: http://www.industrialsymbiosis.it/ (accessed on October 15, 2023).

[18] Superuse Studios. Harvest collect Re-use the new building site. Available from: https://www.superuse-studios.com/de/publication/harvest-collect-re-use/ (accessed on October 15, 2023).

[19] Building and renovating with reclaimed materials. Opalis. Available from: https://opalis.eu/en (accessed on October 15, 2023).

[20] Bamb 2020. Available from: https://www.bamb2020.eu/ (accessed on October 18, 2023).

[21] Madaster. Increasing the value of materials Circular construction starts with Madaster. Available from: https://madaster.com/ (accessed on October 18, 2023).

[22] Yun J. Vernacular participatory designs: The do-It-Yourself (DIY) housing scene in south korea. Space and Culture. 2021; 24: 473-87. https://doi.org/10.1177/1206331219830332

[23] Manjia M, Pettang C, Abanda F. Urban self-building labour cost modelling in Cameroon. J Constr Dev Ctries. 2011; 16: 69-90.

[24] Ham AC, Shroyer J. Bamboo housing in Costa Rica: an analysis of a pilot housing program. Hous Soc. 1993; 20: 25-33. https://doi.org/10.1080/08882746.1993.11430161

[25] Pianegonda A, Favargiotti S, Paoloni F, Polastri A, Casagrande D. An adaptable prefabricated timber-wall system for social emergency contexts: A self-construction participatory approach in Santiago of Chile. In: World Conference on Timber Engineering 2021. WCTE 2021; 2021.

[26] De Gregorio S. Harvest map of tangible and intangible resources in Watamu for sustainable architecture. In: Baratta A, Calcagnini L, Magarò A, Eds. Procedings of the 5th International Conference Recycling. Weimar, Germany: 10-12 October, 2023.

[27] De Gregorio S, Di Domenico G, De Berardinis P. Sustainable architecture in developing countries: Harvest map of the lusaka territory, zambia. Sustainability. 2023; 15(8): 6710. https://doi.org/10.3390/su15086710

[28] Protocollo di Itaca. Available from: https://www.proitaca.org/ (accessed on September 25, 2023).

[29] World bank. Available from: https://www.worldbank.org/en/home (accessed on July 20, 2023).

[30] Info Mercati Esteri. Available from: https://www.infomercatiesteri.it/quadro_macroeconomico.php?id_paesi=16# (accessed on June 15, 2023).

[31] Achenza M, Atzeni C, Mocci S, Sanna U. Il manuale tematico della terra cruda: caratteri, tecnologie, buone pratiche. DEI Tipografia del Genio Civile. Roma; 2008.

[32] Eires R, Camões A, Jalali S. Enhancing water resistance of earthen buildings with quicklime and oil. J Clean Prod. 2017; 14: 3281-92. https://doi.org/10.1016/j.jclepro.2016.10.141

[33] Greco G. Costruire con la terra cruda :un esempio dall'antichità , in Storia dell'Ingegneria . Atti 2° Convegno Nazionale. Napoli 7-9 Aprile 2008 Napoli: 2008, pp. 348-60.

[34] Widera B. Comparative analysis of user comfort and thermal performance of six types of vernacular dwellings as the first step towards climate resilient, sustainable and bioclimatic architecture in western sub-Saharan Africa. Renew Sustain Energy Rev. 2021; 140: 110736. https://doi.org/10.1016/j.rser.2021.110736

[35] Arecchi A. Abitare in Africa: architetture, villaggi e città nell'Africa subsahariana dal passato al presente. Italy: Mimesis; 1999.

[36] Eygelaar J, Kaszner O. Makuti roofing for farmer's housing. University of Nairobi; 1978.

[37] Watamu Marine. Available from: https://www.watamumarine.co.ke/plastic-bottle-buildings/ (accessed on June 12, 2023).

[38] Rael R. Earth architecture. Princeton Archìtectural Press; 2009.

[39] De Gregorio S. (Riuso)n Le potenzialità del fine vita dei componenti in legno e in acciaio. Montefalcone: Edicom Edizioni; 2018.

[40] Bennetts H, Radford A, Williamson T. Understanding sustainable architecture. Taylor & Francis; 2003. https://doi.org/10.4324/9780203217290

[41] Zami MS, Lee A. Economic benefits of contemporary earth construction in low-cost urban housing – State-of-the-art review. J Build Apprais. 2010; 5: 259-71. https://doi.org/10.1057/jba.2009.32