# SUSTAINABILITY OF APPROPRIATE ENVIRONMENTAL TECHNOLOGIES IN DEVELOPING COUNTRIES

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## INTRODUCTION

The implementation of technologies in Developing Countries (DCs) often has to face some critical factors, such as: rapid population growth and changing lifestyle; lack of sensitivity and citizen participation; weakness of the regulatory framework and its application; fragmented and inefficient organizations; insufficient and inappropriate material and infrastructural resources; limited financial resources or inefficient management of tariffs; limited human resources (staff size, skills, ability and motivation); lack of environmental monitoring, etc.. These factors are often among the main causes of the failure of international cooperation projects that promote the use of such technologies. Their introduction and dissemination needs a rigorous multidisciplinary methodological approach, which allows a process of selection and implementation of appropriate technologies able to consider the peculiarities of the context and to integrate with the local traditional uses and capabilities of the beneficiary population.

The topic of the panel was discussed through examples of the application of appropriate technologies in the field of water and wastewater, solid waste management and access to energy. The aim was to collect, through extensive discussion with the participants, suggestions useful in identifying criteria for a proper implementation of appropriate environmental technologies in international cooperation projects.

## CeTAmb ACTIVITY

The issues of international development cooperation are often seen as far away from everyday reality in which young people live. The richness of practical experiences in the sector, often available at different scale at local level, gives the opportunity to make young people closer to these issues. Their involvement can be really important, both from an educational point of view for themselves, both as a practical help and motivation to raise awareness and participation in interventions to find appropriate solutions to the real problems of developing countries.

CeTAmb (Research Centre on Appropriate Technologies for Environmental Management in Developing Countries), a research centre based at the Department of Civil Engineering, Architecture, Land, Environment and Mathematics (DICATAM) of the University of Brescia since April 2000, deals with international cooperation with regard to the technical-environmental aspects, trying to work as a meeting point among the academic world, the international cooperation sector and the young people, in particular PhD, university and high school students.

CeTAmb's main objective is the implementation of projects and research activities to improve the quality of the environment and the promotion of the concept of sustainable development in developing countries (DCs) through the application of appropriate technologies. These technologies are designed, planned, implemented, managed according to criteria of simplicity, economy and sustainability, while respecting the peculiarities of the context of intervention. CeTAmb's main intervention sectors are: drinking water supply and treatment, wastewater treatment and reuse, solid waste management and improved energy access from solid fuels.

The activity is carried out through direct participation in international cooperation projects and through the education programs. This allows to achieve the general objectives of the centre:

1. to contribute to the international cooperation sector through the direct participation in projects that are useful and sustainable over time,
2. to apply scientific and rigorous methods, investigating and valuing research and innovation in the field of appropriate technologies for environmental management in DCs,
3. to educate and train young people to the issues of international cooperation.

In order to adopt a multidisciplinary approach in the implementation of these activities, in the years CeTAmb has created a network of contacts, including research centres (Italian and international), Italian and local Non-Governmental Organizations (NGOs) and involving actively high-school and undergraduate students and professionals. Since its born, CeTAmb availed an active collaboration with several local high schools. This synergy allowed not only the participation of a number of classes of young students to training sessions (seminars and conferences organized ad hoc), but also their collaboration in practical projects of experimental research in both laboratory scale and on the field in DCs.Moreover, since 2008, in collaboration with the Faculty of Medicine of Brescia, a PhD course in "Appropriate Methodologies and Techniques for International Development Cooperation" has been activated, aiming to strengthen research in the environmental and health sector.

**CONTENT OF THE PANEL**

The panel program touched the different research sectors of CeTAmb activity, with contributions of researchers also from other Departments and Universities. The presentations followed the central theme of the practical implementation of appropriate technologies for the environmental management, discussing their sustainability and providing the audience with an overview on the methodological approach adopted and the outcomes of the field case studies presented. The titles of the presentations are listed below.

- Sustainability of appropriate environmental technologies in Developing Countries, Prof. Carlo Collivignarelli, CeTAmb, DICATAM, University of Brescia
- Sustainability of water supply projects: considerations from two case studies, Eng. Sabrina Sorlini, Eng. Luca Rondi, CeTAmb, DICATAM, University of Brescia
- Healthcare sustainable design in the global south. A tale of two stories, Prof. Marco Morandotti, STEP, University of Pavia
- Valorisation and sustainability of crude earth as building material in Chad and Cameroon, Eng. Angelo Mazzù, DIMI, University of Brescia
- Study and design of a low environmental and social impact landfilling in Togo, Prof, Alessandra Bonoli, Code3, DICAM, University of Bologna
- Appropriate technologies for household cooking with solid fuels in Developing Countries, eng. Francesco Vitali, CeTAmb, DICATAM, University of Brescia

The participation to the panel was high with an audience of more than 30 people from different backgrounds (Universities, ONGs and voluntary associations),that resulted in a lively and interesting final discussion with a lot of questions for the speakers and a wide share of ideas and points of view on the panel topic.

# SUSTAINABILITY OF APPROPRIATE ENVIRONMENTAL TECHNOLOGIES IN DEVELOPING COUNTRIES: GENERAL FRAMEWORK

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## ABSTRACT

The implementation of technologies in Developing Countries often has to face some critical factors, such as: rapid population growth and changing lifestyle; lack of sensitivity and citizen participation; weakness of the regulatory framework and its application; fragmented and inefficient organizations; insufficient and inappropriate material and infrastructural resources; limited financial resources or inefficient management of tariffs; limited human resources (staff size, skills, ability and motivation); lack of environmental monitoring, etc.. These factors are often among the main causes of the failure of international cooperation projects that promote the use of such technologies. Their introduction and dissemination needs a rigorous multidisciplinary methodological approach, which allows a process of selection and implementation of appropriate technologies able to consider the peculiarities of the context and to integrate with the local traditional uses and capabilities of the beneficiary population.

## INTRODUCTION

The application of appropriate technologies in specific contexts is the basis of a correct approach to the concept of sustainable development, i.e. a development that ensure the satisfaction of human needs and a balanced use of natural resources and of the environment in general, without compromising the quality of life of future generations. This concept is deep rooted in the research conducted within the activities of CeTAmb (established at the Faculty of Engineering, University of Brescia since April 2000) on specific issues of environmental engineering: drinking water treatment, wastewater and municipal solid waste management, access to household energy from solid fuels.

Water supply is a very current issue, since water is a limited resource and increasingly polluted. The consumption of contaminated water is a major cause of human diseases (not only in developing countries). Moreover other problems are related to the availability of a proper water source (with an adequate quantity and at an adequate distance from the house).

Another issue of interest is the management of waste water, which in many situations is carried out without any treatment or via uncontrolled disposal in the environment. This creates significant risks for human health and hygiene and for the environment, due to the high concentration of pathogens in human and animal excreta. Their proper management is required in order to prevent both pollution of natural water bodies and the spread of infectious diseases. It is therefore important to study, design and implement adequate systems for the evacuation of black and grey water , for their treatment and, possibly, for their re-use.

Solid waste management is another serious environmental issue common for both the industrialized and the developing Countries. Although the responsible administrations increasingly acknowledge the importance of adequate wastes collection and disposal, the increasing amount of wastes generated by the rapid urbanization usually is not properly managed, particularly in the developing Countries. The absence of appropriate systems for the collection, treatment and disposal of municipal solid waste (MSW) is often due to lack of awareness and participation of the local community as well as the lack of financial resources and technical facilities.

The use of traditional solid fuels leads to a number of dramatic impacts not only on the users but also for the environment. In order to gather the fuel required for their daily energy needs, householders have to cover every day longer distances carrying heavy loads or invest a significant share of their budget to purchase it in the local market. Besides wasting a resource (for which a lot of drudgery or money were spent), the use of solid fuels on open fires or inefficient stoves results in a range of health-damaging pollutant emission, often under conditions of poor household ventilation. Women and young children, who usually spend many hours close to the smoky source, are the most exposed. Such emissions have also significant global warming effects, due to incomplete combustion of fuel carbon. Moreover, the unsustainable overexploitation of natural resources leads to their faster depletion. Thus, especially for the weakest income classes, energy poverty seems to be a no-way-out situation: by the one side they do not have any financial mean to step up their own energy condition, accessing the use of more convenient, cleaner and modern fuels. By the other side, the limited energy level provides them with no emancipation means, both to improve their quality of life and to eventually start a small income generating activity.

## THE ROLE OF APPROPRIATE TECHNOLOGIES

With the definition of the "Millennium Development Goals" countries of the world have pledged to reduce by half the people without access to basic services. In particular, analysing the major environmental issues, it can be noted that an improvement in the management of drinking water, wastewater and solid waste management plays a critical role in achieving the eight Millennium Development Goals Millennium Development Goals (MDGs). As a result, international cooperation between countries of the North and South of the world may play an important role as a possible tool for moving towards sustainable development at a global level, to open a dialogue between cultures, and to facilitate the development of environmental, economic and social sustainable technologies.

This involves the adoption of a new model of development, which requires the use of non-conventional technologies, the so-called "appropriate technologies", which are the tool to solve environmental issues but also to allow a more balanced and sustainable relationship between the countries of North and South of the world, with the aim of improving the living conditions of local populations ensuring sustainable utilization of local resources, in full respect and appreciation of local culture.

Indian ideological leader Mahatma Gandhi is often cited as the "mother" of the appropriate technology movement. Though the concept had not been given a name, Gandhi, during his struggle for Indian independence (1915–1945), advocated for small, local and predominantly village-based technology to help India's villages become self-reliant. He disagreed with the idea of technology that benefited a minority of people at the expense of the majority or that put people out of work to increase profit. Dr. Ernst Friedrich Schumacher is credited as the founder of the appropriate technology movement. In 1962, he first articulated the idea of "intermediate technology" as a technology belonging between the capital-intensive advanced technologies of the "West", driven by large scale production and profit, and the traditional subsistence technologies of developing countries. He promoted technologies that are small scale, labor intensive, energy efficient, environmentally sound and locally controlled to improve a community's standard of living. Appropriate technology is the means to promote technical changes that are effective in enabling people with few resources to work their own way out of poverty. Appropriate technology is intended to build upon the existing skills, knowledge and cultural norms of women and men in developing countries, while increasing the efficiency and productivity of their enterprises or domestic activities. By and large it also seeks to sustain the local environment. Intermediate technology is a technical solution to production needs that has costs higher than those too low of the typical solutions adopted in Developing Countries but lower than the costs too high of the advanced technologies applied in Developed Countries.

"Appropriate technologies" are characterized by some basic requirements. They should:

- solve real problems and needs;
- have a low cost of installation and operation;
- have a rational use of natural resources;
- be simple (in the production/construction phase, in the operation and in the maintenance);
- be affordable for the majority of the local population;
- reduce the environmental impact.

The approach to be taken should aim to identify "technology solutions and practical achievements" adapted to the local culture and available resources, so that the intervention does not result imposed, but, on the contrary, is an expression of a real local need, involving directly the population in the process and making them actors of their own development.

## AN APPROPRIATE METHODOLOGY FOR THE IMPLEMENTATION OF APPROPRIATE TECHNOLOGIES

The concepts discussed above stand in the basis of researches conducted within the CeTAmb's activities. The final goal of our projects is to develop appropriate and sustainable technologies, aimed at solving specific environmental problems in developing countries. In order to achieve this goal, it is essential (though not sufficient) that the activity is supported by a proper and scientific methodology, from the initial setup to the final validation of the project. The preliminary steps (from the identification to the design of the project) are essential to know and understand the context of intervention and to allow to frame the problem and to define the objectives to be achieved. The implementation of the project must aim to identify, plan and realize the most appropriate technical solutions to the context analysed. Finally, the validation of the project is an important step to ensure its effective sustainability (under a social, cultural, economic and technological point of view).

### Setting the project

The projects developed by CeTAmb come from specific requests from international or local NGOs, associations and local authorities. The first step is to know the reality in which the project will be implemented. This first work requires a 360-degree approach, in order to gather information and data about the area, the population, the social and cultural contexts (social organization, employment, common practices and habits, presence of groups and organizations active in the environmental field or associations/entrepreneurs involved in the management of environmental services, etc.). The second phase focuses on the specific environmental issue under study. General knowledge of the reality and of the specific environmental issues are developed through on-site surveys, collecting data available with the help of local partners or gathering information directly from local stakeholders (interviews with relevant stakeholders, focus group discussions, social analysis). These surveys are also intended to identify the presence of existing projects already in place and to assess the level of awareness on environmental issues to obtain a frame of the territorial and environmental situation. Information/training on environmental issues may be an useful tool to increase the awareness of local population towards a certain topic. The awareness / knowledge of the problems is a prerequisite to try to find a solution and to stimulate the active participation of the beneficiaries of the project. The research for a sustainable technical solution, given the complexity of the social, cultural, economic and technological contexts, must be the result of a close collaboration between the academic staff and who knows and daily lives the local reality (volunteers on site, local governments, technical universities, project beneficiaries). Finally, the last step in the setup phase of the project is the clear definition of the objectives to be achieved.

**Project development**

The development of the project involves the study, research, design and implementation of the most appropriate technology to context. The technical solution must be identified with the following basic requirements of sustainability:

- environmental: environmental sustainability means a conscious use of natural resources, reducing material consumption and resulting in a reduction of waste from the activities;
- economic: economic sustainability is essential to achieve a stable and durable development (that lasts also after the end of the cooperation action), to increase the employment rate, the generation of income etc.;
- social: social sustainability is a key element for sustainable development , in order to ensure a fair distribution of resources between individuals, the integration of local habits and culture, within the more general framework of the respect for human and civil rights.

*Identification of certain "appropriate technology"*

The first step consists in a research of both environmental regulations present in the context studied and of technical solutions already proposed and/or implemented, with the aim of:

- identifying a range of solutions “simplified” and at the same time efficient and respectful of the human health and of the environment (e.g., in the case of water for drinking purposes, must be complied with the limits imposed by the WHO);
- highlighting the advantages, disadvantages and problems encountered in previous experiences under social/cultural and technical aspects.

This phase can be developed through the consultation of bibliographic material, or through a direct or indirect collection of information on site. The identification of a number of appropriate technology, however, must consider the socio/economic environment in which they are going to be implemented. Then their compatibility with the local reality will need to be assessed. For instance, it should be considered the impact of technology on the daily habits of the beneficiaries, on the employment situation , etc..

*Testing the technology*

In many cases may be useful to develop a preliminary experimental phase to be conducted at laboratory or at pilot scale (on-site or in Italy), with the aim of identifying the most appropriate technology. Lab tests are designed to verify the literature data collected and to study the feasibility of technical and economic sides. The best option is to set up this phase directly in the local context where the technology is supposed to be implemented, thereby allowing a field assessment of the technology, by-passing problems due to different climatic conditions, to the adequacy of local available resources and skills/knowledge, etc..

*Design and implementation of the most appropriate technology*

Given a preliminary evaluation of the technical/economic sustainability of the implementation of the technology through the pilot testing, the consequent phase of design and construction must involve all stakeholders according to respective roles and responsibilities. For example, with regard to the construction phase, it is possible to involve local workshops and laboratories; further contributions to experimentation can come from international and local NGOs, students and researchers from local universities, local authorities and non-state actors.

## VALIDATION OF THE PROJECT

The final stage is the validation of the technology applied at real scale in order to assess the proper functioning in the long-term of the project. This point is crucial, as it allows, by one hand, to make a critical assessment of the project implemented and by the other to appreciate the usefulness of the project. To verify the proper functioning of the technology, the following conditions must be complied:

- a correct operation from the point of view of the process, ensuring the health and environmental yields;
- a proper management of technology , in terms of adequate technical maintenance and proper disposal of residues, i.e. allowing an environmentally compatible management of the technology.

In the evaluation of the technology not only the environmental and technical aspects should be considered but also its social and economic utility, in terms of creation of new jobs, of guarantee of safe job conditions, and of self-sustainability of the activities implemented by means of the technology proposed and promoted by the project.

The second step of the validation regards the assessment of the utility of the project. For this purpose it is useful to respond to a number of questions that allow to estimate the short- or long-term consequences. The following list reports some example questions:

- Has the environmental issue been solved, even partially?
- Are there social positive effects (e.g. creation of job, improvement of living conditions , ...)?
- Was an income-generating activity created? Do the products eventually obtained from the activities promoted by the project (e.g. the re-sale of recovered materials from solid waste) have a market ?
- Are there positive effects on local people's health ?
- Has the awareness work been successful? Do local institutions and association involved continue with the campaign?
- Is the cooperation of local actors active and independent?

Which can be the tools to verify the outcome of a project in a medium- and long-term?

- The first answer comes from the people’s feedback! In addition to the impressions that may be collected on-site talking with people, it can be useful to do an *ad hoc* evaluation (even on specific aspects of the project) through the distribution of questionnaires to the stakeholders involved in order to assess the degree of appreciation of the technology.
- The environmental benefit of the technology implemented can also be evaluated through a qualitative environmental monitoring directly on the field, in order to measure and quantify the real impact of the action done.
- The impact on people's health can be evaluated through the analysis of data sanitation available at clinics.
- Finally, the evaluation of the effectiveness of the project on the general development can be assessed by long-term (at least a few years after the end of the project) through the distribution of questionnaires designed to detect and monitor social and economic development indicators (literacy, sanitation, jobs, ... before and after the project).

## CONCLUSIONS

The points in this paper are inevitably partial, being the result of some reflections on the experience gained from CeTAmb made during these years in a particular sector and in certain contexts. The papers presented in this session present case studies of the application of appropriate technologies in the field of water and wastewater, solid waste management and access to energy. The aim is to collect, through extensive discussion with the participants, suggestions useful in identifying criteria for a proper implementation of appropriate environmental technologies in international cooperation projects and to assess the main features to guarantee their sustainability in the long term.

# SUSTAINABILITY OF WATER SUPPLY PROJECTS: CONSIDERATIONS FROM TWO CASE STUDIES

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## ABSTRACT

In developing countries, drinking water supply is still an open issue: in sub-Saharan Africa, coverage of improved water supply gains only the 63%. Some regions are affected by geogenic contaminants (e.g. fluorides and arsenic) and the lack of access to sanitation facilities and hygiene practices causes a high microbiological contamination of water in the supply chain.
The responses to these problems are the several projects on drinking water supply that aim to improve the water availability and quality all over the world. But, how cooperation projects on water supply can be really sustainable? Can implemented technologies still work after the end of the projects? These are questions that every NGO/Association should answer during project elaboration and implementation.
The main factors that can be a source of failure for water supply projects are: complexity or costs of technologies (even if implemented at domestic scale), technical management, level of acceptance by the beneficiary community (that, if does not clearly recognize the technology benefits, can make hardly sustainable the entire project) and level of support by the local and/or national Institutions.
In order to gain the project sustainability, the activities should be clearly focused after a rigorous assessment in the study area regarding the local availability of human and material resources for the technology implementation, the awareness level of the community in terms of technology need and acceptance, etc.
CeTAmb research center (University of Brescia) has surveyed two projects on drinking water management in Senegal and Burkina Faso, which have confirmed the importance of these aspects. The sustainability level was evaluated after the project implementation: in the first case study, several deficiencies were arisen in terms of material availability and costs, whereas the second case study highlighted successful results in regard to water management system sustainability.

## INTRODUCTION

According to the last update of the WHO/UNICEF Joint Monitoring Programme (JMP) for the water supply and sanitation progress towards the MDGs achievement, drinking-water coverage in 2011 still remained at 89% (even if 1% above the MDG drinking-water target). Thus, 768 million people relied on unimproved drinking-water sources [1]. Moreover, it has to be considered an uncountable amount of people that, while disposing of an improved source, consumes drinking-water of poor quality (above all concerning the microbiological quality) due to the lack of proper handling and hygiene during the transport and storage steps.

Meanwhile, sanitation coverage (in 2011) was 64%, off track to meet the MDG sanitation target of 75%. If current trends continue, it is set to miss the target by more than half a billion people. By the end of 2011, there were 2.5 billion people who still did not use an improved sanitation facility. The number of people practising open defecation decreased to a little over 1 billion, but this still represents 15% of the global population [1].

The worst situation is highlighted to be in the sub-Saharan Africa, where the coverage of improved water supply gains only the 63% and the coverage of sanitation facilities reaches the 48% (improved and shared facilities) [1].

Despite several decades of development aid and thousands of international cooperation projects implemented all over the world, the worldwide situation remains critical, as stated above. More efforts have to be put in place in order to overcome these conditions. But every NGO/Association that has worked or is working or will work in this direction should carefully reflect if development aids or cooperation projects are really sustainable according to the local context.
Indeed, it is only through a coherent focus on sustainability that international cooperation projects can reach the objectives stated by the MDGs, at least in relation to water supply and sanitation. But what does sustainability mean in development projects? According to the World Commission on Environment and Development, the most widely accepted concept of sustainability is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2]. In 1993, in *Agenda 21* (document that provides a general framework for investigating sustainability in water and sanitation), UN declared that sustainability is the integration of environmental and development concerns for the fulfilment of basic needs and improved living standards for all [3].

From a water supply perspective, sustainability can be defined as the utilization of water sources while ensuring that the ability of future generations to use the same sources are not affected [4] or as the ability of an ecosystem to maintain ecological processes, functions, biodiversity and productivity water resources into the future [5]. Whereas a sustainable sanitation can be defined as sanitation technically manageable, socio-politically appropriate, systematically reliable and economically affordable that utilizes minimal amount of energy and resources with the least negative impacts, recovery of useable matters [5].

Regardless of the definitions, in order to evaluate and sustain water and sanitation supplies in developing countries, the international literature offers some proposals as: create a "sustainability chain", consisting of motivation, maintenance, cost recovery and continuing support [6], divide water and sanitation projects in sequential steps as needs assessment, conceptual design, design and action planning, implementation, operation and maintenance [7], or base the project sustainability on three components: effective community demand, local financing and cost recovery, dynamic operation and maintenance [8].

CeTAmb research centre (Research Centre on Appropriate Technologies for Environmental Management in Developing Countries) of the University of Brescia (Italy), which collaborates with NGOs, Universities and other research centres in the elaboration and implementation of cooperation projects in developing countries since 2000, has always sought to put into practice five sustainability elements of the solutions implemented to solve environmental problems: (1) technical sustainability, in terms of use of local material and human resources and in terms of adopt appropriate technologies with an affordable and simple operation and maintenance need, (2) economical sustainability, which means the adoption of technologies or facilities with low costs of investment and operation, trying to create local trade/business opportunities that can guarantee a self-reliance, (3) organizational and institutional sustainability, in terms of acceptance by the local Institutions (from the lowest to the highest) and in terms of create a strong partnership between the local stakeholders (with a key-role of a local NGO/Association) that can guarantee the continuance of the project after its "official" end, (4) social and cultural sustainability, which means develop projects and implement technologies really felt by the local people and that can rapidly show an improvement in the everyday life and/or in the health status, and (5) environmental (and health) sustainability, in terms of minimise the use of natural resources by acting on the reuse or recovery of waste or other resources and in terms of avoid any kind of environmental impact (possibly improving, or at least not worsening, the local people health). Moreover, the concept of sustainability clearly requires a long-term view of the infrastructure/facility/technology implemented or of the behaviour change in the lifestyle generated by the project.

On the base of the elements above mentioned, and suggested also in the scientific literature [4, 5, 9, 10, 11, 12], CeTAmb has surveyed two projects on drinking water management: one in Senegal and the other one in Burkina Faso. The sustainability level was evaluated at the end of the project implementation: in the first case study, several deficiencies were arisen regarding material availability and costs, whereas the second case study highlighted successful results in the drinking-water management system.

## THE STUDY AREAS

The evaluation of the sustainability was made on two water supply projects: the first one implemented in Senegal, in collaboration with the Italian NGO G. Tovini Foundation, and the other one in Burkina Faso, in collaboration with the Italian NGO Medicus Mundi Italy (MMI). As follow described, despite the projects implemented were essentially alike, the two contexts were clearly different both for the stakeholders involved into the projects and for the drinking-water sources available and for the kind of water pollution.

### Case study 1: Senegal

In 2008, the G. Tovini Foundation, together with CeTAmb of the University of Brescia, started a cooperation project in order to improve drinking-water quality in the Rural Community of Patar (RCP), in the Diourbel Region (Senegal). The project was developed and implemented in collaboration with the University of Dakar and the Diourbel Hygiene Authority. After a preliminary survey, three different drinking-water sources used by the local people were identified: (1) open dug-wells, (2) protected wells network that extracts water from a shallow aquifer and serves, through a small distribution system, public taps and (3) groundwater distribution system that pumps water to public and household taps. This latter type of source is the most used by the population for water supply but during the preliminary survey, it was also found that concentrations of fluoride exceeded the 1.5 mg/L Guide Value suggested by WHO. As a response, a bone-char-based filtration for fluoride removal was studied, experimented and implemented at household level as this was initially considered as an appropriate solution for fluoride removal due to its simplicity of construction and operation, low cost and good efficiency of fluoride removal.

In addition to the chemical contamination, whichever was the drinking-water source, a microbial growth was detected in both the transport and storage tanks, due to a lack of hygiene in handling the containers. For this reason, disinfection with chlorine was suggested at household level and awareness campaigns for improving hygiene were organised.

In 2011, the same partners decided to elaborate and develop a new project in order to verify and carry on the activities started previously and to implement a Water Safety Plan (WSP), a plan that aims to ensure the drinking-water quality from the catchment to the point of consumption.

**Case study 2: Burkina Faso**

In 2011, Medicus Mundi Italy, together with CeTAmb of the University of Brescia, began a cooperation project in order to improve drinking-water quality and health conditions of the population of Fingla and Diarra rural villages, in the Béguédo municipality, Centre-East Region (Burkina Faso). This first project in this context was developed and implemented in collaboration with the Burkinabé NGO Dakupa, which works locally since 1997. After a preliminary survey, two main drinking-water sources used by the local people were identified: (1) open dug-wells, and (2) tube wells with hand-pump that are the most used by the people for drinking-water collection. Despite the water quality was acceptable at the source level, a microbial growth in the transport and storage tanks was detected revealing a lack of proper handling and hygiene. On the other hand, chemical contamination was absent.

Due to the microbiological contamination, awareness campaigns to improve hygiene and drinking-water management were led. These represented also the supporting program of the WSP implementation, which was one of the main objectives of the project in order to improve water quality along the supply chain.

## METHODOLOGY OF SUSTAINABILITY'S EVALUATION

The sustainability's evaluation of both projects was carried out by means of (1) surveys on the field, where the concentrations of the main microbiological and chemical parameters were measured along the supply chain, the level of risk of contamination at the sources was measured through sanitary surveys and direct interviews with local communities and stakeholders were carried out, and above all on the base of (2) a series of questions directly related to the five sustainability elements above mentioned.

**Tab. 1 -** List of the sustainability elements and their respective questions.

| **Sustainability element** | **Question** |
|---|---|
| Technical | Are there locally knowledge and technical expertise necessary for the elaboration and development of a WSP? |
| | Are there locally knowledge and technical expertise necessary for the management and update of a WSP? |
| | Are there locally knowledge and technical expertise necessary for the design and construction of a technology for drinking-water treatment? |
| | Are there locally knowledge and technical expertise necessary for the operation and maintenance of a technology for drinking-water treatment? |
| | Is there locally the availability of people and material resources for the WSP implementation? |
| | Is there locally the availability of people and material resources for the construction and management of the technology used for drinking-water treatment? |
| | Is the WSP performing as it was designed to perform? |
| | Is the technology used for drinking-water treatment performing as it was designed to perform? |
| Economical | Is there locally economic availability necessary for the elaboration and development of a WSP? |
| | Is there locally economic availability necessary for the management and update of a WSP? |
| | Is there locally economic availability necessary for the design and construction of a technology for drinking water treatment? |
| | Is there locally economic availability necessary for the operation and maintenance of a technology for drinking water treatment? |
| Organizational and Institutional | Has the WSP team been adequately trained for the implementation and management of the WSP? |
| | Have the managers and operators been adequately trained for the construction, operation and maintenance of the technology used for drinking-water treatment? |
| | Are the WSP managers supported by the local community? |
| | Are the adopted technology managers supported by the local community? |
| | Are the WSP managers supported by the local Institutions (political and technical Institutions)? |
| | Are the adopted technology managers supported by the local Institutions (political and technical Institutions)? |
| Social and Cultural | Has the community been informed about the WSP implementation and its benefits? |
| | Has the community been informed about the technology used for drinking-water treatment and its benefits? |

| | |
|---|---|
| | Is the community favourable to the WSP implementation?<br>Is the community favourable to the use of a technology for drinking-water treatment?<br>Does the community contribute and encourage the WSP elaboration and implementation?<br>Does the community contribute and encourage the use of the technology for drinking-water treatment? |
| Environmental and Health | Has the WSP implementation improved local people health?<br>Has the WSP implementation permitted to guarantee the drinking-water quality according to the WHO standards?<br>Are the adopted technology managers well equipped to assure well-being and health?<br>Have adequate measures been adopted in order to safety dispose of any residues produced by the technology for drinking-water treatment?<br>Has the WSP implementation prevented the arising of any negative impact on the environment? |

As reported in Table 1, each sustainability element was characterised by a series of questions that can be answered with: “absolutely yes” (level of sustainability: 1), “rather yes” (level of sustainability: 0.75), “rather no” (level of sustainability: 0.25), “absolutely no” (level of sustainability: 0) and “not applicable to the project” (in order to elaborate a questionnaire as general as possible and usable also by other researchers, some questions cannot be pertinent for all the projects). This methodology was proposed by Zurbrügg *et al.* [9] but applied for the sustainability’s evaluation of waste management projects. For this reason the questions were elaborated and adapted to water supply projects, in particular projects concerning WSP implementation and drinking-water treatment. This questionnaire was addressed, at the end of each project, to all the people involved in the implementation in order to collect information about the possible reasons of success or failure.

**Case study 1: Senegal**

Regarding this case study, the sustainability’s evaluation was carried out during the second project implementation. The first activities were to assess the level of utilisation of the bone-char-based filtration distributed during the first project, to determine the concentration of the main physico-chemical and microbiological parameters, and to interview some local families in order to understand the main practises in terms of drinking-water management, sanitation and hygiene. With this data it has been possible to make a comparison with the previous situation and, thus, to determine the level of sustainability of the first project. On the other hand, the evaluation of the sustainability elements through the use of the questionnaire reported in Table 1 was carried out at the end of the second project, after the implementation of the WSP. The questions were addressed to the 2 volunteers of the G. Tovini Foundation who worked directly on the field, to 4 representatives of the local partners (University of Dakar and Diourbel Hygiene Authority), to the WSP team (formed by 4 managers of the different water sources, by 3 people of the local Institutions and by 5 representatives of the community) and to the most important people of the Rural Community of Patar involved into the projects (the President of the RCP, the President of the women association and the President of the young people association).

**Case study 2: Burkina Faso**

In this case, all the sustainability’s evaluation was carried out at the end of the project. A comparison between the situation at the beginning and at the end of the project was done in terms of microbial concentration in all the supply chain, application of the control measures provided by the WSP, and level of drinking-water management, sanitation and hygiene among the community. As for the other case study, the questionnaire for the evaluation of the sustainability elements was addressed to the main people involved into the project: the 2 volunteers of Medicus Mundi Italy, who were working on the field for almost the entire period of the project implementation, the 3 people of the local NGO Dakupa responsible for the project and the team of 7 hygienists of Fingla and Diarra villages that has actively worked on the elaboration and implementation of the WSP.

## RESULTS AND DISCUSSION

The results obtained from the sustainability’s evaluation are provided separately for each case study, in order to clearer present the reasons of success or the elements of failure.

**Case study 1: Senegal**

The sustainability’s evaluation of the Senegal case study started from the assessment of the local situation after the implementation of the first project. One of the first activities carried out on the field was the visit of the household bone-char-based filtration systems. It rapidly appeared that none of the 22 filters distributed was in-operation, owning to the unavailability of bone-char. The further meetings with the people responsible of the drinking-water treatment, the local Institutions and the local partners highlighted the problem of bones supply from the slaughterhouse situated in Dakar (approximately 150 km far from CRP), and which the agreement was taken with. Due to the lack of raw material, the filtration systems and all the equipment for the production of the bone-char were abandoned and subjected to degradation. Probably the absence of a leader local partner (as an NGO can be) caused the interruption in the bones supply and the end of the water treatment. To strengthen this idea was the intervention of the G. Tovini Foundation's volunteers, who restarted the business relation with the slaughterhouse and were able to furnish again the beneficiaries of the bones necessary for the filtration system. The enthusiasm of the owners of the filtration system and the still present ability of the technicians to prepare the bone-char were even more strengthening the idea of a lack of efforts by the local partners.

Regarding the water quality along the supply chain, it was clearly evident from the first analysis how the chemical parameters' concentration was unvaried. On the other hand, results from microbiological analyses provided interesting causes for reflection. High concentrations of *E. coli*, faecal coliforms and faecal streptococci were found in the transport and storage tanks of the families that had not followed the meetings to raise awareness of good hygiene practices, proper methods of drinking water management and attitudes to prevent diseases due to polluted water consumption. Indeed, the lack of hygiene in handling the water was the primary reason of contamination. Conversely, families that had received the bone-char-based filtration system or that had actively participated to the awareness campaigns during the first project showed concentrations of microbes in the different containers lower than the other families. Even the awareness campaigns on the consequences that the consumption of water reached in fluorides can determine to the health were successfully. This assumption was confirmed by the change of water source on the part of the beneficiaries of the filtration system when the bones supply was interrupted. Most of them, in fact, preferred to go farther at the public taps of the protected wells network rather than consume the household tap water from groundwater distribution system.

All these considerations lead to the conclusion that the training part of the population carried out during the first project implementation was extremely useful and sustainable.

Concerning the WSP implementation (WSP that was elaborated for all the three water sources, for the transportation system and for the storage/treatment/consumption step), the sustainability's evaluation was carried out after the end of the second project. In particular, four months later, a survey was conducted in order to assess if the most important control measures adopted for preventing water contamination were put in place. Results showed that nothing was done, above all because local partners (responsible for the WSP implementation and monitoring) did not support the WSP team and the other volunteers, who were motivated to put in place the measures envisaged by the WSP, in order to look for funds (private and/or public) and to mobilize economic and material resources inside the RCP. As for the bones supply, the lack of a leader local partner was probably the cause of this failure.

The last evaluation was carried out by means of the questions related to the five sustainability elements. Figure 1 shows the results obtained for the five elements in function of the different respondent groups. As reported in the previous chapter, at each answer a sustainability value between 1 and 0 was assigned in order to compare the results of the different respondents.

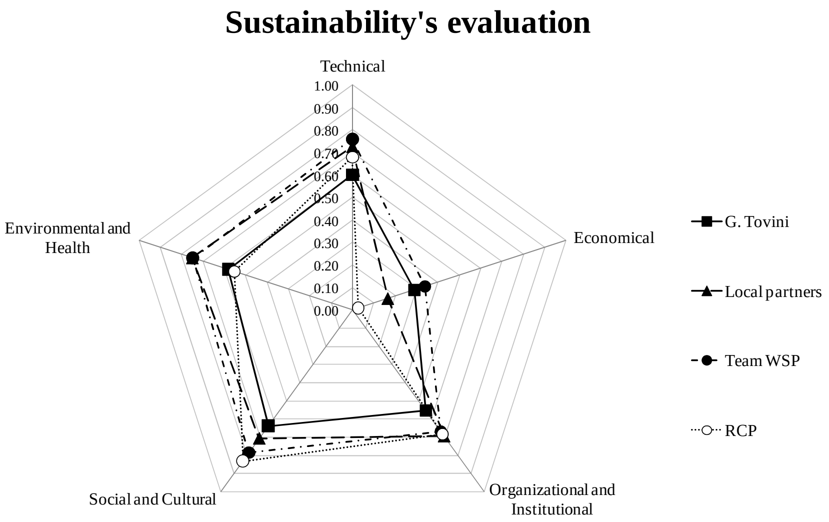


**Fig. 1 -** Results of the questionnaire for the sustainability's evaluation.

As shown by the graph, the highest average values of sustainability were obtained from the technical and the social-cultural elements, whereas the lowest values were provided by the economical ones. This latter result is mostly due to the absence of funds directly available and suggests the need to find contacts/partnerships that are greatly important for the self-reliance of the activities/technologies after the end of the project, in order to put in place all the WSP measures. The cost of the bone-char-based filtration system, in fact, was not high so that beneficiaries were also willing to pay in return for a continuous supply of bones. Regarding the higher values assigned by the different groups of respondents to the social and cultural sustainability, it is possible to highlight the correspondence with the behaviour change of the local people in the drinking-water management after the awareness campaigns of the first project. This can be a proof that the population has deeply understood the cooperation project, has accepted it and is supporting it. About the technical sustainability, answers were pretty positive as technical skills for the WSP and the filtration system implementation and management are locally available. The organizational and institutional sustainability was not so high, revealing the absence of a strong support of the activities carried out with the project by local political and technical Institutions. Concerning the environmental and health elements, results were not that high owning to the lack into respect the drinking-water standards. At the point of consumption none of the analysed samples permitted to respect the international standards in terms of microbes and only the beneficiaries of the filtration system can consume drinking-water with fluoride concentration under the limit value.

Despite all the efforts that a lot of people have put in these two projects, many elements of failure have been provided. Probably the main reason was the absence of a strong leader as local partner that could help to mobilize human and material resources and try to find funds for the self-reliance of the project. The activities, in fact, were carried on only during the projects implementation, when an external support in terms of funds and human resources was provided. As also cited in the scientific literature [12], a project that solves a problem but forever links the beneficiary to an external support is a failed project because it does not create real development but rather further dependency. The aim of the international cooperation projects is to increase sustainability, meaning the autonomy of the project and its efficiency.

**Case study 2: Burkina Faso**

The sustainability's evaluation of the Burkina Faso case study was assessed at the end of the project implementation. One of the main activities carried out on the two rural villages of Fingla and Diarra was the WSP elaboration, which has been used during its implementation as a tool to heighten public awareness of good practices in water management. For this reason the project's evaluation was mainly focused on the behaviour change in drinking-water management that potentially happened thanks to the WSP implementation. In particular, the microbial concentration of *E. coli* in the different steps of the supply chain was analysed before and after the project implementation (in other words the WSP implementation). Figure 2 shows the results obtained from these analyses. The increasing trend of contamination in the supply chain is clear both before and after the WSP implementation, but the average values obtained at all levels at the end of the project are much lower than the ones obtained at the beginning.

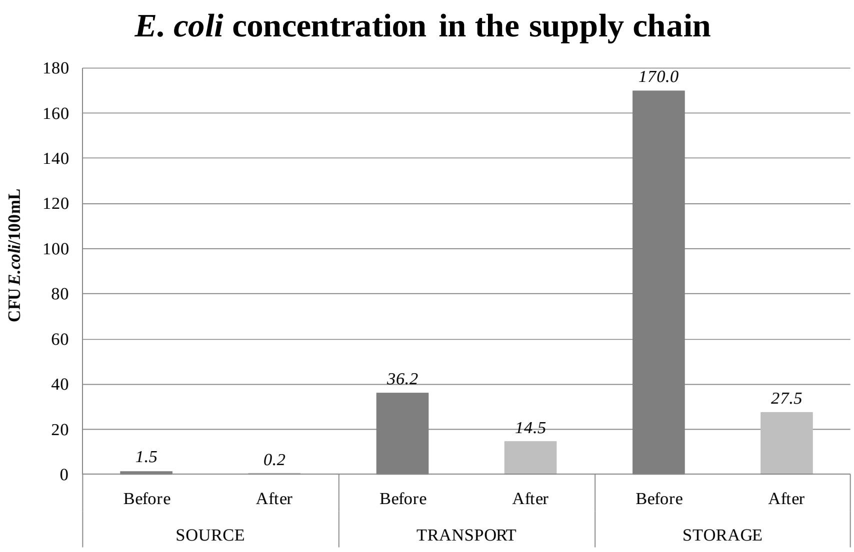


**Fig. 2 -** Average *E. coli* concentration in the supply chain before and after the WSP implementation.

An on field survey was also carried out during the last month of the project implementation, aimed to evaluate the behaviour change of the communities in the drinking-water management. It rapidly appeared how the families that had actively participated at the WSP implementation and at the awareness campaigns on the good hygiene and sanitation practices improved their drinking-water management habits. The results of the interviews to 200 families demonstrated that there has been a significant improvement of the good practices in the drinking-water management (p-value: 10-25) and of the level of knowledge on the methods of diseases transmission and prevention, with particular emphasis on diarrhoeal diseases, (p-value: 10-79) before and after the project implementation. Many efforts have still to be made in order to apply all the control measures established with the WSP for avoiding the water contamination, but important changes on the everyday life were already put in practice (as demonstrated by the microbiological analyses along the supply chain). The use of the WSP as a tool to raise awareness, the campaigns on good hygiene and sanitation practices and the strong support of the local NGO Dakupa in the project implementation are probably the three most important factors of the project's sustainability.

Even in this case study the sustainability's evaluation was assessed by means of the questions related to the five sustainability elements. Figure 3 shows the results obtained for each element in function of the different respondent groups. As for the previous case study, a score between 0 (not sustainable) and 1 (sustainable) was assigned at each question. The highest values were obtained from the social-cultural and economical elements, in despite of low values provided by environmental-health and organizational-institutional elements. Regarding the economical sustainability, it is possible to highlight that the amount of funds necessary for the WSP elaboration and implementation and for the drinking-water treatment (chlorination) is quite low. This is the reason of the pretty high average result obtained for this sustainability element. As for the Senegal case study, the groups of respondents assigned high values to the social and cultural sustainability; actually, it is possible to notice the correspondence with the behaviour change highlighted by the microbiological analyses and the final survey on the part of the communities, who demonstrated to have deeply understood and accepted the project. Concerning the organizational and institutional sustainability, pretty low values were obtained from the questionnaire, owing to the low support of the local Institutions during the WSP elaboration and implementation. This is due to two reasons: the first one is that the technical local Institution (drinking-water Authority) was not operative during the project implementation (the person in charge changed job before the beginning of the project and a new manager was assigned after the WSP implementation), and the second one was that the political local Institution (the municipality) was under election during the WSP elaboration and implementation (and in that period, opposite political parties were also fighting each other). Concerning the environmental and health elements, results were not that high owning to the lack into respect the drinking-water standards. At the point of consumption none of the analysed samples permitted to respect the international standards in terms of microbiological quality. One of the control measures provided by the WSP was the chlorination treatment at the storage level, but the habits and taste of the water induced great part of the community to not carry out the treatment. The time and the support of the local partner will probably permit to reach this objective in the feature. The technical sustainability highlighted a good average value.

Indeed, from one hand there is locally an availability of expertise on the management of both the WSP and the drinking-water treatment, but on the other hand there is a lack of expertise in the WSP elaboration and implementation, due to the use of the WSP development as a tool for raising awareness into the communities on good practices in drinking-water management and to the absence of trained local managers of water supply.

The final assessment of the project has permitted to positively evaluate its sustainability. A lot of efforts were put in place by the local NGO for the success of the project, and this first evaluation has clearly highlighted it.

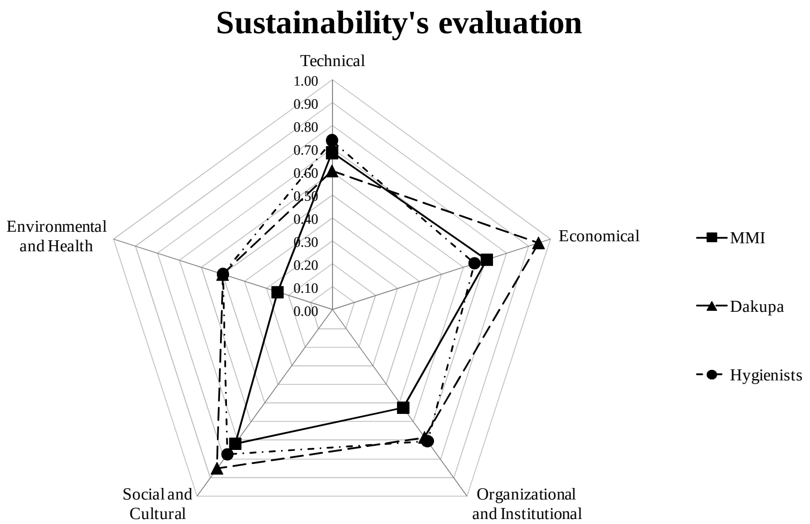


**Fig. 3 -** Results of the questionnaire for the sustainability's evaluation.

## CONCLUSIONS

CeTAmb has surveyed two different projects on drinking water management. The sustainability level was evaluated at the end of each project implementation, using different methodologies. The main considerations arisen from these two case studies are:

- ✓ In these projects, the sustainability evaluation was carried out at the end of the project activities, but a long-term assessment (after 1, 5 or 10 years) should also be provided in order to really understand the projects effectiveness.

- ✓ The two main tools proposed for the sustainability evaluation are an on field survey and a series of questions directly related to five sustainability elements, but the method of inquiry and data collection might differ from case to case: observations, document analysis, informal interviews to key selected individuals or stakeholders are also other methods to take into account.

- ✓ The questionnaire for the evaluation of the sustainability elements was elaborated and conducted at the end of the project implementation, but if revised can be useful for the evaluation before and during the project activities. Moreover, it is necessary to highlight how the questionnaire was realized in order to be used for the evaluation of projects concerning a WSP implementation and a drinking-water treatment.

- ✓ This questionnaire alone cannot be the only method to investigate the sustainability of a project, but it can provide a general overview of the project from the standpoint of the different stakeholders. Indeed, as shown by the results of the two case studies, the application of the questionnaire alone would not have allowed the understanding of important aspects; on the other hand, it has provided interesting and useful information to confirm what has been provided during the final survey.

- ✓ The presence of a strong local partner (as an NGO) can be a reason of success, as highlighted in these two case studies. The partnership with the NGO Dakupa in Burkina Faso has permitted to easily implement the different activities of the project, and probably to gain the reliance of the local communities into the project, assuring its sustainability.

- ✓ The five sustainability elements proposed in this research are, according to the authors, of extreme importance in order to guarantee the sustainability of an international cooperation project. The lack of one of these elements can be a reason of failure, as the Senegal case study has highlighted owing to the absence of a strong local leader.

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## NOMENCLATURE

| | |
|---|---|
| JMP | Joint Monitoring Programme |
| MDG | Millennium Development Goal |
| MMI | Medicus Mundi Italy |
| NGO | Non-Governmental Organization |
| RCP | Rural Community of Patar |
| UN | United Nations |
| UNICEF | United Nations Children’s Fund |
| WHO | World Health Organization |
| WSP | Water Safety Plan |

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# HEALTHCARE SUSTAINABLE DESIGN IN THE GLOBAL SOUTH. A TALE OF TWO STORIES.

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## ABSTRACT

The paper presents the results of a didactic experience and of a research developed at the Faculty of Engineering of the University of Pavia in the field of the cooperation, focused on the sustainable design approach in the global south.
All the different experiences are based upon a multidisciplinary and holistic design concept as a possible strategy to control both the technical feasibility and the environmental and social sustainability of the intervention. The paper is focused on two different experiences both regarding the health planning sustainable design in Kenya, Africa.
The first one is the results of an International Winter School *BSuR-Building Sustainable (Re)Construction. Innovative design approach for developing countries*, developed on February 2012. The school had been attended by engineers, architects and PhD students of different universities, such as Pavia, Milan, Turin. The project activities consist in frontal and multidisciplinary lectures and in workshop focused on different design topics held by professors and designers with direct experience in collaboration with NGOs and international organizations. Students had to work on real needs, regarding the formulation of workable solutions for the Maternity Unit at the Malindi General Hospital, dealing with realistic data of context, materials and costs.
The second case study concerns the design of a medical dispensary in Chakama, near Tzavo Park. The need to design a first medical support health was expressed by the local diocese and the Hospital San Matteo of Pavia and it's developing under the technical support of the Laboratory STEP, University of Pavia. The main idea is to design and implement a modular, sustainable and expandable unit that could be used as a prototype to be implemented in different territorial contexts, as a possible answer to the needs of the community, settled in an area without care facilities and characterized by an extremely critical of the socio-general health.

## INTRODUCTION

The paper aims to describe two different design activities developed in the last year at the STEP Laboratory within Civil Engineering and Architecture Department of the University of Pavia.

The research team is composed by Prof. Marco Morandotti, who initiated and coordinated the activities, by Prof. Daniela Besana and Eng. Elisa Salvaneschi. This paper contains the results of the joint work of the authors. In particular, the first and second paragraphs are due to Prof. Marco Morandotti, while the third paragraph is written by Prof. Daniela Besana. The common theme of these experiences is the design of two different health care facilities in Central Africa and more specifically in Kenya. In both cases, over to the same geographical location of the projects, the project aims to improve previous conditions of significant distress, by means of a common approach.

This approach is the product of teaching, research and experimental experience gained in recent years in terms of design in the global south; it is based upon three different pillars: "knowledge", "sustainability" and "feasibility".

"Knowledge" understood as "global", in terms of theoretical debate and international examples of design actually realized, and "local" in the context of a single intervention, in terms of anthropological, cultural, environmental and climatic study. It is evident that at these two basic levels of knowledge, a specific one must be added, relative to the understanding of the requirements related to the design function, especially, if particularly complex, as in the case healthcare construction.

"Sustainability" of the intervention must be considered in its three basic dimensions. The strictly environmental one, declined in this context as a possible developing use of renewable and low-impact energy sources, but also for example the possibility of using recycled materials, or, where it is possible, traditional building techniques and materials locally available. The economic sustainability, understood not only as the ability to acquire the resources necessary to carry out the work, but more generally, with a view life-cycle oriented, such as long-term economic sustainability. It means not only to verify the feasibility of the work, but its maintainability in use and its right management over time. The third dimension of sustainability - the so-called "social" - is also central, because it takes into account, both the coherence and consistency of the project with the typological and spatial patterns specific to the local context and, on the other hand, involves the local community in the design process, and certainly in the management phase of the intervention. Only one project that is perceived by the local community not only as a satisfaction of a specific need, but also as an expression of a system of relations compatible with the existing social structures, can be perceived as being part of the community.

The "feasibility" of the work is finally the third key element of our approach. This is an essential component of any design activity and a specificity of the scientific-disciplinary research team. This implies not only economic feasibility, closely linked to the economic dimension of sustainability of the project, but also the technical feasibility of the work itself. It means to verify the design project ideas to the feasibility of the technological solutions, regarding both techniques and materials. Specifically, in developing countries, this technological dimension of the project plays a relevant role to ensure the design feasibility starting from technical and local possible solutions. Not so simply to verify the general feasibility of a design idea, but that it is in the specific context without generating technological dependencies, through the use of "alien" materials and technologies and therefore difficult to control during the construction and especially the management of the work (Fig. 1).

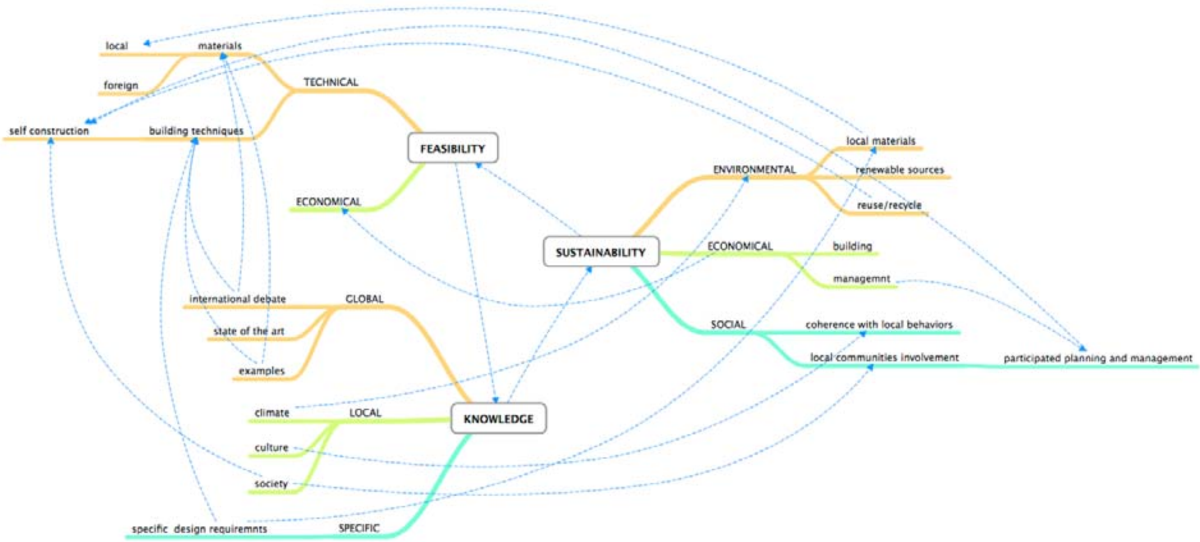


**Fig. 1**- Theoretical approach to the project design.

## Hospital design between didactic activities and applied research. A case study in Malindi, Kenya.

In February 2012, the first edition of the winter school "Building Sustainable (Re)construction – B.Su.r" has been held, thanks to a grant of the University of Pavia (Director Marco Morandotti; Scientific Coordinator Daniela Besana; Organizing secretariat Elisa Salvaneschi; Tutor Elisa Salvaneschi, Paolo Baldini).

The objective of the school, through the projects developed and in the hope of a second phase of work, is to identify and concretely to experience an operating scientific and cultural path will lead to greater awareness of the objectives of sharing, coherence, consistency and quality in the project design.

The two weeks long full time school has been attended by 22 students from five Italian universities, aimed to apply a coherent design approach in developing countries. The didactic approach was oriented to mix theoretical lectures from teachers and experts with experimental design activities focused on the topic of health design. Participants have been divided into five mixed groups and every one developed a different design proposal.

Since the beginning it was established that the school would have stressed a real case study, not only an academic simulation. Therefore participants have been asked to develop design ideas dealing with a real physical context, moving from real users' requirements and in the perspective of building's feasibility.

Prof. Giovan Battista Parigi, coordinator of the Centre for the International Cooperation of San Matteo Hospital in Pavia, helped us in establishing a contact with the Malindi District Hospital (MDH) management office. Due to MDH involvement in an international cooperation project by San Matteo Hospital since few years the new action has been integrated into a consolidated relationship framework. The cooperation between our technical unit and local doctors and managers clarified the general local scenario in terms of functional needs and human available resources to be involved in the new structure.

Hospital design in developing countries shall consider economic and financial sustainability as well as climate adequacy and technological feasibility.

The hospital is located in south Malindi and is articulated in several pavilions built almost casually along the time in a wide area. Many of them are connected by a covered path slightly elevated respect other public open spaces. Existing pavilions are pretty simple as regards morphological and technological aspects. One of them has been recently upgraded as a new High Dependency Unit, as like as both existing emergency unit and the building hosting two surgery theatres has been renovated.

The existing Maternity Unit is one of the most stressed concerning its carrying capacity and probably one of the most under-dimensioned structures. The set of functional requirements for an effective Maternity Unit in relation to actual and expected trends have been stated as following:

- 20 Antenatal beds
- 15 Postnatal beds
- 10/15 cradles
- 10 labour beds
- 8 delivery rooms
- service rooms (staff's dressing room, storages, waiting room, services, sluices...)

The existing unit offers just two delivery rooms and four labour beds; has poor typological, functional and typological quality and is affected by several conservation issues. Moreover its location makes it impossible to plan any kind of dimensional growth of the existing structure. Therefore it seemed necessary to plan a completely new Maternity Unit, designed according to updated health criteria, in a more comfortable area of the hospital, suitable to become in the near future another entrance to the complex.

Before the opening of the school a booklet concerning local history and culture as well most relevant climate parameters has been prepared by the scientific staff of the school and distributed to participants.

A relatively wet belt extends along the entire Indian Ocean coast of Africa. The main rains come between late March and early June with the rainfall decreasing from August. Some rain occurs between October and November but from December, rainfall decreases rapidly once again to a minimum during January and February. Annual total rainfall ranges from 508 mm in the drier, northern hinterland to over 1,016 mm in the wetter areas south of Malindi. Relative humidity is comparatively high all the year round, reaching its peak during the wet months of April to July. However, there is a marked diurnal change particularly in Mombasa where it is around 60-70% during the afternoon, rising to 92-94% during the night and in the early morning. The windiest time of the year at the Kenya Coast is during the Southeast Monsoon from May to September, while the calmest months are March and November when the winds are also more variable in direction. Wind records show a consistent daily pattern whereby wind strength (in knots) drops during the night. The strongest winds are likely to be experienced in August.

Information concerning materials and techniques available in Malindi region has been shared among the participants, in order to base any design idea on a reliable technological background. The local prevalent construction material in the so called "coral block" which is a limestone coming from ancient coral reef material, nowadays available through superficial outcrops that can be quarried. It is quite easily shaped in square blocks of different dimensions and mostly used both as continuous structures element both as non structural block in most relevant buildings provided with concrete frame. Roof structure are mostly built by means of sheet steel but traditional constructive techniques are mostly based upon typical wooden structures, such as Makuti. It is an handcraft procedure mostly based upon craftsmanship experience without any formal design. Many of these wooden structures may become really relevant in dimensions, and are kind of trusses with external finishing in fastened leaves. This allows relevant roof slope and considerable maximum height. This kind of technological solution is really adequate to local climate due to the fact that allows a natural ascendant movement of warm air under the roof itself. Unfortunately it needs continuous maintenance and is highly vulnerable to fire. In recent years the realization of this type of coverage is for touristic building (Fig. 2).

The requirements defined by the management of the Hospital have been verified by means of a preliminary design idea, developed by Paolo Baldini as degree thesis, which become a kind of functional and dimensional benchmark solution for the participants of the school. Due to its early preliminary stage it was not impossible to define a kind of contractual construction budget, but it was necessary test a sort of general compatibility assessment between requirements, available area end sustainable economic funding. The idea was to develop a quite simple building according to a "T" shape, by means of three modular elements each assuming a well defined function: pre-natal, natal and post natal.

During the two weeks training five different ideas have been developed. Each of them answered to the general requirements, but according to pretty different typological and morphological solutions. Some design solutions focused on a "comb" shape either with one or two connection paths along the perpendicular elements. The second solution allows a clearer separation between the internal fluxes of users but it necessary requires wider internal surfaces and also a higher number of nurses. Someone else provided a central court, according to a somehow common morphological solution, in order to define a semi-public sheltered space dedicated to inpatients and sometimes to relatives. Someone finally imagined a plate typology, maybe more rigidly defined by pure volumes, maybe more dynamically shaped by means of a number of internal patios.

Many students focused their own design strategies on local climate, by means both of the orientation of the building and of its specific dimensions in order to favour natural cross ventilation phenomena. Specific structures, like wind towers, have been provided in order to enhance this natural climate behaviour also underlying a relevant morphological role. Other students tried to enhance the performances of traditional technologies, introducing a kind of steel reinforced masonry moving from local and available materials. Such idea needs a scientific experimental support that cannot be provided during a two weeks long initiative. However it introduces an experimental dimension that could be deepened in future (Fig. 3).

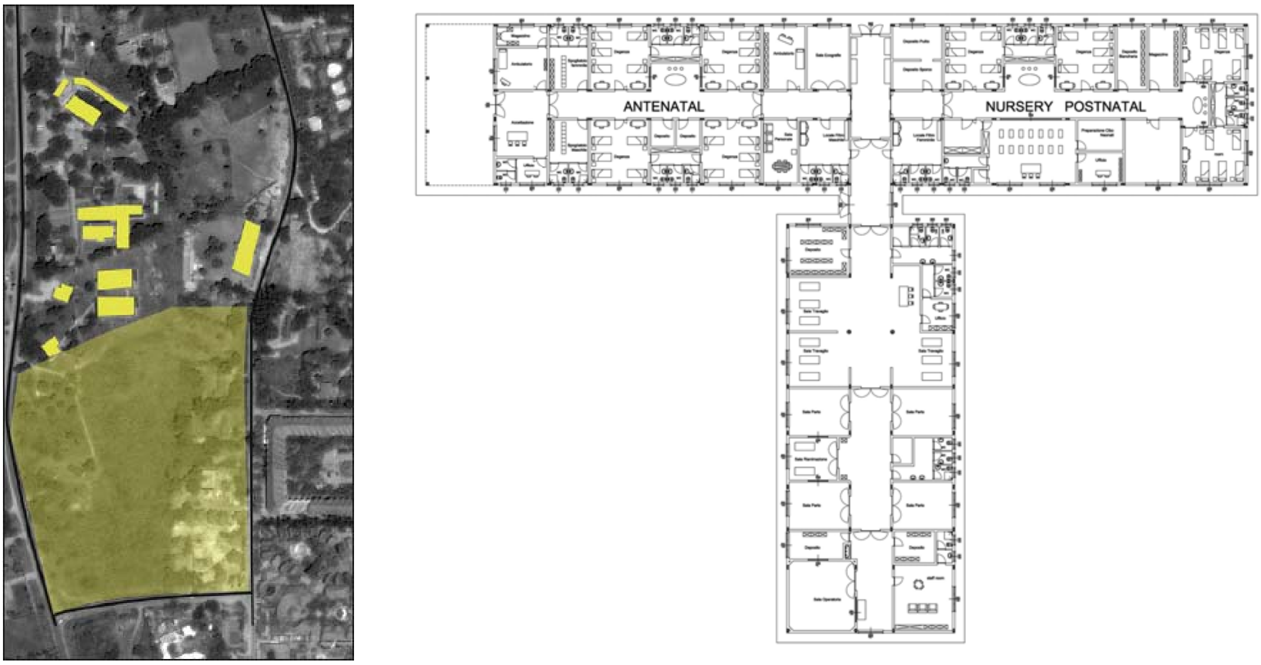


**Fig.2** - Masterplan of Malindi General Hospital and preliminary design idea developed by P. Baldini.

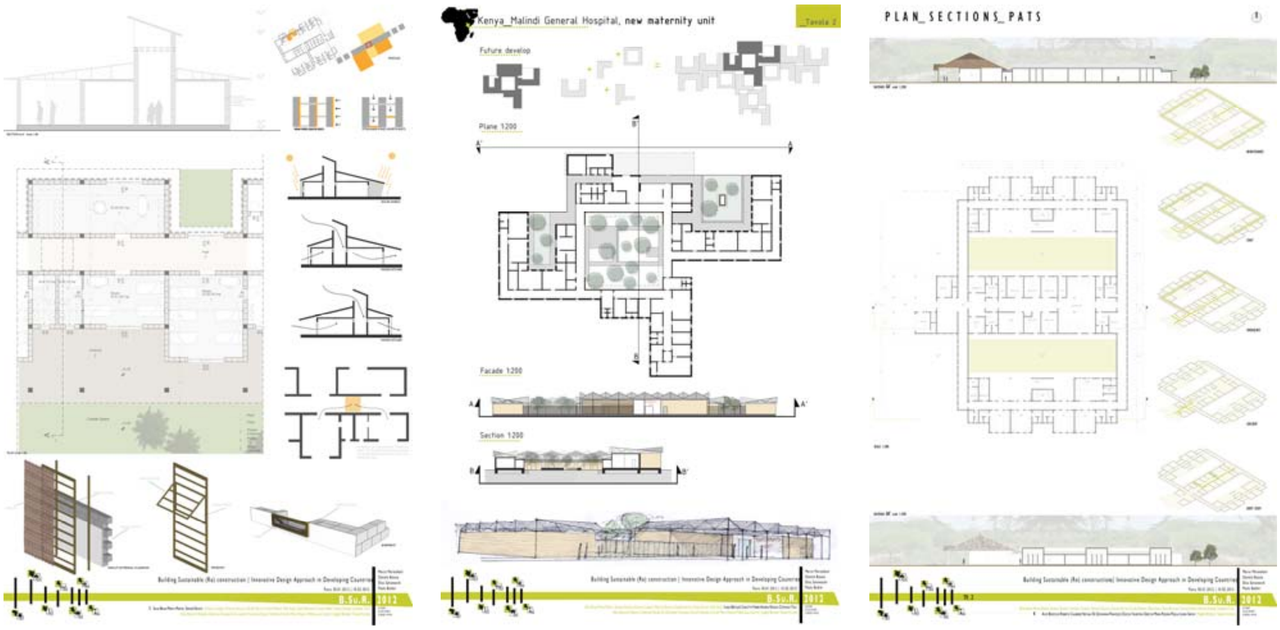


**Fig. 3** - Some of the design ideas for the maternity unit in Malindi.

All the developed designs have been analysed by means of a specific multilevel tool aimed to evaluate the internal coherence level of each solution in the following topics:

- building/environment adequacy
- morphological adequacy
- functional adequacy
- technological coherence
- health requirements fulfilment
- building coherence with local communities expectations

Design solutions have been illustrated to the local authorities and to the hospital management in March 2012. A joint discussion about the different ideas proposed was useful not only in order to verify the satisfaction for the efforts produced, but mainly to focus on some functional and technological issues in the perspective of a truly participated design approach.

**Modular and repeatable health units in extreme environments**

The second experience concerns the design of a medical dispensary in Kenya, about 70 km west of Malindi, in the direction of the Tzavo park. The project, still under development, started on a proposal from the Policlinico San Matteo of Pavia and the support of the Diocese of Pavia as a result of a specific request by the local diocese.

The project aims to give a response to the needs of Chakama community, living in a village consisting of about 2500 people. The isolation of this village from other settlements made as primary emergency the opportunity to start the construction of a small residential care to become a first aid and health care medical unit. The University of Pavia, through the Laboratory STEP (project team: Marco Morandotti, Daniela Besana, Francesco Maccarone), provided the technical support project for the construction of the dispensary. The main aim of the intervention was therefore to provide small rural dispensaries for local assistance and to address the most serious cases to neighbouring largest hospitals such as the Malindi General Hospital in Malindi.

The village of Chakama is located in a rural area about 70 km west from Malindi, without existing transportation infrastructure and the obvious difficulties of moving during the rainy season, when unpaved paths become impassable. Therefore, for Chakama and other nearby villages, the hospital in Malindi represents the nearest health service. ,For the geographical and climatic conditions mentioned above, it often becomes impossible to be reached, especially by sick people, because of the almost total absence of private transport and adequate infrastructure.

The health and welfare is certainly a major gap in the Kenyan socio-cultural context also due to the fact that in the last years urbanization is increasing in Kenya at a rapid peace. According to the Government of Kenya statistics, urban centres have increased from 15.1% (1979) to 34.8% of the total population in 2000. More than 70% of the urban population live in slums with limited access to water and sanitation, housing and social services and secure tenure (UN Habitat 2007). For example Kibera is the largest slum in Nairobi, with approximately 800,000 residents. It is clear that within these areas there is no control over living quality standards and also health care facilities.

This aspect is even more dangerous compared with the climatic situation of the Kenyan context and, in particular of neighbouring Malindi. There is a general decline of rainfall in the main rainfall season of March-May. Drought in the long rains season is more frequent and prolonged. On the other hand, there is a general positive trend (more rains) during September to February. This suggests that the "short rains" (October-December) season is extending into what is normally hot and dry period of January and February. This aspect caused another phenomenon that is the problem of desertification. Only 17% is arable while 83% consists of arid and semi-arid lands (ASAL). Due to climate change and other human factors, desertification, the extent of arid and semi-arid land, is increasing. It is clear that this aspect as the main cause it impossible to obtain food from the earth and, in general, all the agricultural products needed to sustain the population. It has been observed that the number of indigenous and important species has dwindled tremendously. The Kenyan coastline is characterized by 4600 hectares of land will be submerged area with a sea level rise of only 0.3 meters.

The water resources are unevenly distributed in both time and space. Climate change will worsen this already precarious situation as it affects the main hydrological components. Finally, serious droughts have occurred in the last four consecutive years. Major rivers show severe reduced volumes during droughts, and many seasonal ones completely dry up. Malaria, cholera, Ebola, Lyme disease, plague, tuberculosis, sleeping sickness, yellow fever, and rift valley fever are some of the diseases that are expected to spread as temperatures rise and precipitation patterns change.

As a result of knowledge of the social and climate context of the project, our first idea was primarily directed to respond to a primary need, the care as a human right. The starting point was therefore a structure that primarily responds to functional needs for the community but, at the same time, could be easily recognized by local communities and repeatable in the African land for a future network of health care in the area. It was therefore attempted to emphasize the sustainable approach, understood in its environmental, economic, social components and real technical and economic feasibility (Fig. 4).

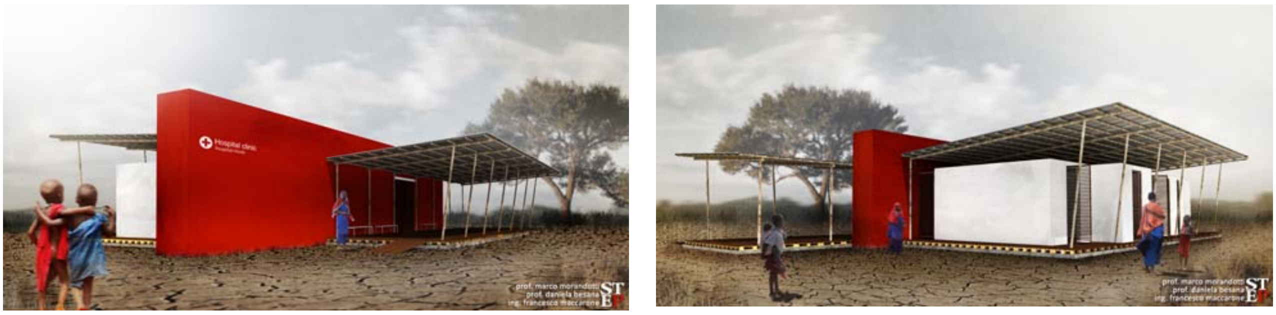

**Fig. 4** - General views of the dispensary and, in particular, the red vertical technical wall.

A vertical wall that becomes functionally the implant and technological plug of the entire structure characterizes the morphological layout of the dispensary. It allows dividing the space into two areas: one, more public, just covered by a roof, and the other, more private, reserved for health services. This functional distribution is simple and clear and easily recognizable.

The public space is paved, open but covered by a roof with sunscreen function. Functionally, this space allows the family members of patients to rest in a separate space from the health area and also acts as a waiting place for any patients who require treatment that, through a single entrance at the wall, can enter in the strictly medical area.

The dispensary medical wing consists of modular spaces dedicated to the care and is compatible with different building technologies, according to the final budget.

Once you have crossed the access from the front, there is a clinic for early medical evaluation and triage. Adjacent to it you can go directly to a medication room and first responders. The triage room also leads to a doctor's office and a room for the conservation and storage of medicines. The dispensary is finally equipped with a room and toilets for both doctors and for patients. Typologically the volumes containing the medical functions are standardized by a single over-wooden cover equipped with extruded eaves to limit overheating of the surfaces from solar radiation.

The dividing wall between the two spaces is therefore the plant technological element that lets the building make self-sufficient in the use and management. Into the wall thickness are thus content, as well as stores and warehouses, technical spaces such as tank for collecting rainwater, filter for water purification, the generator and the battery for the domestic hot water and the alternator and batteries for photovoltaic systems (Fig. 5).

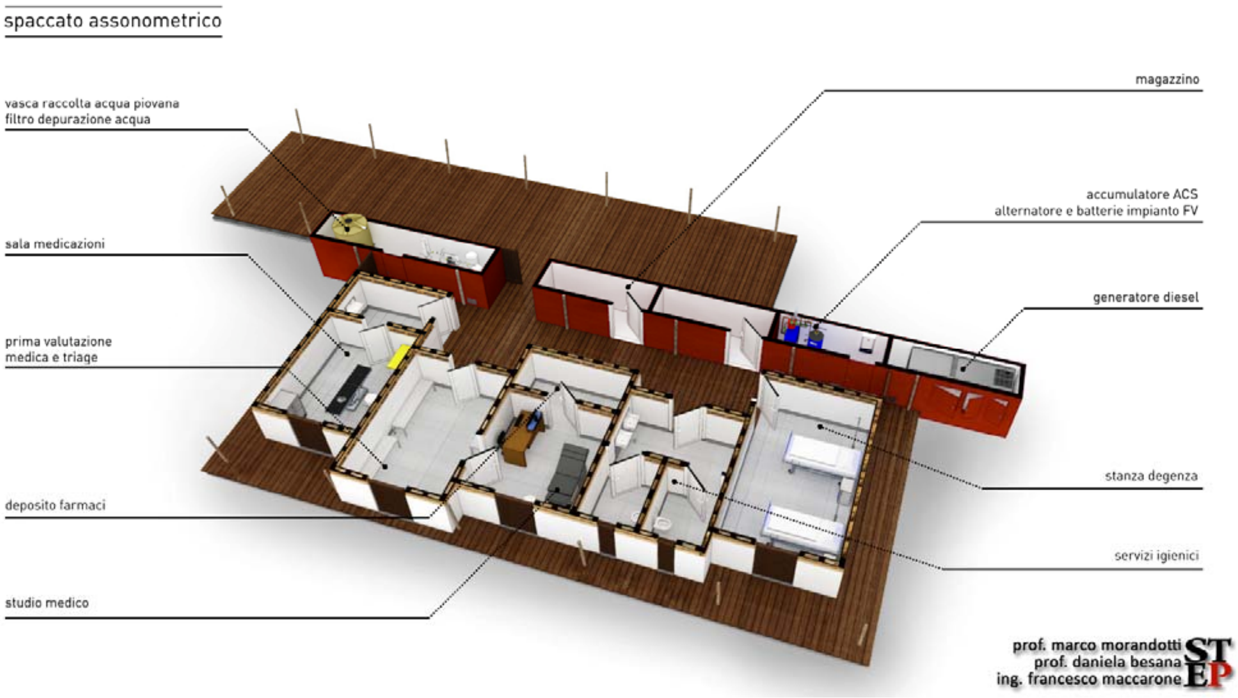


**Fig. 5** - Functional layout of the dispensary unit.

Designing the dispensary we tried to work on the theme of sustainability both for construction technology used and for the choice of materials.

The ability to use a simple technology without penalizing quality allows the project to be built with local resources and unskilled labour. If the project is conceived as easily accomplished even by the local community, immediately the choice is winner both for a future repeatability of the model realizing a health network spread in the territory and for the ability to provide the community with tools for building independence.

This principle is therefore based on the concept of self-construction in which users are involved in the project. The theme of self-construction presents a number of advantages: it promotes education in the local community and contributes to the work group identity, in which the sharing of effort and, at the same time, the enjoyment of the results obtained is a strong social cohesion. Also the fact of contributing to the building achievement through their own effort, facilitate the acceptance by the population of the final result, and therefore the actual use of the building. Last, but not least, the community acquires techniques and expertise in the work and can used them in the event of further construction needs.

Analogously this occurs also for building materials. Working with materials specific to the location means getting both easy availability and therefore minimum costs and also knowledge regarding using by labour. In fact using sophisticated technologies or imported materials would be senseless because they will increase the cost of construction and especially not make independent the population during the management and use of the building. The materials that are not known by the workers inevitably cause difficulty to the maintenance of the building and dependency of the community by skilled workers.

The project was conceived as a prototype of spatial and functional quality both if it is made with local materials and traditional building technologies but also with recycled materials, commonly discarded materials readily available without costs. The project was therefore designed both with modular proportions of the rooms to avoid getting waste materials and increasing costs and flexible for the choice of the functions and of construction technology.

Before choosing materials and technology, a research on materials commonly used and found in the territory of Malindi was carried out, as previously discussed.

In general, a concrete framework makes the most common structure typology while the vertical walls are realized with bricks made of coral blocks. Roofs are typically realized with the so-called “makuti” technique. This traditional technique presents a lot of problems linked with safety and maintenance: it must be renovate every five years; it is highly inflammable and in case of fire the temperature can exceed 800°.

Regarding the materials, in Kenya, concrete is the most common material used for construction. It is currently produced in three major factories for both the local and export market. Domestic prices have steadily increased over time. The current price is approximately 450 shillings (about 6 US$). The high cost of cement coupled with occasional shortages, high transport costs and its unavailability in some remote parts of the country has adversely affected the cost of many cement based building materials like concrete blocks, mass and reinforced concrete, slabs. It is also possible to find concrete blocks either factory or manually produced. They depend on cement and are therefore expensive. They are however the most commonly used walling material for residential properties within Nairobi. A study carried out in 1983 revealed that they were the most expensive input in construction contributing about 26% of the overall materials cost. Natural stone is a cheaper walling material as compared to concrete blocks. It is also commonly used especially in the outskirts of the city or main towns. Finally, the most common roofing materials are tiles and galvanized corrugated iron sheets. Tiles are either clay or concrete.

After this research, we tried to explore the use of recycled material, such as the traditional pallets used for commercial packaging as a building material. It has good properties regarding its behaviour in use and also some geometric characteristics of the joists and their distances very similar to frame structures such as balloon and platform frame. The birth of the pallet is of U.S. origin due to World War II, when Americans discovered that placing the goods on wooden platforms these were more easily transported and handled and they guaranteed protection from wet surfaces. In the 50’s in Europe a gradual standardization of wooden pallets EPAL and EUR (800x120mm) begun. In America, the most common is the pallet 40x48 inches (1000x1200mm). As a result of increasing industrial development in the 60s the pallet was stated as an instrument of international exchange of goods between industries in several states. In order to approve its international circulation, the European Community has introduced a legislation (Directive 2000/29 of 5 May 2000), which establishes protection treatments that must be applied during manufacturing, since the wood is a potential vehicle for harmful organisms to plants world. It has been made compulsory a preventive treatment, defined as "fumigation", through the use of chemical products based on methyl bromide, or alternatively HT treatment, consisting in a heat treatment in which the wood is treated in special cells called dryers, the two systems are equivalent, and both recognized as valid for the purposes of Directive ISPM 15 FAO in order to eliminate the parasites that can lead to severe damage to forests (Fig. 6).

Thus, the use of pallet would respond positively to a number of requirements searches in the dispensary project such as the concept of self-construction. Working with light elements and small dimensions means using a simple technology easily learnable by the local community and finally an easy construction phase. Contextually the realization of a structure dry assembled using only mechanical joints and riveted or bolted connections is very important in a context so devoid of water. It also responds positively to the requirements of components manoeuvrability thereby allowing the its handling by a single person and, therefore, making simplified the assembly operations. The requirement of construction durability is satisfied by the material itself because it is a prefabricated element that have already been subjected to treatments that guarantee an acceptable life cycle and controls to be placed on the market. The wooden material is so healthy because it does not emit harmful substances during the operating phase, does not constitute a danger to the health of users. Pallets are exported all over the world because they move with goods, therefore, substantially materials have no cost (if you need to buy them, they have an average price of 6/8 euro each).

After the knowledge of pallets characteristics, a search to find suitable references of architectures or installations produced with the pallet was carried out. A critical analysis showed that in all cases, the pallet has been used vertically as a curtain wall while the structural component was entrusted to a wooden frame due to the balloon frame. The structural function of the pallet was delegated only to its positioning in the horizontal. Aim of the research, endorsed also by other research such as a degree thesis developed by V. Marconcini, was to exploit the versatility of the pallet, but trying to use it in an upright position, verifying its bearing capacity.

In conclusion, the performance characteristics that have accompanied the design choices, still in the initial feasibility study, were mainly anchored to these themes:

- modularity of the structure and its components;
- future expandability in dimension;
- environmental, social and technical sustainable design;
- economic and constructive feasibility;
- architectural and linguistic identity;
- self-sufficient for its use and management;
- self-construction.

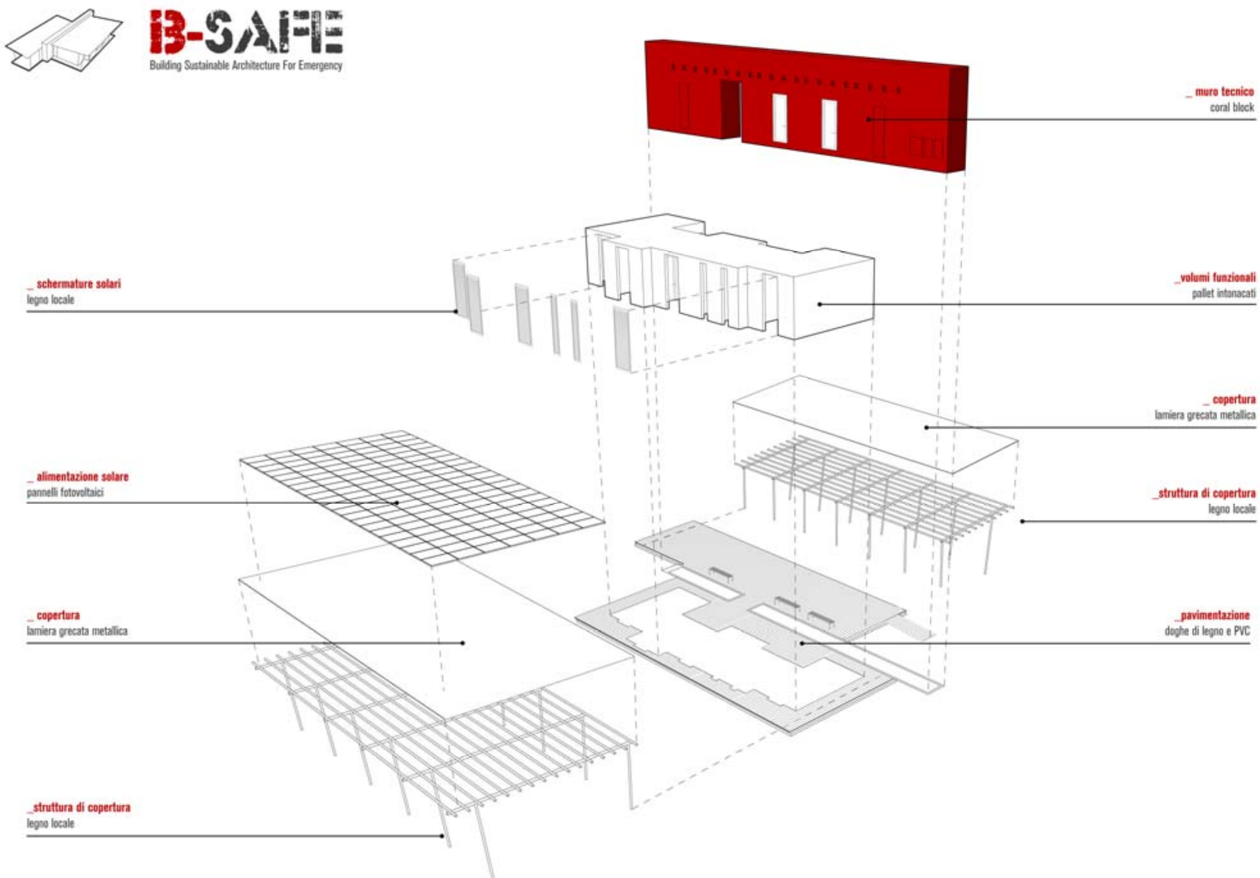


**Fig. 6** - Structural schemes showing use of dry construction assembled by pallets.

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# INTERNATIONAL UNIVERSITY COOPERATION FOR VALORIZING CRUDE EARTH AS BUILDING MATERIAL IN CHAD AND CAMEROON

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## ABSTRACT

Deforestation is one of the most dramatic threats to environmental equilibrium and food safety in many regions of the world, and particularly in sub-Saharan Africa. It is enhanced by many kinds of human activities, among which is the earth brick firing process, that needs large amounts of wood for attaining and maintaining temperatures required during this process. Crude earthen bricks can be used as an alternative for buildings, with environmental benefits; however, the economical and social sustainability of this building technique is linked to the improvement of the brick production technology, based on a deeper knowledge of the local resources. For this reason, a partnership was developed between an Italian University and a Cameroonian one for valorizing crude earth as building material in the Logone valley, located at the border between Chad and Cameroon: this way, the knowledge of the local context owned by the Cameroonian university was an added value to the technical skills of both universities, driving the choices made during the project. The Cameroonian university carried out mainly morphological and geotechnical analyses on soils, in order to choose the best site for brick production in the region; the Italian university designed and followed the realization of a machine for improving brick production. As a result, a pilot plant for crude earth brick production was installed.

## INTRODUCTION

Forests are a crucial factor in preserving the environment vitality and human life: they are the main mean of carbon storing and climate change protection, and preserve biodiversity; furthermore, in many regions forests are designated for soil and water conservation, avalanche control, sand dune stabilization, rain regularization, desertification control and coastal protection [1,2].

Although in the last decade the global deforestation rate has shown signs of decrease, in some regions, such as South America, Africa and Oceania, a net forestry loss was registered, with increasing rate with respect to the previous decade: this is also source of economical and social harms, such as lack of food and wood for domestic use as a consequence of soil deterioration and rain irregularity [1, 3-5].

In particular, since 1990 to 2010 the forest surface has decreased by about 12% in Chad and 18% in Cameroon, mainly due to wood exploitation as fuel, both for domestic and handicraft uses [1]: among these, the use as fuel for earth brick firing is an increasingly important part of the total wood exploitation [6,7]. Different techniques are used in African countries for fired brick production at handicraft level; however, in general they are very inefficient and fuel consuming [7].

Fired earth bricks are replacing the traditional crude earth as building material all over Africa; this trend is due to the fact that fired bricks are more resistant to deterioration by atmospheric agents (mainly rain), but also because crude earth is perceived as “poor” material, in contraposition to the modernity associated to fired earth [8]. However, there are many reasons for valorising the crude earth technology, among which the main is energy saving: producing 1 m³ of concrete consumes 1.0-1.8 MJ, whereas the same volume of raw earth for building uses only 1% of this quantity of energy [9]. Other benefits of the crude earth technology are: absence of carbon emissions, reduction of environmental impact related to building waste, low cost, raw material availability, richness and variety of the traditional knowledge about this construction technique. However, in order to obtain competitiveness of crude earth as building material, some innovations are necessary for obtaining a good product in terms of durability and reliability, aesthetics and cost.

In this context, a partnership between European and African researchers was established, within the ambit of the VALRENA[1] European project. This project had the aim of promoting the sustainable exploitation of natural resources in the Logone valley, along the frontier between Chad and Cameroon; among the different activities planned in the project, there was the promotion of crude earth as building material, to be achieved by introducing an innovative production technology and setting up a pilot plant.

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[1] « Applied research for natural resources valorization and transformation in a process of fight against poverty in Chad and Cameroon »; subvention: FED/2009/217079; project website: www.valrena.org.

In particular, as the activity on earthen bricks was concerned, the collaborating partners were the following:

- the Italian NGO ACRA, an organization for rural cooperation in Africa and Latin America;
- the University of Ngaoundéré (Cameroun), in particular the Department of Earth Sciences;
- the University of Brescia (Italy), in particular the Research Centre on Appropriate Technologies for Environmental Management in Developing Countries (CeTAmb), and the Department of Mechanical and Industrial Engineering.

Each partner had a specific role, according to his competence: ACRA was in charge of the local and international coordination and logistics; the University of Ngaoundéré was in charge of the soils analysis and choice of the pilot plant site; the University of Brescia was in charge of the environmental analysis and machinery design. In this paper the main phases of the project implementation and the obtained results are described, with a particular emphasis on the role of each partner. First, a survey on housing and building techniques in use in the Logone valley was carried out, in order to identify features, problems and possibility of improvement in the field of the handicraft earth brick production. Subsequently, an analysis of the morphological and geotechnical characteristics of the local soils was carried out, finalized to evaluate their suitability to brick production and identify the best locations for earth extraction. Then, a new extrusion press for improving crude earth brick production was designed and tested, taking into account the local market features emerged from the survey; the extruded bricks were tested and compared to the local traditional ones. Finally, the new machine was reproduced in a workshop in Cameroon and loaned to a local brick producer, verifying the economical and environmental sustainability.

## SURVEY ON HOUSING AND BUILDING TECHNIQUES IN THE LOGONE VALLEY

The Logone valley (Figure 1) is located across the border between Chad and Cameroon, and is characterized by tropical climate, with seasonal rains and savannah – grassland landscape. The main cities in the region are the capital N'Djamena, Bongor and Mondou on the Chadian side; Yagoua, Maroua, Garoua and Ngaoundéré on the Cameroonian side. In March 2011 and subsequently in March 2012 two surveys were carried out in the region in order to obtain data about local needs related to house building. The surveys were carried out by students and researchers of the Brescia University, in strict coordination with the local staff of ACRA. Several crude and fired brick production sites were found in the region, both at household and handicraft level. Crude bricks are used especially for building houses in rural villages (Figure 2). The production is conditioned by the rainy season, when many crude earth houses are damaged because of a twofold action: the walls are eroded by the impacting drops, and the bottom part of the walls is weakened by the water absorbed from the ground because of flooding. Each year, at the end of the rains, new bricks are purchased at city markets for substituting the damaged ones; somebody makes bricks manually for his own necessity, especially in case of lack of funds.

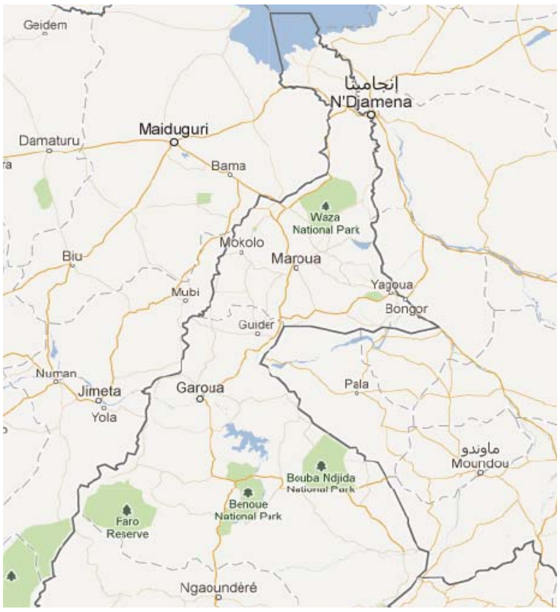


**Fig. 1** - The Logone valley region.

**Fig. 2** - House in crude earthen bricks in the Logone valley.

**Fig. 3** - Manual brick forming.

**Fig. 4** - Typical scove brick kiln.

Several manufacturers of fired and crude bricks were visited during the missions, in the regions of N'Djamena, Bongor, Maroua and Yagoua. A single enterprise was also contacted in Maroua producing non fired bricks in sand with about 5-10% cement. Some information about the practice of brick making in the region was collected by means of interviews to local producers, with the aim of depicting the state-of-the-art and understanding the context where the project had to be developed.

In general, the first phase of earth bricks production process does not differ for fired and crude ones: a dough of clay, sand and water, with the addition of vegetable fibres and/or animal dejections is prepared. The percentages of the different components vary according to local soil characteristics, materials availability, manufacturer experience and financial resources. The components are usually mixed on the ground by a shovel, adding water gradually, until sufficient homogeneity is reached; subsequently, the dough is covered by a waterproof plastic film and left for a couple of days, in order to allow uniform water penetration. After that, the dough is formed through wooden moulds giving the typical brick shape, and exposed to sun drying for 3 days (Figure 3). The brick dimension is also a varying parameter, with thickness ranging from 7.5 to 10 cm, width from 15 to 20 cm, length from 30 to 40 cm. After drying, they are ready to use as crude bricks; in case of firing, they are stacked in a typical scove kiln structure (Figure 4), with channels in the bottom region to be filled by solid fuel; other fuel is also put in the gaps between the bricks in the interior stack part, whilst in the exterior part the gaps are filled by dough in order to reduce heat dispersion. The solid fuel is also wetted by liquid fuel (petrol or gasoline) in order to facilitate ignition. Once the fuel is fired up, the combustion is kept for 3 days, with periodical fuel refilling. The production rate varies from 160 to 250 bricks per day, with 3-4 employees.

As production cost and selling price are concerned, different data were found according to the location and brick typology: the selling price of crude bricks ranged from 25 XAF [2] (0,04 EUR) per item in Maroua (CM) to 40 XAF (0,06 EUR) per item in N'Djamena (TD); the fired brick price ranged from 60 XAF (0,09 EUR) per item in Bongor (TD) to 150 XAF (0,23 EUR) in Yagoua (CM); the sand-cement brick price was 175 XAF (0,27 EUR) per item in Maroua. The fuel cost in the production process varied from about 2 XAF (0,003 EUR) per item in the Cameroonian cities up to 17 XAF (0,025 EUR) per item in the Chad capital N'Djamena: this is also due to the fact that in Chad the charcoal production and commerce is forbidden since 2009, and consequently the price of other fuels rose up. In all cases of fired bricks production, the wood cost is most of the total fuel cost (50-80%); other fuels used to integrate the combustion are local tree nuts, animal dejections, petrol and (only in Cameroun) charcoal. The wood consumption of the stove kiln was estimated; the details of the estimation procedure are given in [10]: the result was that the environmental cost of a mean 4 rooms house of 65 $m^2$ is about 11 $m^3$ of round-wood forest per house.

These data showed that the crude bricks market should have many chances of expansion, both for economical and environmental reasons, provided that the problems of aesthetics and structural stability are solved. A way for improving the crude brick quality is mechanizing the production process, as the machines can give adequate compaction and regular shape to the bricks; furthermore, binding agents (typically cement or lime) can be added to the dough in order to improve their resistance to water.

An inquiry was also carried out about previous projects aimed at promoting mechanized crude brick production, based on manual presses for brick forming and compacting, with dough containing cement in percentage ranging from 6% to 12%. These projects resulted not economically sustainable, because the production and the number of employees were similar to the case of the traditional procedure, but with higher costs due to the use of cement and to the initial investment for machine purchasing, not adequately compensated by brick quality increment.

## ANALYSIS OF THE LOGONE VALLEY SOILS

The activity of soil analysis in the Logone valley was leaded by the University of Ngaoundéré, involving students and researchers that extracted 32 soil samples from different clay deposits located on both sides of the Logone valley.

[2] Central Africa CFA Franc; 1 EUR = 655.96 XAF.

They used a Highway auger of 500 mm diameter, up to 6 meters in depth for extracting samples, that were used for morphological and geotechnical characterization of the soils.

**Morphological characterization**

In general, the tested clay materials were gathered into four main groups [11,12], based on their appearance:

1. clay materials from vertisols: these soils are located at stream edges in small alluvial ridges depressions (Grand Tougoudé), in the north of the Bongor plain near major flows of flood waters of the Logone, and in the south of Yagoua (Datchéka).They have a depth range of about 3 to 6 m above the water table and are characterized by dark colour, clayey texture, massive structure, deep open superficial desiccation cracks and micro-reliefs (gilgaï);
2. clay materials from gley with vertisolic character: this group of soils has been divided into two subgroups: soils with superficial gley characters and typical gley. Soils with superficial gley characters constitute a term of transition between vertisols and typical gley. They are mosaics of soil settling ponds, channels and distributaries in sandy clay materials. They were observed in the north of Pouss, in Guirvidig, in Miogoye Bla, in Tikem, in Kalfou and Lokoro etc.. Typical gley covers an extensive surface area of the Logone valley, notably the lowest part of the floodplain. They are formed from alluvial clays settled in place by the floods of the Logone River and its tributaries. They were observed in Maga, Vélé, Dourang, Binga, Kim etc.;
3. clay materials from pseudogley and gley: they occupy the upper part of the floodplain, and are formed by alluvial clay or sandy clayey materials. They were observed in Bongor and Nahaïna;
4. clay materials from pseudogley: they are present in the upper part of the sequence of clay materials in the valley, and vary from sandy clayey to clay loam deposits. They were observed in Manga, Bongor and Gounou-Gaya.

Globally, the soils of Logone valley are characterized by three main horizons of clay materials: top surface horizons, which are dark grey to brown-grey, sandy clayey to clayey, prismatic and plastic when wet; subsurface horizons, which are grey to yellow-brown, clayey to sandy clayey, plastic, prismatic with presence of slickenside; and deep yellow-brown horizons, sandy clay, massive, somewhat plastic. Samples of soils were collected in different horizons of each representative soil profile for laboratory analyses.

**Geotechnical characterization**

Geotechnical analyses were performed in the laboratory of the Local Materials Promotion Authority (MIPROMALO) in Garoua (Cameroon), in order to determine the behaviour of clay materials. These analyses included in particular the measurement of Atterberg plastic and liquid limits $W_p$ and $W_l$, i.e. the water content $W$ determining the transition respectively from semi-solid to plastic behaviour, and from plastic to liquid behaviour. These limits were determined respectively by the roller method and the Casagrande liquid limit device; subsequently, the plastic index $I_p$ was obtained as difference between liquid and plastic limit ($I_p = W_l - W_p$). The testing method complied the ASTM standard for this kind of analyses [13].

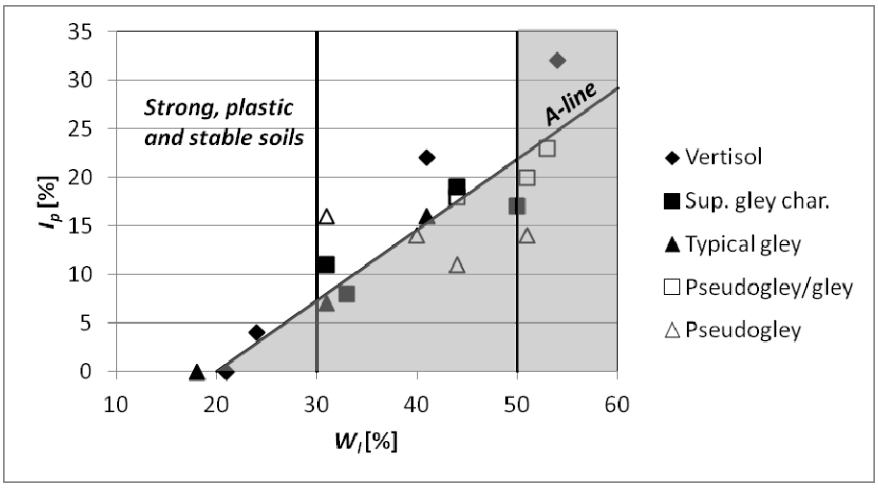


**Fig. 5** - Casagrande chart of the soils of the Logone valley.

In [10] the detailed results are given; here the Casagrande chart [14], which summarizes the results by characterizing the different soils depending on $W$ and $I_p$ is shown (Figure 5): the area standing above the inclined line (identified as “A-line”) and with $W_l < 50\%$ identifies the best soils for brick making, because of high strength at dry state, high plasticity and low dilatancy at wet state. Vertisols and soils with superficial gley characters result in general the best within the analyzed soils: therefore, the region between Yagoua (Cameroon) and Bongor (Chad), where these soils are prevalent, seemed the most appropriate for setting a plant of brick production.

## STUDY OF AN APPROPRIATE TECHNOLOGY FOR BRICKS PRODUCTION

A new press for earthen dough extrusion was designed and prototyped at the University of Brescia [10]. Brick production by extrusion is a continuous process, allowing simultaneous dough feeding, brick compaction and brick removal, without the stops required by block pressing machines; this allows a more efficient and speedy production process, with the same number of employees. The dough has to be inserted manually into the machine; subsequently it is extruded by a piston mechanism, and the extruded matter is cut and removed manually. The piston mechanism is studied in such a way to facilitate dough insertion and brick removal. The machine design was conceived in such a way that the fabrication of most components does not require machining tools with numeric control, so that they can be produced in handicraft workshops of developing countries.

A prototype of the machine was first realized at the University of Brescia, producing bricks of 5 cm in thickness and 10 cm in width, running at about 15 piston cycles per minute, a sustainable speed for feeding and brick removing. The prototype was equipped by electronic instrumentation (inverter, load cell, computer control) in order to measure some running parameters, such as the instantaneous piston velocity, the compression force on the dough, and the consumed energy. Preliminary tests were carried out with non stabilized dough and with the addition of cement as stabilizer, with extrusion pressure ranging from 2 to 8.7 bars, i.e. up to more than 4 times the declared maximum pressure of manual presses: the measured electrical energy consumption for one $m^3$ of bricks ranged from 80 to 250 $kJ/m^3$, and a production of 2-3 bricks per minute was obtained.

The quality of the bricks in terms of structural strength and resistance to water action was tested (see [10] for details).

The structural strength was evaluated by means of compression tests, carried out directly on the extruded bricks. Different specimens were tested: extruded non stabilized bricks, obtained with different pressures on the wet dough, after two weeks drying; stabilized bricks extruded at 8.7 bar, after 28 days drying; fired bricks coming from N'Djamena (Chad).

The following main indications can be obtained by these data:

- the compression strength is higher than the minimum recommended value of 1.7 $N/mm^2$ [15] for all extruded bricks at pressure exceeding 4 bar; bricks extruded at 2 bar are very close to the minimum required;
- fired bricks in general have lower strength than extruded ones, and do not always satisfy the minimum requirement;
- the effect of the extrusion pressure is determinant up to 4 $N/mm^2$; further pressure increments have a limited effect on the brick strength;
- the effect of cement is not determinant.

As the water effect is concerned, two different aspects were considered: the erosion due to raindrops impacting on the walls, and the water absorption from the ground in event of flooding. Erosion was evaluated by means of two kinds of tests, aimed at simulate both beating and moderate rain. The water absorption from the ground was evaluated by means of immersion.

The indications useful for the practice obtained by these results were that extruded non stabilized bricks have good compression strength, as well as an acceptable resistance to rain erosion; on the contrary, their real weakness is the low resistance to water absorption. Therefore, stabilized bricks can be used for building the house parts more exposed to water absorption from the soil, i.e. the floor and the bottom part of walls; non stabilized bricks are suitable for the top part of the walls, which usually is partially protected by the roof.

### Implementation in Cameroon

After the prototype experimentation, the machine was replicated in Cameroon, by the technical and industrial school "Centre Technique de Maroua" (CTM), where workshops equipped by carpentry and machining tools, without numerical control, are present. The construction of the machine was carried out under the supervision of a student of the University of Brescia, who had followed the machine conception. Some changes in the design were introduced: the extruder section was increased up to 10x15 cm, in order to meet the local consuetude, and consequently also the piston diameter was increased; further minor modifications were necessary for fitting materials, components and semis available in situ. All the machine components were manufactured at the CTM, except the electric motor, the gearbox and the control cabinet that were imported from Italy, mainly for logistic and timing requirements rather than for unavailability on site. The final appearance of the machine is shown in Figure 6. Preliminary machine running and brick quality tests were carried out, obtaining results comparable to the ones of the laboratory tests made in Italy.

**Fig. 6** - Earthen brick machine constructed in Cameroon.

The machine was loaned to a local producer in the city of Yagoua (Cameroon), chosen because of his experience in fired brick production, for which he had already invested in technical and logistic facilities. He also provided information about transport, manpower and energy cost; his annual production is presently of 12.500 bricks, but this datum is constantly increasing since many years. He quantified in 150 XAF (0,23 EUR) per item the price of his fired bricks.

An approximated simulation of the management of this pilot plant, after conversion from fired to crude bricks production, was carried out (see [10] for details). The initial investment, energy, manpower and transport costs were taken into account; two different scenarios were considered, i.e. production of stabilized and non-stabilized bricks, with adequate contribution margins (30% of the unit cost for stabilized bricks, 15% for non-stabilized bricks). Figure 7 shows the cash flow in the two scenarios, supposing that all the produced bricks are sold: a payback period between 3.5 and 7 years is predicted, depending on the scenario.

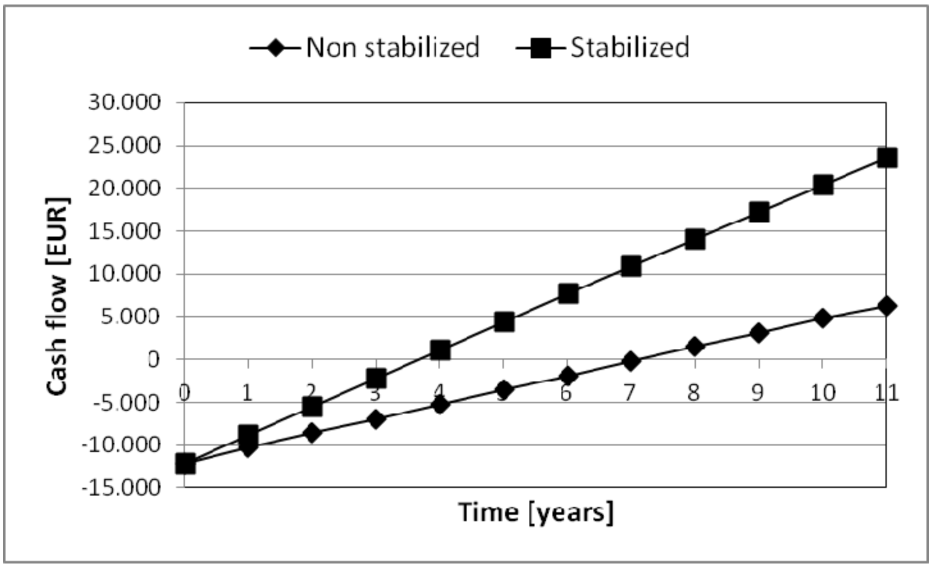


**Fig. 7** - Cash flow in the simulation of stabilized and non-stabilized earthen bricks.

An evaluation of the Greenhouse Gas (GHG) emission and energy saving due to conversion of fired to crude bricks production was also carried out. As fired bricks are concerned, GHG emissions and energy consumption are due only to brick firing; as crude bricks are concerned, thermal energy consumption and GHG emissions are connected with the production of electric energy and, in case of stabilized bricks, of cement.

Table 1 compares the annual energy consumption and GHG emission related to crude bricks production (both stabilized and non-stabilized) with the same parameters if the same quantity of fired bricks were produced: for both parameters, a saving higher than 99% is obtained with non-stabilized bricks production, and higher than 90% with stabilized bricks.

**Tab. 1** - Energy consumption and GHG emission in fired and crude brick production.

| **Scenario** | **Annual production [metric tons]** | **Thermal energy consumption [MJ]** | **GHG emission [kg $CO_2$]** |
|---|---|---|---|
| Non-stabilized crude | 1356.5 | 15565.6 | 1255.2 |
| Stabilized crude | 1356.5 | 369796.7 | 33390.0 |
| Fired | 1356.5 | 3737102.4 | 363401.0 |

## CONCLUSIONS

A partnership between Italian and Cameroonian entities was built for facing the problem of excessive wood consumption for earthen brick firing in the Loagone valley, in Chad and Cameroon. In particular, actions aimed at promoting crude earthen bricks production were made, with different roles of the partners according to their competence.

A survey of the handicraft fired brick production technology diffused in the Logone valley was carried out by the Brescia University, with the support of local staff of the NGO ACRA; the survey was particularly focused on the environmental impact in terms of greenhouse gas emissions and wood-fuel consumption.

The University of Ngaoundéré carried out a morphological and geotechnical characterization of local soils in order to evaluate their suitability to brick production and individuate the best earth fields.

Subsequently, a new machine for brick extrusion was designed and realized in a workshop in Cameroon under the supervision of the Brescia University, optimizing its conception to the technological resources available in situ. Laboratory tests on bricks made by the new machine were carried out, showing that extruded crude bricks have good properties in relation to fired bricks in use in the Logone valley.

Economical and environmental impact analyses allowed predicting a good performance of the machine within ten years, in terms of pay-back period, energy and greenhouse gas emission saving.

## ACKNOWLEDGMENT

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## NOMENCLATURE

| | |
|---|---|
| ACP | African, Caribbean and Pacific group of states |
| ACRA | Cooperazione Rurale in Africa e America Latina |
| ASTM | American Society for Testing and Materials |
| CeTAmb | Centro di documentazione e ricerca sulle tecnologie appropriate per la gestione dell’ambiente nei Paesi in via di sviluppo |
| CTM | Centre Technique de Maroua |
| EUR | European currency |
| GHG | Greenhouse Gas |
| MIPROMALO | Local Materials Promotion Authority |
| NGO | Non governmental organization |
| XAF | Currency of the Central Africa Franc |
| VALRENA | Valorisation et transformation des ressources naturelles |

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# ENHANCING ENERGY ACCESS FOR THE POOR: THE ROLE OF APPROPRIATE TECHNOLOGIES IN THE USE OF TRADITIONAL SOLID FUELS

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**ABSTRACT**

The use of traditional solid fuels leads to a number of dramatic impacts not only on the users but also for the environment. Often national household energy policies do not have the capacity to effectively target an adequate diffused energy access, chasing the hope to switch to more modern and clean fuels, like LPG, and missing meeting the financial capacities and the needs of the population. Thus, especially for the weakest income classes, energy poverty seems to be a no-way-out situation. Appropriate technologies play a key role in breaking this vicious circle, providing with the intermediate solutions to escape from this limiting condition. Actually there are many technology options to use traditional fuels more efficiently. The suitability of the existing improved technologies depends on factors such as availability, applicability, acceptability and affordability, including access to finance to cover initial investments. The adoption of improved technologies, which allow using even poor fuels, but in a convenient, cleaner and more efficient manner, appears to be a viable way to walk to reach the goal of minimum energy access for the poor.

The approach adopted in this work is strongly influenced by the above considerations. A specific context, the Logone Valley at the border between Chad and Cameroun, was the one were field observations and activities were implemented. The introduction of improved stove models were studied in order to provide the local population with alternative fuel stove to cover their daily energy needs. Not only technical aspects such as the material availability or the local artisan skills were considered, but also aspects such as the adaptability to local cooking practices, the sustainability and the acceptance by users were addressed.

## INTRODUCTION

Energy is one of the basic requirements of human societies. It is vital for human life and for technological advancement. In general energy can contribute to widening opportunities and empowering people to exercise choices. Energy poverty is related to the absence of sufficient choice in accessing adequate, affordable, high-quality, safe and environmentally benign energy services to support economic and human development [1]. Without access to efficient and affordable energy sources, people living in poor conditions have very limited opportunities for economic and social advancement. The International Energy Agency (IEA) [2] estimates that 1.3 billion people – over 19% of the global population – lack access to electricity and about 2.7 billion people – some 40% of the global population – rely on the traditional use of solid biomass for cooking. This number is higher than previously estimated in 2008 by IEA due to population growth, rising liquid fuel costs and the global economic recession, which have driven a number of people back to using traditional solid biomass.

The use of traditional solid fuels leads to a number of dramatic impacts not only on the users but also for the environment. In order to gather the fuel required for their daily energy needs, householders have to cover every day longer distances (carrying heavy loads) or invest a significant share of their budget to purchase it in the local market. Besides wasting a resource (for which a lot of drudgery or money were spent), the use of solid fuels on open fires or inefficient stoves results in a range of health-damaging pollutant emissions, often under conditions of poor household ventilation [3]. Women and young children, who usually spend many hours close to the smoky source, are the most exposed. Such emissions have also significant global warming effects, due to incomplete combustion of fuel carbon. Moreover, the unsustainable overexploitation of natural resources leads to their faster depletion. Often (where existing) national household energy policies and strategies do not have the capacity to effectively target an adequate diffused energy access, chasing the hope to switch to more modern and clean fuels, like LPG, and missing meeting the financial capacities and the needs of the population. Thus, especially for the weakest income classes, energy poverty seems to be a no-way-out situation: by the one side they have no financial means to step up their own energy condition, accessing the use of more convenient, cleaner and modern fuels; by the other side, the limited energy level provides them with no emancipation means, both to improve their quality of life and to eventually start a small income generating activity.

Appropriate technologies play a key role in breaking this vicious circle, providing with the intermediate solutions to escape from this limiting condition. Actually there are many technology options to use traditional fuels more efficiently. The suitability of the existing improved technologies depends on factors such as availability, applicability, acceptability and affordability, including access to finance to cover initial investments. The decreasing availability of existing sources of fuel makes switching to modern alternatives a necessity in some places. In some others, the inconsistence of a market not supported by realistic political energy strategies makes unaffordable for most of the people gaining access to more appropriate fuels, getting back to traditional cheaper fuels. According to these aspects, and to the estimated increasing number of people relying on biomass for cooking purposes in the next future, the adoption of improved technologies, which allow to use even poor fuels, but in a convenient, cleaner and more efficient manner, appears to be a viable way to walk to reach the goal of minimum energy access for the poor.

The implementation of appropriate cooking technologies in contexts with limited resources is strictly required in order to give a practical and sustainable response for this issue. In particular this work focuses on a specific region, the Logone Valley at the border between Chad and Cameroun. The research was carried out within the activities of an international development cooperation project (ENV/2006/114-747) implemented by the Italian NGO ACRA and funded by the European Community. Given the local background and the relative constraints, the challenge was to find the appropriate solutions, under a technical point of view, for the reduction of wood consumption. The main part of the project focused on the protection of natural resources, in particular through the creation of community-based committees for the protection of the local forests. Among the project activities, one addressed the decrease of the consumption of the main household fuel, charcoal, which was produced locally from very low efficient carbonization processes. The research, subject of this work, was developed in parallel with the project activities in order to identify a pool of appropriate energy technologies to target the objective of fuel use reduction at household level. The challenging research question that drove this work is: “Which cooking technology is appropriate for household energy access in the Logone Valley?” This work looked by the one side to the most recent findings and interests of the international research community, trying to the other side to conjugate them in the most appropriate way with the local constraints given by the peculiarity of the implementation context. Both technology and impact related aspects were taken into account in order to give an overall assessment of the cooking technologies studied.

## STUDY AREA

A specific context, the Logone Valley at the border between Chad and Cameroun, was the one where field observations and activities were implemented. The research leans on the activities of an international development cooperation project (ENV/2006/114-747) implemented by the Italian NGO ACRA and funded by the EU. At the beginning of the project (2008), in the intervention region charcoal and wood were the traditional fuels for household energy supply. Only in urban areas some high income families used to cook with LPG gas. Charcoal production and sale have been forbidden by the Chadian national government since 2009. This had a shocking effect on local wood prices that more than doubled, from 15 CFA francs /kg in 2008 to 35 CFA francs /kg in 2010. The project aimed at the reduction of wood consumption at household level. The dissemination of low-technology but high-efficiency models was implemented according to the socio-economic conditions of the local people (minimal investment capacity due to the very low level of income) and of the skills and the tools available for small local workshops (in particular the lack of electricity impacting in basic manufacturing capabilities).

## MATERIALS AND METHODS

A number of activities on the field were implemented to gain knowledge about the cooking energy issue in the local context. Among the social research qualitative methods in this research the followings were applied:

- observation of the target groups, villages and project interventions through local field staff was used in order to gain a first impression of energy patterns. Even though not as accurate and representative as structured surveys, observations can be especially useful for preparing further scientific research (e.g. questionnaires) by providing site-specific knowledge [4].
- Focus Group Discussions allowing interviewers to study people in a more natural setting than in a one-to-one interview [4]. This method was used during the workshops organized for local artisans in the production of some models of improved stove to assess their opinions by talking to various people at once in a less forced environment.

Quantitative approaches are concerned to quantify social phenomena by collecting and analysing numerical data in a statistical reliable and valid manner.

- Semi-structured interviews were used in quantitative surveys to obtain comparable information representative for the total target group. Standard questionnaires (IEA, WHO) were adapted to fit objectives of surveys implemented on relevant assessment fields. Random samples were chosen among the population living in the intervention area. Questions were structured in order to avoid bias due to undesired effects on the respondents such as social-desirability (people tend to answer not according to their own opinion but according to social norms or what the respondent thinks would be the desired answer for the interviewer) and revised after some pilot tests.

Besides information that need to be gathered from interviews or observations, data on particular indicators were provided from local databases, statistics and registers.

**Stove testing**

Over the last thirty years there have been many attempts to develop improved stoves, but often they failed due to lacks in quality and performance control. The technical performance of stoves is tested according to internationally agreed test procedures related to energy efficiency, emission control and safe use. Historically the main focus of the performance of an energy system is given to its efficiency, an indicator that expresses the ratio of energy useful to achieve a specific task on the total energy consumed. Thus, such a parameter is too narrow to describe the effectiveness of a stove, as a number of factors beyond the stove design takes influence in similar conditions, like the quality and characteristics of the fuel, the handling of the fuel, the handling of the stove, the management of the cooking process, the environment of cooking.

With focus on relative performances of stoves, the assessment of stove efficiency is circumstantial. A clay stove is perceived as an efficient stove in households with open fire places and as an inefficient stove in households that are using an advanced improved stove. International standards on stove quality have been discussed for many years. While they are desirable to enable a global comparison of stove performances, there is a danger that cheap solutions for the very poor households are abandoned due to their low performance in relation to the global standards, when in fact they could still be a relevant improvement in comparison to the baseline situation of the poorest of the poor. That’s why a stratification of quality standards has been developed in the “Lima consensus” reached during the 2011 Forum of the Partnership for Clean Indoor Air. The consensus reached among major stakeholders in standards and testing resolved to adopt a temporary rating system of stove technologies in tiers of performance in the areas of fuel efficiency, indoor air quality, emissions of PM and CO, and safety. Each area has to be ranked separately, reflecting a sequence of evolution from Tier 0 for ‘typical unimproved’ to Tier 3 ‘to achieve significant, measurable high goals’. The new protocol should also evaluate particulate composition including black carbon, address batch-feeding stoves that are not well captured by the current protocols.

*Water Boiling Test (WBT)*

This laboratory-based test is designed to explore the most basic aspects of stove performance in a controlled environment [5]. A prescribed amount of water is brought to the boil and kept simmering for a given period of time, while the fuel consumption (and recently also the emissions) is measured. As it is a short test, and the results are not highly variable, relatively few tests can give informative and quick feedback. The WBT is a useful tool in the process of stove development or when comparing very different stoves. It allows to accurately spotting the effect of small changes in stove design, fuel quality or other physical variables. It can also be used in field tests to determine whether stoves have been built to match their design criteria on cooking time, fuel use and emissions. It does not reflect field performance because the way typical local dishes are prepared can be very different from just boiling water. Currently revisions of the test protocols are being discussed, but no new protocol has yet been accepted [6].

*Controlled Cooking Test (CCT)*

Like the Water Boiling Test, the Controlled Cooking Test measures the fuel consumption of a stove for a specific standardized cooking task typical for a certain region [7]. The CCT can be done either in a laboratory-environment or in the kitchen of a real user while the regular user operates the stove and the tester observes and records all the influencing parameters. The duration of the CCT is determined by the chosen typical cooking task. As well as being closer to day-to-day life, it allows the stove properties to be measured in a reproducible way by minimizing the influence of other factors.

*Kitchen performance test (KPT)*

The Kitchen Performance Test is an entirely field-based procedure that evaluates the effect of stove interventions in real-world conditions: the KPT is carried out over several days in the users’ households[8]. Fewer parameters are controllable as the tester is not present all the time during the test. It includes quantitative surveys of fuel consumption of the participating household and qualitative surveys of stove performance and acceptability. The KPT is more time-consuming, thus more expensive; however, it is the best way to monitor the stove’s real impact on fuel use and cooking behaviour in the participating households. The KPT is increasingly important for projects that want to register for the voluntary carbon market to prove the actual fuel savings realized by the users in their day-to-day cooking [9].

*Monitoring of impacts and assessment of the appropriateness*

For a "proper" impact assessment it is recommended the use of a shared list of indicators, the conduction of baseline studies before project intervention and impact studies after households got access to a form of modern energy, the use of a theory based approach by applying the result chain for developing the study design, the use of a mixed methods approach. The inclusion of control groups if possible (households which do not have access to modern energy) into the baseline and impact study In particular the use of mixed methods allows looking at things from multiple points of view (Mikkelsen 2005) capturing different effects of one intervention, assessing in multiple ways the complexity of a system, strengthening the results if these converge, limiting the bias. Quantitative impact evaluation done in experimental or quasi-experimental way is preferable to qualitative assessment.

Impact assessment in different phases of an intervention allows to monitor and to compare the results of the activities with the baseline. These include: income generation from stove production, women engaged in new activities, time and expenses saved, perceived reductions in the levels of indoor air pollution and reduction in the number of accidents. To collect empirical data on the impacts of energy projects, a wide range of methods and approaches is available. These may differ significantly in terms of time, money and expertise needed for implementation (Baker 2000).

Results Based Monitoring (RBM) is an international monitoring standard designed to monitor development results applied regularly to GIZ programmes. Results are defined as development changes that follow directly from an intervention; they can be outputs, outcomes or impacts resulting from a development intervention. RBM is a method to examine the result hypotheses in an empirical and systematic way. The two key results are usually considered to be stoves sales and correct stoves use, since all further outcomes and impacts depend on stoves on the market and their correct use. The stove effects strongly depend on the capacity of the user to achieve maximum reduction of fuel use and emissions. An interesting case is the Participatory Impact Assessment applied by ProBEC (Programme for Biomass Energy Conservation) in selected Sub-Saharan African countries, where local stove artisans conducted impact assessment interviews. This approach to impact assessment requires high involvement by the producers and creates business awareness. The results of an assessment by the manufacturers inevitably cannot be considered neutral.

The data from impact assessment can provide the starting point for an economic evaluation of the project, including a Cost-Benefit-Analysis (CBA) and a Cost-Effectiveness Analysis (CEA). Analyzing both the economic efficiency of the investments and the benefits deriving from energy efficient stoves on a macro and micro level can be helpful for further lobbying, public relations and keeping control of the project. Financial and technical criteria have generally prevailed, while the possibility of using a conceptual framework that encompasses sustainable energy development has often been neglected. In this perspective a multi-criteria approach to decision making appears to be the most appropriate tool to understand all the different perspectives involved (Kahraman and Kaya 2010).

## RESULTS

A number of tests were conducted on site to evaluate which stove model, in combination with proper fuel, would be suitable for the dissemination among the local population. Stove models were chosen among traditional and improved stoves already available in the region and tested following international recognized standard protocols (Water Boiling Test and Controlled Cooking Tests). The two models chosen for the dissemination (through the training of local artisan) were the Ceramic and the Centrafrican effective improved cookstoves [10]. Both of them were selected not only for their good (but not "best" compared to advanced improved cookstove) performances, but mainly for the appropriateness to the local contest in terms of acceptability by the users and suitability to the local technical manufacturing skills. Result based impact assessment was done by means of a number of surveys both quantitative (Kitchen Performance Test, Indoor Air Pollution monitoring, $CO_2$ avoided emissions estimations) and qualitative (interviews, observations). Increasing adoption rates (more than 3,500 units sold at March 2011) and appreciation by the users indicate the appropriateness of the stove model proposed by the project to the local context. Fuel consumption reduction (-55% for the Centrafrican ICS in comparison with the traditional three stone fire) and adaptability to the local cooking practices are the main features that the users indicates as strengthens of the technology. These aspects have been fundamental for the successful scaling-up of the Centrafrican stove [11].

A parallel activity done was the experimentation of a new stove design. The input was given by the local availability of a waste biomass, rice husk, which was thought to be recoverable as an alternative fuel to wood for household energy supply. In full collaboration with DIMI a proper stove was designed and tested to recover such a biomass [12]. The crude-earth brick stove is equipped with a chimney and an internal bi-cylindrical metal-net reactor to contain the fuel. Such a lay-out allows a mix of combustion/gasification of the biomass occurring in a completely burning fire, appropriate for cooking tasks. A rigorous Research & Development pathway was implemented in order to investigate in detail the operation of the stove, resulting in a final configuration with very good and reliable performances (average efficiency 18%, low indoor and environmental emission of pollutants). The stove has not been disseminated on site yet. Nevertheless, the design of the prototype was always driven by local inputs. Not only technical aspects such as the material availability or the local artisan skills were considered, but aspects such as the adaptability to local cooking practices, the sustainability and the acceptance by users were addressed. According to the outputs of a simple economic model elaborated ad hoc, the introduction of the mlc rice husk stove in the cooking energy system of a household resulted economically sustainable. All the scenarios elaborated show how the rice husk stove adoption would reduce significantly the household fuel expenditure, within the limits of the local availability of such a biomass [13]. The use of the technology proposed in combination with improved woodstove would provide householders with an appropriate and convenient cooking technology pool, increasing the opportunities of choice of the preferred energy system for the user. That results even more important considering the increasing wood fuel price observed on site that may affect negatively the advantages related to the use of the only improved wood stoves.

A final multi-criteria analysis assesses the appropriateness of the technologies studied providing with a global overview of the results obtained in different activities [14]. The analysis structure was built in order to point out the best cooking technology for the local context according to the different impacts that such a system is supposed to have on the user. Thus, four main clusters have been investigated, structuring quantifiable indicators for financial, environmental, social and health related impacts of the use of a certain energy technology. The weight systems adopted were chosen in order to consider the features of each technology according primarily to their relevance to the local needs. A sensitiveness analysis taking into account a weight system based on priorities listed by a group of energy experts marked some differences between the point of view on people working in the sector and that one of people supposed to adopt and use daily the technology. A shared and appropriate set of priorities should be achieved by one side through awareness and education of local population on environmental and health protection, so that also negative impacts related to these clusters could be effectively perceived by the direct users. By the other side friendly usage, adaptability to local cooking practices and reliability of fuel and technologies are aspects that should not be neglected but they should drive the design of a new cooking system.

## CONCLUSIONS

The analysis done in this work allows drafting some general final considerations. The traditional "energy ladder", like any such general model, is likely to provide only a limited view of reality in actual households (Masera et al 2000). Due to the failures of the linear energy ladder to describe adequately the fuel use dynamics in several cases, a "multiple fuel" model appears more appropriate. The wide range of new cooking technologies available has a great potential to make use of a variety of biomass residues that are difficult to burn cleanly in conventional stoves. In many places in the developing world wood is still the most preferred fuel, due to traditional habits and social rooted practices, even if the physical drudgery and time losses related to the collection activity or the financial impact on household budget is very high, and often increasing day by day. At the same time in the same areas where charcoal and firewood are becoming a scarce and/or an expensive resource, innovative systems, like micro-gasifiers or alternative fuel stoves will be of growing relevance as an option to cleanly burn biomass fuels. Making available these new technologies, promoting the research and finding the more appropriate and local tailored scaling-up strategies could help practically people living in energy poverty to escape from their miserable condition, gaining access to a wider energy technology portfolio. The adoption of a variety of combinations of affordable, reliable, convenient and clean cooking systems based on a multiple-fuel supply, could further protect low income population who are the most exposed to fuel price shocks. That would define a new comprehensive and "higher" first step in the classical view of the energy ladder, defining a new "flatter" energy ladder (Figure 1). Indeed new technologies available may reduce significantly the gap in adequate access to cooking energy between low- and high-income classes and achieve an efficient (not only effective) use of biomass at the level of the more modern fuels.

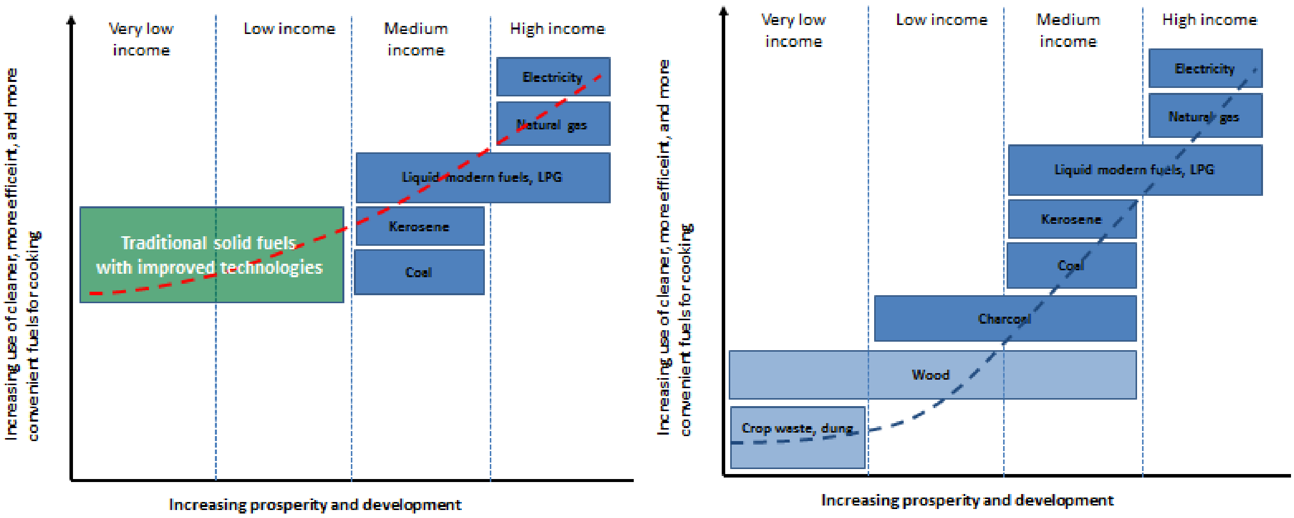


**Fig. 1** - Definition of a "new" energy ladder. Comparison between the conventional one (on the left) and the one proposed by this work (on the right).

## ACKNOWLEDGEMENTS

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## NOMENCLATURE

| | |
|---|---|
| CCT | Controlled Cooking Test |
| KPT | Kitchen Performance Test |
| IAP | Indoor Air Pollution |
| ICS | Improved Cook Stove |
| IEA | International Energy Agency |
| LPG | Liquefied Petroleum Gas |
| RBM | Results Based Monitoring |
| WBT | Water Boiling Test |

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# STUDY AND DESIGN OF A LOW ENVIRONMENTAL AND SOCIAL IMPACT LANDFILLING IN TOGO, ASSAHOUN VILLAGE

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## ABSTRACT

Waste disposal in landfilling, in association with a separate collection of organic and non-organic waste, seems to be the easiest and cheapest urban waste management method, compared to others, for a developing country, as Togo, poor in economic and technological resources. Obviously, a landfill construction requires an accurate environment and economic assessment in order to minimize the impact on the local population. It means to consider local population conditions and behaviors, municipal solid waste fluxes and their characteristics in terms of quality and quantity, climatic conditions, geotechnical and hydrological characteristics of the site and many other environmental and social factors in order to perform an optimal design. But first of all it must be considered the evaluation of economic and technological resources available and the level of information to the population about environmental impacts and health risks related to waste landfilling. The landfill in the village of Assahoun, Togo, conceived by Soutien Planète and developed by CODE3 has been designed in such a way to reduce the negative environmental impacts using appropriate technologies approach with simple solutions by the point of view of construction, management and cooperation between inhabitants and stakeholders. The project has been thought and designed to make waste management and disposal as compatible as possible with environmental and local population requirements, to ensure that it is not just a project, but to make actually possible to its construction. It would be also necessary a recycling perspective of some fractions as paper and cardboard, glass and plastic, organic waste but for the moment it is not possible for the local population to start up a separate collection and an appropriate managing of these materials: that needs a few more years of strong awareness by not only the environmental and humanitarian associations, but also, and especially, by government.

## INTRODUCTION

Togo accuses a real delay in waste management, as almost all the other African states. The current system of waste collection is provided only in the big cities and, in any case, it seems totally inadequate since it based on the payment of a substantial fee that families are always not able to afford.

The consequence is that the poorest households (the biggest slice of the population) and the inhabitants of all villages discharge their waste in illegal way, in dumps, in the sides of roads, in the fields or burn their waste open air (figure 1), creating a polluted and unsanitary atmosphere that can develop diseases, respiratory (pneumonitis is the first cause of infant death) and carcinogenic, encouraging also the proliferation of insects and rodents, which cause severe epidemics (malaria, plague, cholera , etc.). Another important effect of an uncontrolled discharge is represented by the production of leachate inside the landfill, that contaminates soil, subsoil and groundwater with the risk of a whole food chain contamination.

**Fig. 1** - Examples of illegal waste burning and dumping [1], [2].

The situation is really critical, but in Togo, there are a multitude of local groups involved in environmental protection who are fighting to improve health and social development of their people.

In collaboration with an African NGO (Soutien Planète) [3], a better waste management disposal for the village of Assahoun (Togo) has been designed. The project for the construction of the landfill takes into account many environmental and social factors in order to guarantee a low environmental impact and a health protection: the minimization and the proper collection and treatment of biogas, produced by anaerobic degradation, and of leachate, produced in the landfill by percolation, in relation with the presence of untreated organic waste.

## SOCIAL AND ENVIRONMENTAL CONTEXT AND ISSUES

The landfill has been designed in collaboration with the Association “Soutien Planète”, that develops project for social, health, education and environmental growth in Assahoun Village, Togo, and for several other villages in the same Region. Assahoun, which is located at about 55 km, in the north-west direction (Figure 2), from the Capital of Togo, Lomè, is a rural village of about 10.000 inhabitants. Its economy is principally based on agriculture, that satisfies the local needs and also guarantees an interesting exportation activity. About the 43% of the region surface is dedicated to agriculture.

Another natural resource is represented by forests, that occupy about 16% of the national area. However forests up to now show a strong degradation due to the irrational exploitation of the recent past, with an impoverishment of the finest woods and a consequent lowering of their economic value.

Therefore, preserve and restore the ecosystem balance appears a crucial challenge for that area, not only for health and environment, but also by economic point of view.

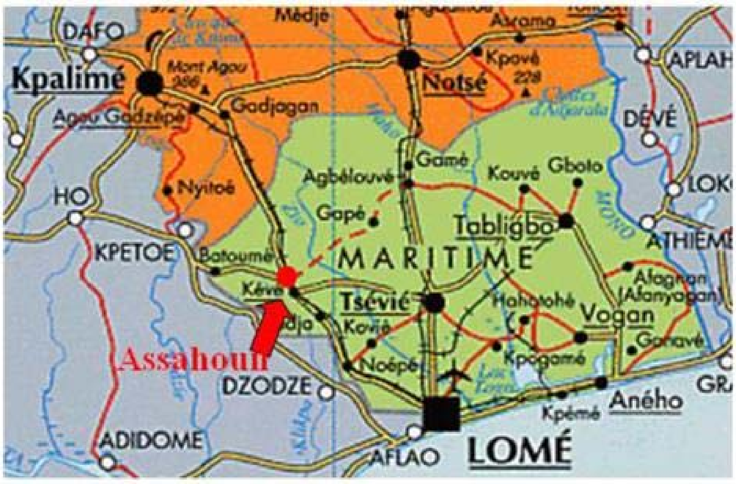


**Fig. 2** - Geographical location of Assahoun (Lomé Region, Togo) [3].

Up to now, no funds have been allocated for municipal solid waste management and for a landfill construction. Due the absence of a public integrated waste management, of course an uncontrolled disposal occurs: people burns waste at home or discharges waste directly on village streets, during the days of the public market, as it can be shown in figure 3.

The consequence is a very high level of pollution for the whole environmental system: air, soil, surface water and groundwater. In particular, water pollution represents a very alarming issue because of the contamination also in many domestic wells, compromising the quality of drinking water and water for agriculture, with a high risk for human health and food supply. During our study the level of pollution has been tested through water chemical analysis. The results confirm the presence of pathogens and of heavy metals in 4 wells located at different distances from the uncontrolled discharging site.

## THE LANDFILL DESIGN

The main parameters that have to be considered for a correct design are: climate conditions, waste composition, waste quality and quantity, pre-selection possibility, site selection, landfill configuration and sizing, surface water management systems, background water and leachate drainage and treatment system, daily covering, final covering and dump closure. In the following each parameter considered [2].

**Fig. 3** - The uncontrolled waste discharging on the Assahoun streets.

## Climate Conditions and Hydrologic Balance

In figure 4, meteoric precipitations in Togo are shown, in a period of ten years (2000 – 2009), while table 1 reports mean value of meteoric precipitations and of the temperature per year. Of course these meteoric data are necessary for the hydrological balance calculation.

| Climat - Togo | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tableau 1 : Nombre de jours de pluie par an et hauteurs de pluie annuelles | | | | | | | | | | | | |
| TOGO | | Unités | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| Les cinq principales stations : | | | | | | | | | | | | |
| Lomé | Nombre de jours de pluie par an | jour | 57 | 81 | 77 | 77,00 | 82,00 | 86,00 | 90,00 | 98,00 | 97,00 | 76,00 |
| | Hauteur de pluie annuelle | mm | 423,9 | 699,6 | 839,7 | 876,4 | 1008,2 | 784,4 | 931,3 | 1026,6 | 1075,3 | 886,3 |
| Kouma - Konda | Nombre de jours de pluie par an | jour | 163 | 132 | 149 | 139 | 128 | 119 | 129 | 125 | 147 | 144 |
| | Hauteur de pluie annuelle | mm | 1731,9 | 1103,5 | 1531,4 | 1587,6 | 1290,7 | 1052,4 | 1468,8 | 1657,1 | 1579,22 | 1757,9 |
| Sokodé | Nombre de jours de pluie par an | jour | 117 | 98 | 107 | 121 | 112 | 116 | 111 | 103 | 114 | 108 |
| | Hauteur de pluie annuelle | mm | 1176,9 | 983 | 1335,9 | 1536,1 | 1282,7 | 1646,2 | 1059,4 | 1125,6 | 1031 | 1419,1 |
| Kara | Nombre de jours de pluie par an | jour | 118 | 99 | 105 | 129 | 125 | 109 | 114 | 115 | 105 | 124 |
| | Hauteur de pluie annuelle | mm | 1203,7 | 1238,5 | 1194,5 | 1771,1 | 1231,3 | 1003,7 | 1142,022 | 1093,6 | 1308 | 1488,3 |
| Mango | Nombre de jours de pluie par an | jour | 83 | 72 | 76 | 78 | 92 | 86 | 77 | 93 | 90 | 101 |
| | Hauteur de pluie annuelle | mm | 919 | 747,4 | 931,4 | 999,5 | 1166,5 | 905,7 | 874,3 | 1270,7 | 1109,4 | 1148 |
| Source : Direction de la Météorologie Nationale | | | | | | | | | | | | |

**Fig. 4** - Rainfall and rainwater levels (period 2000-2009). [source: Direction de la Météorologie Nationale, Togo].

**Tab. 1** - Average Precipitations and Temperature (By Direction de la Météorologie Nationale, 2010).

| Month | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitations (mm) | 8 | 25 | 50 | 90 | 146 | 243 | 90 | 32 | 86 | 86 | 60 | 60 |
| Average Temperature | 27 | 30 | 30 | 30 | 29 | 27 | 27 | 27 | 27 | 28 | 30 | 29 |

Referring to these data and using a simple equation, the hydrological balance can be calculated in order to define the total amount of leachate that can be drained from landfill. Where:

L = total leachate amount
P = precipitations
R= runoff
E = Evaporation
T = Transpiration

In that way we are able to calculate the hydrological balance for each year. The total volume of leachate has been calculated considering a green covering on the landfill surface. In table 2 it can be defined the amount of leachate per month, naming as P* the value P* = P – (R+E+T) and considering a landfill surface area of 1200 m2.

**Tab. 2** - Water amount per month inner landfill.

| Month | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P* (mm) | 5.4 | 16.0 | 35.7 | 72.5 | 120.0 | 225.0 | 84.8 | 30.1 | 78.1 | 65.4 | 43.2 | 40.8 |
| Leachate ($m^3$/month) | 6.5 | 19.2 | 42.8 | 87.0 | 144.0 | 270.0 | 101.7 | 36.2 | 93.7 | 78.4 | 51.8 | 49.0 |

**Urban Waste characteristics**

Specific data of the Assahoun village about urban waste production were unavailable and very difficult to find. Therefore data of the near city of Kora have been used. The biggest amount of waste percentage is constituted by organic waste (about 25%) and sand (40%). The other fractions: plastics (5%), paper (2%), other inert materials and glass (16%).

The presence of fine and extra fine sand represents a peculiarity in this urban waste production related with the presence of unpaved roads. In fact, roads cleaning activity produces a lot of powder that is collected together with the other waste.

Through a pre-selection treatment it's possible to separate organic and sand from the other fractions, by screening, with the following several advantages:

- reduction of the total amount of municipal solid waste destined to landfilling;
- minimization of biogas and leachate production;
- local reduction of subsidence and settlement.

By an economic point of view, it is preferable to adopt a separate collection for the best selection of wet organic waste and undifferentiated dry fraction, while screening may be useful for the separation from solid waste going to landfill of the particles having a very small size, fine and extra-fine sand.

**Site Selection**

Thanks to the excellent relationship established among the members of the association and the leaders of the village of Assahoun it has been possible to carry out a screening of potential sites that could be used for landfill construction.

The main parameters required for the screening were:

- distance from town and houses;
- absence of surface waters (river, streams and lakes);
- absence of seismic activities;
- presence of a basic layer characterized by very small values of permeability (hypotheses to be tested through geotechnical investigations );
- presence of groundwater at a high depth.

**Landfill design**

The project of the landfill has been characterized by the following options (see Figures 5 and 6).

*Shape and surface*: an appropriate site for the landfill will occupy an area of about 2.400 m2, having a regular rectangular shape.

*Slope*: the excavation will be done with a maximum slope of 12% in the width direction of the ground, having a minimum depth of about 5 m (from the bottom in correspondence with the lowest point).

*Embankments and side wall*: the perimeter walls will be supported by retaining walls filled with concrete bricks around the perimeter of the excavation. The concrete masonry allows for easy installation and it is preferable because of the lower cost of the used materials. By an environmental point of view it would be better a reinforced soil slopes construction, but it represents a too expensive option.

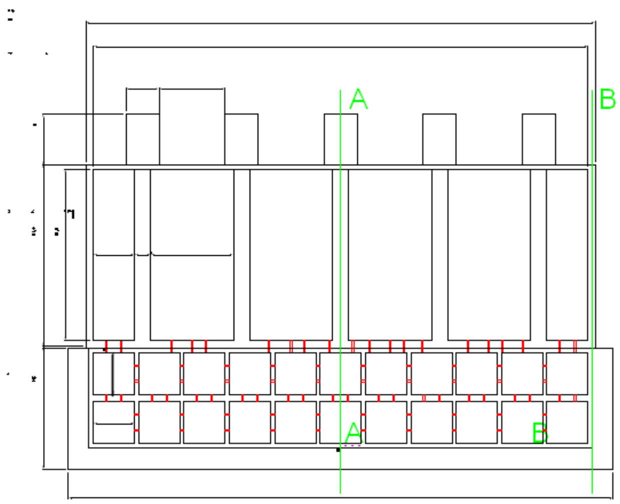


**Fig. 5** - Landfill plan.

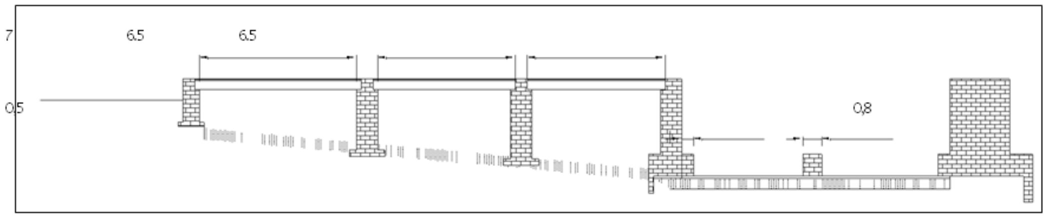


**Fig. 6** - Section A-A.

*Access ramps and steps for filling and maintenance*: the access ramps are designed plan to use bricks filled with concrete. Decks, designed for the passage of vehicles and personnel for maintenance and daily waste discharge, will be constructed using teak wood, which is present near the area. Teak wood can be reused when the landfill will close. In that way it's possible to reduce the impact derived from deforestation and in this issue the same Association organizes every year some days of labor camps for the reforestation of wetlands. At the landfill perimeter lateral drain channels will implement for rain water runoff to prevent any infiltration.

*Impermeabilization*: the internal surfaces and the bottom of the basin will be impermeabilized through additives (sikalite) to prevent infiltration of rainwater and leachate.

*Volume waste storage and life of the landfill*: given the lack of data relating to the information on the type of waste the following assumptions have been done (referring to statistical data of the State of Nigeria):

- Municipal Solid Waste Total volume = 460 m3/year
- Landfill life time = 4.63 years ≈ 5 years

*Daily cover*: it must be provided in order to avoid the dispersion of waste because of the wind action and to protect the area from the presence of insects and animals. In the design it was therefore chosen to perform the daily covering using the same compost produced by organic waste treatment. It seems to be the best solution not only by an economic point of view but also by a sustainable and appropriate approach.

*Final Cover*: In figure 7 the final Section A-A showing cover and waste layers draft in closed landfill configuration. Final cover has a strong importance for recovery and requalification of the site. It's also useful to prevent rainwater filtration and to encourage a vegetation growth. For these reasons, it has been designed a traditional barrier, as it's shown in Figure 8, composed by:

a) a surface vegetation cover: it allows to minimize wind erosion, to maximize evapotranspiration and to protect underlying sectors from thermal excursion.
b) A protection layer (30 cm): it creates a physical separation between waste and plant roots protecting at the same time underlying levels by wetting/drying phenomena. Compost has been recommended.
c) A drainage layer (thickness 20 cm): it's fundamental for the removal of rainwater, with a consequent reduction of leachate production.
d) A waterproof barrier: the use of a geo membrane (thickness 12 mm) has been recommended in order to avoid stability issues: it's not subject to heavy loads and rupture risk is negligible. In addition, its flexibility allows to adapt to waste movements and it's easily repairable.
e) Foundation (20 cm): this is the leveled base layer for the correct other upper strata laying.

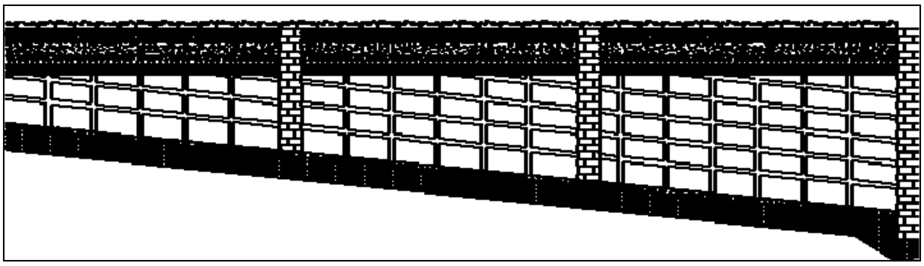

**Fig. 7** - Final cover and waste layers draft for the closed landfill configuration (Section A-A).

a) Surface vegetation
b) Protection layer
c) Drainage layer
d) Waterproof barrier
e) Foundation

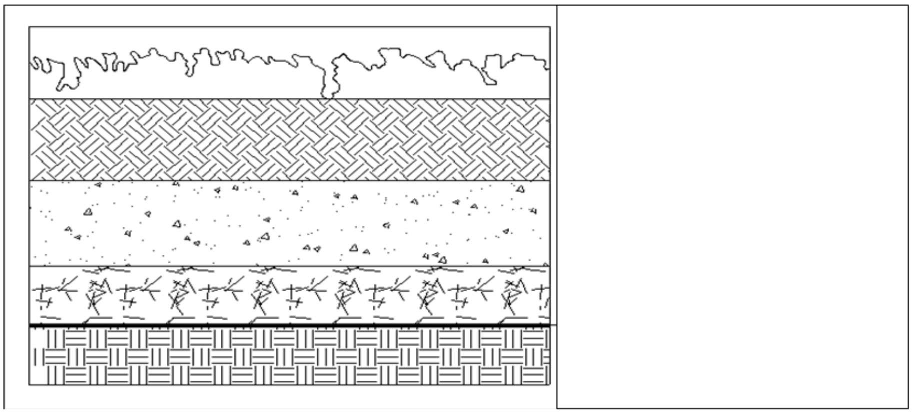

**Fig. 8** – Final Cover design.

## CONCLUSIONS

As almost of the other African states, also Togo accuses a real delay in waste management.

Waste disposal in landfilling, in association with a separate collection of organic and non-organic waste, seems to be the easiest and cheapest urban waste management method, compared to others, and the best appropriate technology for a country, as Togo, poor in economic and technological resources.

First of all it must be considered the evaluation of economic and technological resources available in the site and the level of information to the population about environmental impacts and health risks related to waste landfilling.

The landfill in the village of Assahoun, Togo, conceived by Soutien Planète and developed by CODE3 has been designed to reduce negative environmental impacts and using an appropriate technologies approach with simple solutions by the point of view of construction, management and cooperation. The project has been thought and designed to make waste management and disposal as more compatible as possible with environmental and local population requirements, to ensure that it is not just a project, but to make actually possible its construction.

The project seems to be a good answer to the actual needs of Assahoun population both by environment and social point of view in the relation with the available human and economic local resources.

Assahoun landfill, together with the related correct municipal solid waste management, is actually only at a planning stage, but the hope is that it will be really constructed in a near future. That will be possible of course only if a strong awareness of local population needs in terms of environmental and health saving issues will be arisen not only by humanitarian associations, but also, and especially, by the Togo government.

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