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MEASURING FRUGALITY - APPLICATION TO A SOLAR WATER DISTILLER

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Abstract

This paper explores the concept of frugality to help designers in optimizing the resources needed for the design of products. A metric proposes to integrate the geographical origin of the components which participate at the achievement of the product's functions. The resulting profile gives a global notation of the frugality, and suggests ways of improvement by targeting functions that are less frugal. A case study on a solar water distiller supports the proposal in order to prove the efficiency of the methodology.

Keywords: Sustainability, Ecodesign, Functional modelling, Frugal

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1 INTRODUCTION

Most scientists agree that global warming is a worldwide issue. The consequences of human activities on the environment have now been proved, it is necessary to implement environmental policies at all structural and functional levels of our societies. Global demographics acts as an aggravating factor in this situation. With 7 billion inhabitants in 2016, 9 billion in 2050 and 11 billion in 2100 according to the United Nations (UN 2016), it has become urgent to have a sustainable management of our resources. The increase in population is accompanied by an increase in demand for products and services and its corollary waste. Furthermore, Earth is a limited planet and the resources are exhaustible. For example in Europe, there is a significant risk of supply shortage of 20 critical raw materials by 2030 (EC, 2014). Europe is highly dependent on non-energy raw materials to sustain businesses and the economy. This is due to the monopoly of some countries (China produces 95% of the rare earths used in electronic circuits), or due to the lack of recycling sectors, and the non-substitutability of some materials.

Plans are now being made within the UN to ensure that sustainable development goals could be met. The 2030 Agenda for Sustainable Development adopted in September 2015 (UN, 2015a) is a set of 17 goals leading to a renewed partnership for development. The 12th goal proposes to ensure sustainable consumption and production patterns. It promotes a consumption and production aiming at “doing more and better with less” by “increasing net welfare gains from activities by reducing resource use, degradation and pollution along the whole life cycle, while increasing quality of life”.

To meet this objective, frugal engineering offers a new alternative (Rao, 2013; Tiwari, 2014). It is a concept used and developed in emerging economies for Base of the Pyramid (BoP) countries. The idea is to propose goods and services economically in adequacy with the customers’ resources for a large market (Herstatt, 2012). The literature considers that Africa and India are pioneers in this area. The famous examples of the M-PESA service created by the Kenyan mobile operator Safaricom and the MittiCool refrigerator created by a potter in India are emblematic. M-PESA is a fast, convenient and affordable way to send and receive money or pay for goods and services via a mobile phone (Safaricom, 2016). There are nearly 100,000 M-PESA agent outlets in Kenya alone, and over 23 million registered users. The idea is simple but brilliant: if the population doesn’t have a bank account, but 80% have a mobile phone, then it can be possible to create a P2P (Person to Person) money transfer. M-PESA is a common payment system in Kenya, and is now available in India. For the MittiCool system, an Indian potter created a smart refrigerator made from a specific combination of clay found in his local area. The system does not need electricity, it uses an evaporative cooling which creates an inside temperature up to 8°C lower than the outside temperature (MittiCool, 2016). The inventor received many awards for his invention.

From the academic point of view, frugal innovation is especially studied under the economical aspect. Many researchers produce analysis on the business models for emerging economies (Alcoot, 2008; Bhatti, 2013; Evans, 2011). Due to its novelty, the study from an engineering viewpoint is poorly documented, its implementation in businesses remains at a strategic level, or is just a commercial approach, is doesn’t exist at the operational level. However, an interesting work (Lecomte, 2015) can be mentioned, the author defines the concept of Non-Trade-Offs representing the fundamental functionalities the designer should achieve. From a practical point of view, it means the non-negotiable elements that guide design choices. The author proposes three strategies to manage the Non-Trade-Offs: design by aggregation, design by extension, and design by focalization. Focalization seems to answer frugal design issues, as it isolates the functions representing the essential value of the product in order to reduce drastically the overall cost.

In order to explore the concept of frugality, the paper proposes an experimental approach to create an index that measures the frugality of different versions of a product. For this, a methodology is first presented. A product is considered as a set of functions and not anymore as a set of components. Then, a qualitative metric aims at the evaluation of the functions achieved by the product depending on the geographical origin of the components/materials. The methodology is illustrated with a case study on a solar water distiller. Three versions of the product are evaluated and compared using the metric. A discussion is then engaged to examine the advantages and the limitations of the proposal. Finally, the conclusion lists complementary fields of research that are already engaged to improve the approach.

2 FRUGAL DESIGN METHODOLOGY

2.1 Objective

The frugal design of a product is a global process that should integrate the whole life cycle of the product. The idea is to choose the just necessary means (matter, energy, process, …) to achieve the just necessary service adapted to the client's resources. Two aspects must be consequently explored: the operational/environmental aspect of the product and the associated business model (Leadbeater, 2014). In this paper, we are proposing to explore the operational aspect by developing a metric aiming at understanding and promoting frugality. Based on the metric, the (re)design process of a product can be engaged to improve its frugality.

2.2 Methodology

2.2.1 Qualitative approach

The measurement of frugality requires a multi-criteria approach that should integrate economic, technical, social and environmental considerations. According to (Tshidimba, 2015) FRUGAL is an acronym that stands for : Functional; Robust; User friendly; Growing; Affordable and Local. The factors F,R,U can be related to the technical/operational aspects, and G, A can be related to the business model. This acronym has the advantage to give five simple objectives, but the complexity releases in their interconnections.

In order to reduce the complexity of the multi-criteria approach, we propose to integrate U and R in the F factor. Indeed, the functional modelling of a product is a well-known representation being used in the value management/value engineering approaches. Functional analysis considers the interactions of a product in its environment for each phase of its life cycle. The resulting functional specification represents the objectives a designer has to achieve. An adjustment must be proposed in order to fit the global frugal objective which is to choose the just necessary solutions. If a product can be represented by its functional modelling, the just necessary solutions must achieve the just necessary functions. In this way, a global strategy in suppressing the non-necessary functions must be proposed. Even if the functions are first considered as useful (third step of value analysis), a frugal filter must be applied to suppress the non-necessary functions that are not related to the fundamental service of the product. The only constraint to consider is the safety of the user or all other operators that could be in interaction with the product.

After this primary requirement, the process consists in focusing on the L factor that concentrates all the energy that should be spent in the frugal process. Indeed, the assumption is that if the designer can integrate local resources, it will decrease the cost of the supply chain, and consequently the associated environmental impacts (CO2). At the same time, it will create local industrial synergies with social values (not relocated jobs for example) (Krishnan, 2013).

2.2.2 Metric based on local value

The term local refers to the value addressed by the designer to the resources based on their environmental impacts. The more the resources belong to the immediate environment of the designer and the users, the more important the associated value is. Consequently, the distance from the extraction of the resources and their transformation to their integration in the product quantifies the local value.

The notion of local value must be considered depending on the spatio-economical configuration of a country (area, density) and not only based on the distance. For example, if Australia covers an area equal to fourteen times the size of France, its population is only 42 million inhabitants, very unequally distributed in relation to France (65 million). A distance of 300 km in Australia can be considered as local, while in France the distance covers many cities and counties.

In order to create a homogeneous value, and considering that the designers is a decision maker for the choice of the resources, a relative scale based on a spatio-economical consideration is introduced. The local value can take four states: micro, meso, macro, macro+. The micro level expresses the area where the designer can access the resources in the city where the company is located. The meso level represents the area of the nearest cities where the designer can access the resources. The macro level represents the rest of the area of the country, the macro+ level represents the rest of the world.

The objective of the designer is to choose the nearest resource that can achieve the functions of the product at the lowest possible cost. Consequently, the strategy consists in moving gradually along a spiral from the micro scale to reach the following status if necessary for each function of the product. Note that a function is formalized according to the definitions of the Value Management standard (EN 16271, 2013), a function describes an action of the product on its environment.
A global representation of the local value of a product can be illustrated by a radar chart (Figure 1). Each axis of the chart represents a function, and the position from the center represents the status of the local value associated to the resources used to achieve the function.

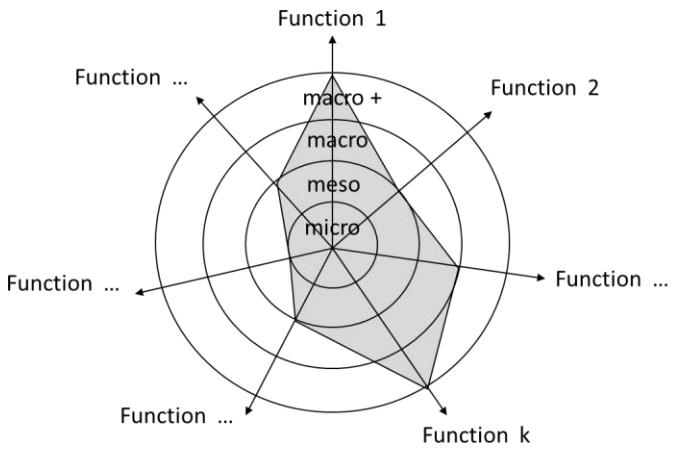

Figure 1. Local values of a product's functions

The diagram confers to the designers an easy representation of the local values attributed to the functions. Its advantage is to simply compare on the same diagram the upgraded versions of a product according to a local strategy. It can give priorities to the designers in improving the local value of some functions.

3 CASE STUDY

3.1 System delimitation and objective

Among the major societal challenges, the access to safe water is a priority issue. The 2015 report of the United Nations (UN, 2015b) indicates that 749 million people cannot access to safe drinking water, and 2.5 billion do not use sanitary facilities. It is estimated that 1.8 billion people drink water contaminated by Escherichia coli, and 6,000 children die every day from diseases related to water. Faced to this global challenge, programs were conducted with varying degrees of success. According to the NGO IRC, coordinator of the research program Europe/Africa WashTech (IRC, 2013), one-third of the installations dedicated to the supply of drinking water does not work in Sub-Saharan Africa. To overcome this problem, the WashTech research program proposed a set of decision support tools called TAF (Conditions of Application of Technology) to help the implementation of sustainable technology solutions WASH (Drinking Water Supply, Sanitation and Hygiene).
The context of water serves as a field of experimentation to explore the concept of frugality. The approach used is empirical, it tries to give a more understandable definition of frugality from an operational point of view. For this, a solar water distiller is developed and improved to increase its frugality. Three versions of the distiller are described, and the evolution between the three versions is explored, based on the criteria proposed in Section 2.

3.2 Prototyping of a solar water distiller

The physical principle of a solar water distiller is simple. It consists in heating water in a box in order to evaporate it and condensate it on a surface, the resulting distilled water is then recovered. Many experimentations can be found, an illustration in Figure 2 presents one of the possible configurations which consists in a box with an inclined glass. The water stored in the bottom of the box is heated by the infrared waves, it is then evaporated due to the confinement of the water, it condensates on the glass, the resulting drops glide along the glass and are collected and recovered out from the box.

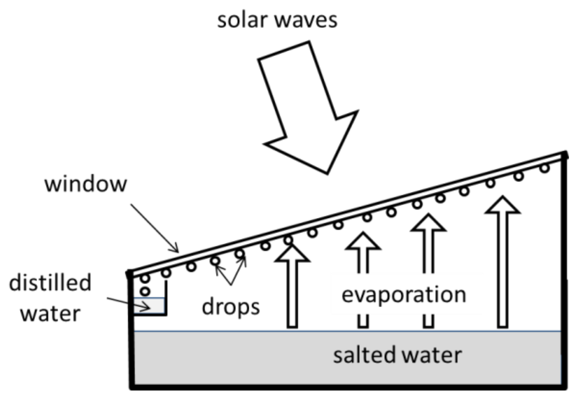

Figure 2. Solar water distiller principle

The systems works, but its efficiency can be increased. The factors that can be easily manipulated are the volume of the box and the distance between the stored water to the condensation surface. The materials used for the box and the surface can influence the thermal insulation of the system, but are not included in the study.
Based on this proposal, a solution can be to move the water in front of the condensation surface in order to limit the internal volume V of the box and the distance L between the window and the belt. A real product produced by the F-CUBED company (F-Cubed, 2016) uses this proposal. Their solution called Carocell receives impure water at the top of rectangular box, and the water slowly runs down the solar/collector evaporator. Solar energy heats the water, it vaporizes and condenses the water on the inside of a composite panel enclosure. The resulting desalinated/purified water runs down at the bottom of the unit. The systems works, but the speed of the water that flows in the unit cannot be controlled.
In order to increase the efficiency of the process, a new solution has been recently proposed by a private inventor (Grandpierre, 2016) to control the speed of the impure water that runs down in the collector. He proposes to move the water inside the box in front of the inside condensation surface with an endless belt. The difference between F-CUBED and Grandpierre's solution is that the speed of the water in the Carocell system is only controlled by the inclination of the fabric on which the water flows, whereas that of Grandpierre slowly moves the water absorbed in the fabric of the belt animated by an electrical motor (Figure 3).

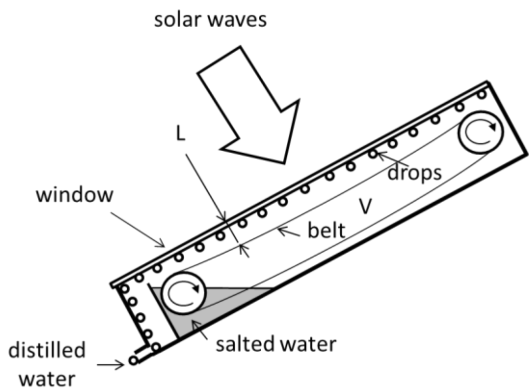

Figure 3. Grandpierre's principle

3.2.1 Prototype version 1.0

Based on the Grandpierre proposal, a prototype was built (Figure 4). The salted water stored inside the box is moved as closed as possible to the glass with a moving endless belt which captures the water from a container located below the box. The endless belt is stretched between two rollers, and the rotation of one of the rolls driven by an electric motor (tourney pin) generates the endless displacement of the belt. When the belt goes into the water tank, the water is absorbed and moved near the condensation surface (a mineral glass), it evaporates and the thermal shock with the glass creates drops (condensation of distilled water). Because of the inclination of the glass, the drops glides on it, the resulting distilled water is recovered and stored in an external container.

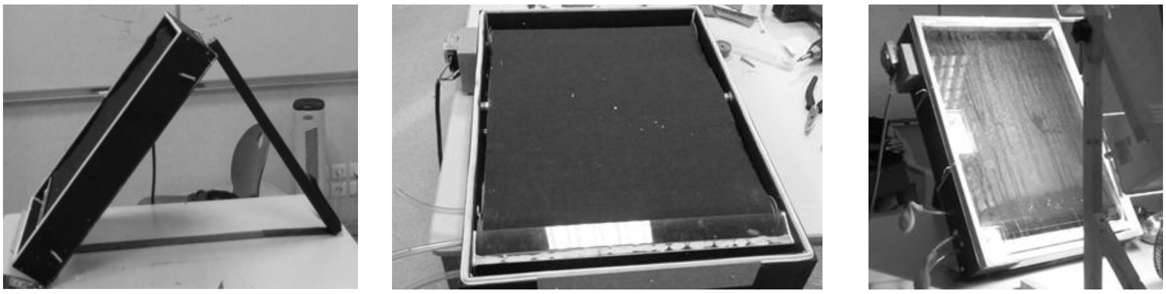

Figure 4. Prototype 1.0 : side view, motor and belt; condensation

Several tests of the box have been performed to measure its efficiency. Infrared waves have been generated with halogen lamps to simulate solar waves. The temperature inside the box grows to 75 celsius degrees, and the production of the distilled water is about 325 mL per hour with a 0.25 square meter surface for the solar energy capture.
In terms of usability, it is important to note that the maintenance of the system is complicated. In order to clean the belt, the operator has to remove successively the glass maintained by springs, the roll axle, the rolls and belt.
A list of seventeen functions has been defined to express the functionalities of the solar water distiller. They are presented in the fourth section of the paper in order to make the comparison with the two other prototypes. For each function, a local value has been assigned depending on the geographical origin of the resources used for the technical solutions

3.2.2 Prototype version 2.0

The second prototype has been designed and built to improve the use of local resources. The solar water distiller consists in a wheel recycled from a bike which creates a circular box (Figure 5). A piece of wood is used at the bottom of the box and a circular piece of plexiglass as a cover. A circular plate with a fabric turns inside the container. The water comes from a pipe connected to an external water container and flows onto the fabric. The circular movement of the plate is ensured by a float in the water container which returns a torque in a rope by the means of a pulley. The continuous movement of the plate ensures the complete distribution of the water in the fabric. The insulation is ensured by a tire which has been cut longitudinally and placed around the box.

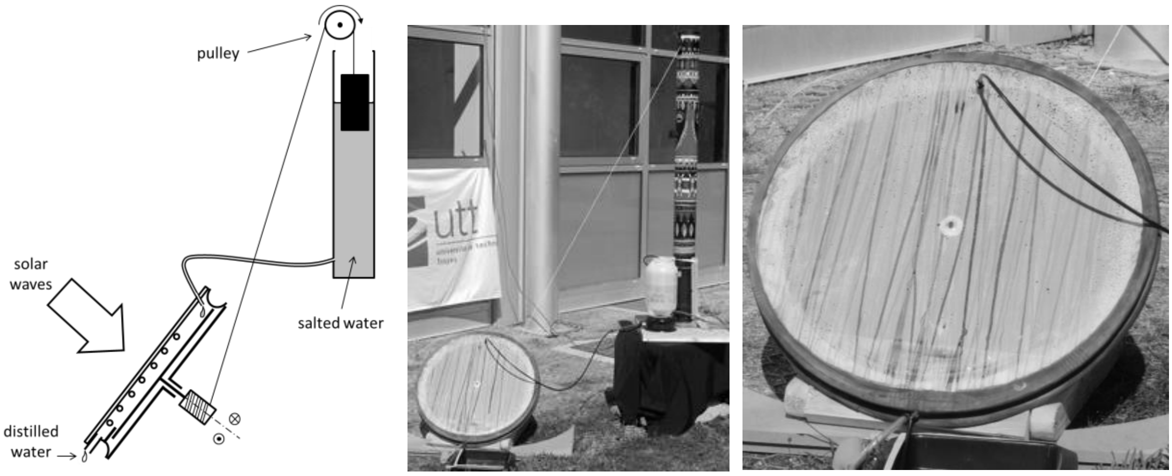

Figure 5. Prototype 2.0: principle, prototype, condensation

3.2.3 Prototype version 3.0

The last prototype is an upgraded version of the second. Its design proposes more components of the recycled bike to partly suppress the wood used in version 2.0. The wood for the orientation of the wheel is replaced by metallic parts of the luggage carrier. The rest of the system does not change (Figure 6).

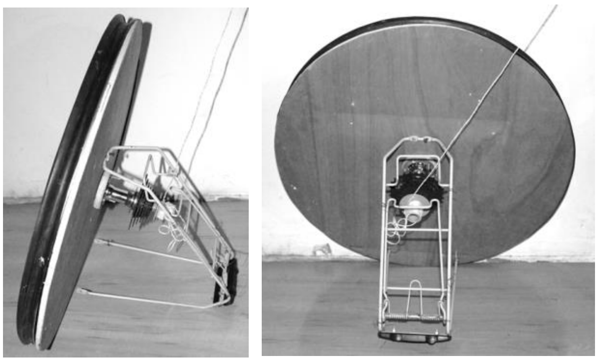

Figure 6. prototype 3.0: side view, back view

4 ANALYSIS AND DISCUSSION

In order to improve the solar water distiller (SWD) from a frugal point of view, the methodology defined in Section 2 proposes to achieve the just necessary functions of the product by a better usage of local resources. In order to apply the metric expressing the level of local usage, the functional analysis of the product aims at the definition of the just necessary functions of the SWD:
F_1: SWD transfers solar energy to salted water.
F_2: SWD moves the salted water in front of the solar energy.
F_3: SWD evaporates salted water.
F_4: SWD condensates the evaporated water.
F_5: SWD collects the distilled water (evaporated water).
F_6: SWD delivers distilled water to the user.
F_7: SWD stores salted water.
F_8: SWD delivers distilled water.
F_9: SWD resists to salt.
F_{10}: SWD resists to salted water.
F_{11}: SWD stores solar energy.
F_{12}: SWD is easily usable by the user.
F_{13}: SWD is easily cleanable by the user.
F_{14}: SWD is easily transportable by the user.
F_{15}: SWD resists to the environmental conditions.
F_{16}: SWD is insulate from external air.
F_{17}: the volume of the SWD underneath the moving salter water is minimized.
For a continuous improvement of the SWD, the designer assigns the value (micro, meso, macro or macro+) at each function depending on the associated resources used to support the technical solutions. From the first prototype to the second, five function have been improved (F_2, F_{11}, F_{12}, F_{16}, F_{17}). From a technical point of view, the electrical motor is suppressed and replaced by the existing salted water stored in a pipe to create the energy (with a float) to turn a flat fabrics instead of to turn an endless belt. From the second to the third prototype, two functions have been improved (F_1, F_3). The wood used to support the system and to orientate it is replaced by the part of the bike. The local value assigned to each function of the three prototypes is illustrated in Figure 7.

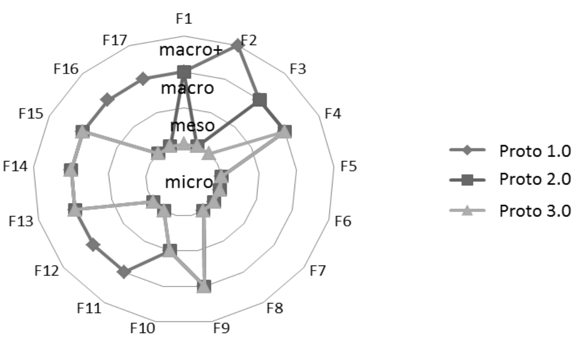

Figure 7. Comparative local value of the prototypes

The differences between the prototypes 1.0 and 3.0 express the qualitative gain from a frugal point of view. The simplicity of the approach can be a powerful tool for designers, but it has some limitations. In fact, there are many approximations. First, the metric of the local value is applied on prototypes in the case study and not on an industrial product. The redesign with local considerations must be taken with some precautions. The designers are academics, their will to build an object considered as frugal is praiseworthy, but the result is biased. They don't need this product in their everyday life because their country offers safe running water in every home. Consequently, the choices of new solutions based on local resources can be questionable. The redesign of the prototypes looks like a Jugaad approach (Radjou, 2012), whereas a frugal innovation approach should applied on a mass market. But beware, the economic aspect does not necessarily depend on the choices of the designer, it will mainly depend on the business model that will be approved by the company. Second, the qualitative scale describing the local value of the resources cannot be rigorously applied since several technical components are involved in performing a function. Moreover, the components of the prototypes 1.0 and 3.0 come from a recycled bike, but the bike comes from a company located in a neighboring town. If the components were new, the local value would change into meso instead of micro. Third, the definition of the just necessary functions can provide a powerful impact on frugality. Indeed, the designer has to respect the functional specification of a product, and if the specification contains useless and unnecessary functions, the product cannot be frugal. The definition of an unnecessary function must be therefore explored and studied in a further research. Fourth, the complexity of the technical solutions is not considered in this paper. Even if the origin of the components is micro, the complexity of the solutions should be integrated to express how easy could be the maintenance or recycling of the product. Fifth, the efficiency of the products must be considered in order to be compared with an equivalent service. In the same as for a LCA (Life Cycle Analysis), the functional unit of the product must be clearly expressed to justify the comparison of the upgraded versions of a product, or competitive products.

5 CONCLUSION

Due to the population growth and due to the limitation of resources on earth, new paradigms must be explored to design products and services. In this way, the notion of frugality can offer an opportunity to deliver affordable products and services. Frugal innovation is a concept provided from emerging economies in BoP countries. In this paper, the frugality notion is explored according to the ability of the designers to achieve the just necessary functions of a product in using local resources. The idea is to help the designer in choosing the most appropriate solutions according to the geographical origin of the resources. The more the origin is near the company, the more the local value is important and considered as frugal. A qualitative metric proposes to measure the local value into four status: micro, meso, macro and macro+. The status is associated to the just necessary functions of the product. The metric expresses how far the resources are from the company by measuring the relative distance depending on the spatial repartition of the economy (city, county, country, world). After the definition of the metric, it has been applied on a case study to illustrate the simplicity of this approach. Three upgraded versions of a solar water distiller have been developed. The frugality of the versions is measured in establishing the local value associated to the functions of the product. A discussion is then engaged to analyse the simplicity of the approach in the context of Small and Medium Sized Enterprises. Indeed the qualitative approach is simple and does not need environmental experts or to perform a LCA (Life Cycle Analysis). However, the methodology has some limitations that are being discussed. Because of some approximations, as for the study of prototypes instead of industrial products, or the assignment of the value to the functions aside from the quantity of components/materials, or the absence of economic evaluation, the methodology must be reconsidered. For this, a global multi-criteria approach has been already engaged in a two years joint research project entitled "Solar Tears" which started in September 2016 with the collaboration of the HAMAP NGO. Experimentations of solar water purifiers with villages in India and Africa are scheduled, the results of the program will be next published.

REFERENCES

Alcoot, B. (2008), The sufficient strategy: would rich-world frugality lower environmental impact?, Ecological Economics, Vol. 64, pp. 770-786.

Bhatti, Y., Khilji, S.E., Basu, R. (2013), Globalization, Change and Learning in South Asia, Chandos Asian Studies Series, Woodhead Publishing limited, pp.123-145.

EC, European Commission (2014), Report on Critical Raw Materials for the EU, https://ec.europa.eu/, access on 10/16/16.
Evans, D. (2011), Thrifty, green r frugal: Reflections on sustainable consulption in a changing economic climate, Geoform Vol. 42, pp. 550-557.
F-CUBED (2016), http://www.fcubed.com.au/, access on 10/16/16.
Herstatt, C., Tiwari, R. (2012), Frugal Innovations for the unserved customer, Technology and Innovation Management, Hamburg University of Technology, Working paper 69, https://cgi.tu-harburg.de, accessed on 10/16/16.
Ilgin, M.A., Gupta, S. M. (2010), Environmentally Conscious Manufacturing and Product Recovery (ECMPRO): A review of the State of the Art, Journal of Environmental management, Vol. 91, pp. 563-591.
IRC International Water and Sanitation Centre (2013), Washtech 2011-2013, https://washtechafrica.files.wordpress.com/, accessed on 11/21/16.
Krishnan, R.T., Jha, S.K. (2013), Local Innovation: the Key to globalisation, Management Review, Vol. 25, pp. 249-256.
Leadbeater, C. (2014), The frugal Innovator, USA, Palgrave Macmillan Publication.
Lecomte, C., Blanco, E. (2015), Dealing with Non-Trade-Offs for Frugal Design, ICED15, Vol. 4, Milan, Italy, 27th – 30th July 2015.
MittiCool (2016), http://mitticool.com, access 10/16/16.
Radjou, N., Prabhu, J., Ahuja, S. (2012), Jugaad Innovation, USA, Jossey-Bass Publication.
Rao, B.C. (2013), How disruptive id=s frugal ?, Technology in Society, Vol. 35, pp. 65-73.
Rosca, E., Arnold, M., Bendul, J.C. (2016), Business Models for Sustainable Innovation – An Empirical Analysis of Frugal Products and Services, *Journal of Cleaner Production*, available online,
Safaricom (2016), Annual Report 2016, https://www.safaricom.co.ke, accessed on 10/16/16.
Tiwari, R., Kalogerakis, K., Herstatt, C. (2014), Frugal Innovations and Analogies: Some Propositions for Products Development in Emerging Economies, *Technology and Innovation Management*, Hambourg University of Technology, Working paper 84, https://cgi.tu-harburg.de, accessed on 10/16/16.
Tshidimba, D., Lateur, F., Sneyers, N. (2015), Frugal products, Roland Berge Strategy Consultants Publication, https://www.rolandberger.com, accessed on 10/18/16.
UN (2016) United Nations (2016), http://www.un.org/en/, accessed on 10/15/16.
UN (2015a), United Nations, Transforming our world: the 2030 Agenda for Sustainable Development, A/RES/70/1.
UN (2015b), United Nations, The United Nations World Water Development Report 2015, Water for a Sustainable World, Unesco Publication.

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