IV CONVEGNO INTERNAZIONALE

PRE-FREE UP-DOWN RE-CYCLE

PRATICHE TRADIZIONALI E TECNOLOGIE INNOVATIVE PER L'END OF WASTE

a cura di
Adolfo F. L. Baratta

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Architetture e Design / Architectures and Design

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E-waste recycling for monitoring the microclimate in sub-Saharan Africa

E-waste, Climate changing mitigation, Microclimate monitoring, Low-cost weather station

Summary

The paper presents some microclimate monitoring actions, in sub-Saharan African countries, where activities is taken to mitigate the water crisis, through the installation of weather monitoring stations built with components recycled from e-waste. The whole research was leaded by the Department of Architecture of Roma Tre University in partnership with Gente d'Africa, a non-profit organization, and involves the Department of Architecture of the University of Florence, and the École supérieure d'ingénierie, d'architecture et d'urbanisme of Bamako.
The Italian and Malian universities and the international cooperant involved Romagna Acque Società delle Fonti SpA, an italian manager of drinking water sources in Romagna. The operational contribution of AES Architettura Emergenza Sviluppo, another non-profit association operating in depressed areas of the world, have allowed the reconstruction and performance improvement of two small dams (barrages also known as sand dams) around Kita, the capital of the Kayes region. The contribution focuses not only on the water problem, but also on the environmental issue, linked to incorrect behavior in the e-waste management. Therefore, in order to achieve the target of monitoring and acquisition of microclimatic data, aimed at verifying the mitigation of overheating due to the presence of artificial water basins, weather stations are designed using, when possible, recycled e-waste.

Climate change and water crisis

Sub-Saharan Africa is suffering from a ten-year water crisis. Many countries, in particular Mali, are characterized by the presence of important water resources, however poorly distributed both in the territory and throughout the year, because their availability is affected by strong seasonality.

In Mali, the access rate to drinking water is 61% in rural areas and 69.2% in urbanized areas [Dao, 2014]. To this bad distribution is added a bad resources management based on a complex regulatory framework, detached from local dynamics.

Climate change is among the factors with the greatest impact on all sub-Saharan Africa. It will affect those countries that hardly depend on agriculture characterized by little crops variety and strong seasonality [Rigaud et al., 2018].

As regards Mali, the annual average temperatures are between 27°C and 30°C, but with large temperature variations that occur mainly in the desert areas to the north [USAID, 2018a]. However, in 2015, the maximum recorded temperature was 51°C and the minimum was only 10°C [NCEA, 2015]. The rainy season varies according to latitude: in the south of the country, it lasts up to six months, with a sharp intensification between June and October, while in the north it contracts up to just three months between July and September.

This data affects the rainfall which in the areas close to the Sahara is only 50 mm / year, in the Sahel area it is between 100 and 1,100 mm/ year, while in southern Mali it exceeds 1,100 mm / year [USAID, 2018a]. These data are not stable: Mali is in the so-called Intertropical Convergence Zone where the typical monsoons of West Africa occur. Furthermore, due to climate change, between 1960 and 2015 average temperatures increased by 1.2°C, with a future expectation of linear growth: it is estimated that, by 2050, temperatures could increase by a value between 0.9°C and 1.5°C with the largest differentials in the Kayes.

These data have an impact on precipitation, the main source of hydrological supply [MMES, 2018]. The mathematical models predict a slight average increase in precipitation (between 1 and 3%), together with a serious decrease in the driest regions to the north. Furthermore, the variation in the seasonal distribution will cause a translation of the wettest period towards the initial part, between June and July with a consequent drying (between 6 and 10%) in the rest of the period. In addition, rain-related destructive phenomena are expected to increase.
The impact on water resources will be substantial: there will be a reduction in the increase rate of underground resources in parallel with the need to use them, since surface resources will tend to be less available due to intrinsic phenomena (increase in evaporation in consequence of the increase in temperature) and extrinsic (growth of water demand because of population growth) [USAID, 2013].
The result of climate change will be an increase in food insecurity and malnutrition, with a consequent increase in mortality and a reduction in life expectancy [USAID, 2018b].
The complex political situation linked to the internal conflict, which in June 2019 saw the forced migration of almost 148,000 Malians [US-

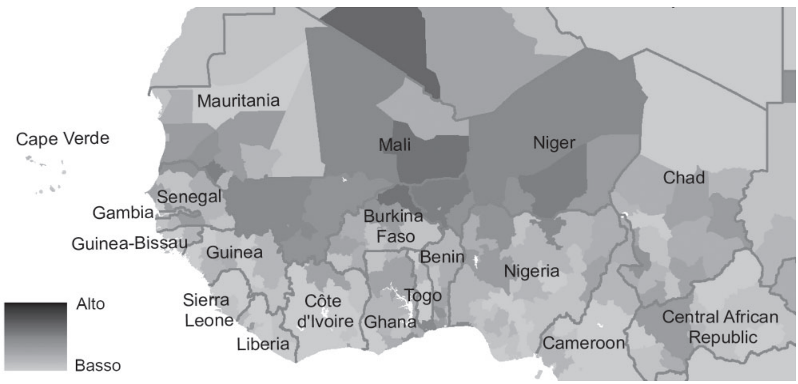

Figure 1. Number of climate-related catastrophic events in West Africa [Busby, Smith e Krishnan, 2014].

AID, 2019], exacerbates these discomforts. Furthermore, climate change, food insecurity and social, economic, and political instability favour long-range migration.
Working to rationalize and improve the water resources management, especially at the local level, would favour food security, with the consequent reduction in mortality. Furthermore, improving the country's agro-pastoralism economy would mean reducing the phenomena of political instability, producing, over time, a reduction in the uprisings of the people. Therefore, the lever of water improvement is the one capable of improving living conditions in the country and reducing migration phenomena. Finally, the mitigation of the effects of climate change due to the creation of artificial water basins, allows the improvement of the quality of life.

Electronic waste on the African continent: the "landfill" of the world

Electronic waste, also known as e-waste, includes all those electrical and electronic objects and tools of common use, or their parts, which are disposed of without any intention of recycling or reuse [Step Initiative, 2014]. This description includes a wide range of products, or any domestic or commercial object that has a battery or an electrical or electronic circuit inside. E-waste can be classified into the following categories [Baldé et al., 2015]:

1. heat exchangers, such as refrigerators, air conditioners, heat pumps, etc.
2. screens, such as computer monitors, televisions, tablets, etc.
3. bulbs, both fluorescent, LED or other
4. heavy appliances, such as washing machines, dryers, dishwashers, etc.
5. small appliances, such as fans, microwave ovens, electric razors, radio equipment, toys, tools for self-diagnosis or self-medication, etc.

6. radios, toys, tools for self-diagnosis or self-medication, etc.
7. small telecommunications devices such as smartphone, satellite navigators, etc.

Each product category is characterized by a different life expectancy and a different economic value, a different environmental impact, a different quantity, etc.: this implies different recycling chains for each product.

The amount of e-waste produced in 2017 was approximately 46 million tons, which corresponds to more than 6 kg per inhabitant or 4,500 times the weight of the Eiffel Tower.

The projection predicts that 52.2 million tons will be produced for the current year, considering an annual growth of between 3 and 4%. The management of this volume of waste is poorly regulated: in 2017, around 66% of the world population lived in one of the 67 countries with specific regulations.

However, despite the increase over the previous three years had been 8 countries and a further 22%, many of the regulations do not provide for a concrete outcome. In fact, only 20% of all e-waste is channelled into a certified recycling path, while the remaining 80%, is channelled into paths that are not always transparent, are buried, resold, or recy-

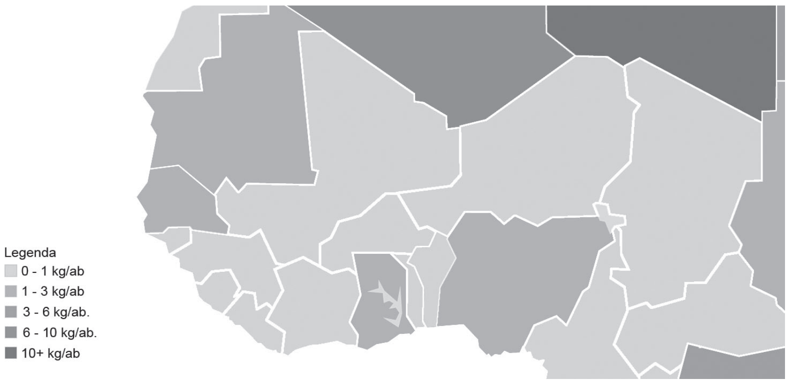

Figure 2. Amount by weight of e-waste per capita in West Africa [Baldé et al., 2018].

cled in downcycling. The case of the African continent is complex. If only pure data are evaluated, Africa is the continent that has the least e-waste in the world, both in kg per inhabitant (1.9) and in millions of tons (2.2).
However, only 0.004 million tons are conducted within documented recycling processes, 10 times less than in Oceania, 475 times less than in the American continent, 675 times less than in Asia and 1,075 times less than in Europe. This data is still not enough to describe the situation; therefore, it seems necessary to compare the quantity of e-waste in relation to the Gross Domestic Product (GDP) per capita. The ratio between kg/inhabitant and € GDP/inhabitant by continent reveals that Africa and Asia, with 1.05 and 0.75 kg of e-waste respectively for every € 1,000 of GDP per capita, are the two continents with the major problem.
This indicator is one of the results of the research, and highlights how, being Africa and Asia at the same time the continents with the lowest GDP per capita, they could hardly accumulate a lot of e-waste, derived from consumer products, if not because they were imported from other continents.

	Countries [n.]	Population. [mln.]	Rel. weight [kg/ab]	Abs weight [Mt]	to recycle [Mt]	Weight/ GDP [kg/k€]*
Africa	53	1.174	1,9	2,2	0,004	**1,05**
America	35	977	11,6	11,3	1,9	**0,27**
Asia	49	4.364	4,2	18,2	2,7	**0,75**
Europa	40	738	16,6	12,3	4,3	**0,64**
Oceania	13	39	17,3	0,7	0,04	**0,49**

*Table 1. Main data on the amount of e-waste in the different continents. The seriousness of the problem in Africa is verified using the original indicator linked to the weight in relation to GDP per capita. [Fonte: Baldé et al., 2018. * Fonte: Reyes, 2021 [Original from author].*

A further demonstration lies in the fact that the problem is greater in countries with the most frequent contacts with former colonizing countries.
Among e-waste, a particularly relevant problem concerns cars battery. African countries import an ever-increasing number of used vehicles, which contribute to the fleet of 42 million mobile cars currently in use [Deloitte Touche Tohmatsu Ltd, 2017]. Each of them requires the replacement of the battery, generally lead-acid: when illegally disposed, these devices irreparably pollute the soil and the aquifer [Charles et al., 2018]. Furthermore, the few establishments that deal with the recycling of exhausted batteries, apply protocols and processes that are not always verified, which cause concentrated soil pollution in the vicinity of the plants [Gottesfeld et al., 2018].
Exhausted batteries are no longer reliable for installation in vehicles but can extend their useful life by storing energy to power low-cost environmental monitoring or weather stations devices.

Mitigation of the water issue and the impacts of climate change in Sub-Saharan Africa

The actions to monitor micro-climatic variations are developed following the design and applied research activities relating to the construction and restoration of water collection and retention structures in sub-Saharan Africa, with reference to Mali. This research is the result of the scientific collaboration between the Departments of Architecture of the University of Roma Tre and of the University of Florence, which involve the *Ecole Superieure d'Ingénierie d'Architecture et d'Urbanisme* (ESIAU) of Bamako.
It was funded mainly by *Romagna Acque Società delle Fonti* and saw the operational support of *Gente d'Africa*, a non-profit organization which has been operating in Mali for a decade and of *Architettura Emergenza Sviluppo*, a non-profit organization that deals with the mitigation of housing and social hardship in marginal areas of the world. This collab-

oration aims to plan, design, and build small and medium-sized infrastructures, with a prevalent hydraulic character, within urban and rural areas. The water infrastructures include the distribution network, the terminals and the collection and retention work aimed at the creation of artificial basins. These are called barrages, or barriers with a dam function, equipped with locks for the control of flooding.
The research was divided into phases, each of which was carried out by one or more partners [Baratta et al., 2021]:

- analysis. Identification of the architectural, technological, structural, and environmental characteristics influencing the design choices and economic evaluation of the solutions identified and formulation of the cost / benefit balance.
- project proposal and execution of the works. The two universities dealt with the design of the works, through the involvement of students, researchers, and teachers for the purpose of theoretical/practical cultural exchange.
- collection and dissemination of results. The associations involved dealt with the promotion and communication of the initiative, presented at International Conferences, and exhibited at EXCO 2019, an event dedicated to cooperation and development of depressed areas.
- monitoring of results, currently in progress.

Among others, the monitoring phase includes a series of actions aimed at quantitative assessment of the mitigation of the effects of existing climate change, linked to global warming.

Design of a low-cost microclimate monitoring system with recycled e-waste

A micro-climate monitoring system (MMS) that must operate in such extreme conditions, as those of Mali, must be able to withstand seasonal environmental changes, continuing to work without significant variations in reliability. For this purpose, the MMS consists of three fundamental parts: the acquisition station, the processing station, and the recording station. The acquisition station is responsible for collecting meteorological data by means of sensors. It consists of two parts:

a. the solar energy supply system, which avoids having to wire the different stations located on the territory and, above all, makes up for the lack of basic infrastructures typical of the context. The system consists of a 20 W solar panel, a charge control that regulates the output voltage at 5V for the acquisition electronics and 12 V for charging the 12V / 21A recycled car battery.
b. data acquisition electronics, based on the PIC24FJ64 microprocessor, chosen for its simplicity of programming even with portable devices, in relation to the processing capacity of its architecture, and for its very low cost (just over 2.5 € even for small quantities). Furthermore, it is equipped with some functionalities

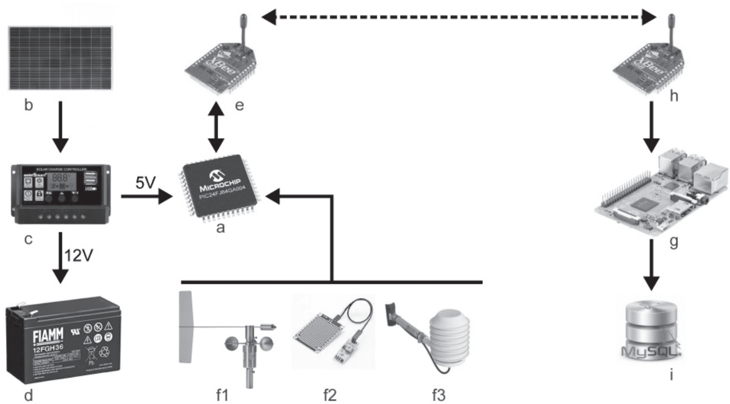

Figure 3. Operation diagram of the monitoring station. The processor (a) elaborates the information obtained from the anemometric sensors (f1) of rain (f2) and of air temperature and humidity (f3), feeding on solar energy (b) stabilized by the converter (c) and accumulated in the battery (d). Through the radio transmitter (e) the data are sent to the Single Board Computer (g) which stores them in a web database (i) [Original from author].

implemented directly on the processor, such as a voltage regulator, a timer and an energy consumption optimizer, all functions that allow it to operate for prolonged periods of time without interruptions. A series of sensors are connected to the processor, for the acquisition of anemometric data, for rain, humidity, and air temperature. Finally, it manages a radio transmission module based on the IEEE802.15.4 standard with 256 kbps of bandwidth on 2.4 Ghz frequency, capable of communicating in a radius of about 1.6 km in the absence of obstacles.

The processing station receives the data sent by the acquisition station via radio. It must ensure a stable architecture to avoid data loss and reduced energy consumption.

The system heart is the Raspberry Pi 2B single board computer, capable of running a Linux operating system, equipped with a USB port for cable connection with the radio reception modules and the ability to record data on media such as SD cards. It is powered by 5V and is connected to a 3G router capable of sending data in real time to a MySQL database.

To replace the components with e-waste, a census was carried out in the local landfill, recovering, and regenerating the parts related to power supply (car batteries, charge controllers, inverters from PC power supplies and solar panels).

Conclusions

Current climate change accentuates the water crisis that has afflicted sub-Saharan Africa for decades. This has a dramatic impact on the international geopolitical situation, from conflicts to migration. To mitigate the water issue, the self-construction of small local infrastructures such as barrages can be encouraged.

The three-year research leaded by the Department of Architecture of the Roma Tre University, in scientific collaboration with the University of Florence and in partnership with *Gente d'Africa* onlus, *Romagna Ac-*

que Società delle Fonti S.p.A. and *Architettura Emergenza Sviluppo*, led to the reconstruction of two damaged and no longer working *barrages*, in the Kayes region, near Kita (ML) [Baratta et al. 2021].
Among other activities, the research envisaged a series of on-site missions, articulated between inspection and construction operations, in addition to all other activities for extending the state of the art, designing, and collecting and disseminating the results. At the end of the activities, the collateral results of the restoration appear to be relevant, indirectly triggered by the reconstruction of the artificial basins. Among these results, those aimed at mitigating the local microclimate are very interesting. With the aim of carrying out the quantitative assessment and monitoring, the research involved the design and systematic installation of a series of data collection stations, created by recycling e-waste, with reference to exhausted batteries In this sense, the research intends to establish a circular mechanism that affects the mitigation of climate change, the improvement of water resources and the reduction of soil pollution due to the lack of protocols for the disposal of exhausted batteries.

Figure 4. Example of environmental insertion of the monitoring station [Original from author].

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Il IV Convegno Internazionale PRE|FREE - UP|DOWN - RE|CYCLE, dedicato alle "Pratiche tradizionali e tecnologie innovative per l'End of Waste", si è tenuto sulla piattaforma Microsoft Teams il 28 maggio 2021. I contributi sono stati distribuiti, a seguito della procedura double blind peer review, all'interno delle tre sezioni che caratterizzano il Convegno Internazionale: Saggi, Ricerche, Architetture e Design. La partecipazione ha visto il coinvolgimento di numerosi atenei, centri di ricerca e start-up oltre al nutrito numero di membri del Comitato Scientifico. La raccolta degli Atti fornisce lo stimolo alla riflessione sulle pratiche tradizionali e la loro intersezione con le azioni più innovative, attraverso un ripensamento dell'End of Waste. L'elemento più interessante degli Atti è la varietà di prospettiva: sebbene non vi sia la possibilità di leggere i contributi in continuità, essi restituiscono un panorama che promuove la conoscenza e stimola ulteriori indagini e ricerche.

Adolfo F. L. Baratta è Architetto e Dottore di Ricerca. Dal 2014 è Professore Associato in Tecnologia dell'Architettura presso l'Università degli Studi Roma Tre e, dal 2018, è abilitato come Professore Ordinario. È stato docente presso l'Università degli Studi di Firenze e Sapienza Università di Roma, nonché Visiting Professor presso la Universidad de Boyacá di Sogamoso (COL) e la HTWG di Konstanz (DE). Dal 2020 è esperto della Struttura Tecnica di Missione del Ministero delle Infrastrutture e delle Mobilità Sostenibili. È autore di oltre 200 pubblicazioni.

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