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ORIGINAL PAPER

Participatory Design and Technologies for Sustainable Development: an Approach from Action Research

Andrés Esteban Acero López[1] **·**
María Catalina Ramirez Cajiao[1] **·**
Mauricio Peralta Mejia[2,3] **·**
Luisa Fernanda Payán Durán[4] **·**
Edier Ernesto Espinosa Díaz[5]

Abstract This paper explores the relevance of the action research for design of technological solutions that lead to both systemic sustainable development and active involvement of the community. The paper shows how this idea was implemented in a project for water resource conservation with educational institutions of rural areas in Colombia. Through the use of technology, a reduction in water consumption increases in awareness about the use of this natural resource, and the active involvement of the community were sought. Additionally, social processes related to the conservation of natural resources were addressed through a socio-technical approach for analysis and design. During the application of the Soft Systems Methodology (SSM), the participants and researchers created technological prototypes that allowed to: 1) give visibility to the community's initiatives, and 2) save water in the households. This paper focuses on the importance of the design process of innovative solutions for social and environmental issues through the participative approach of action research.

Keywords Drinking water conservation · Participatory action research · Technology design · Participation

✉ Andrés Esteban Acero López
Ae.acero539@uniandes.edu.co

[1] School of Engineering, Universidad de los Andes, Bogotá, Colombia

[2] Business Administration, Swiss Management Center, Zug, Switzerland

[3] Parque Científico de Innovación Social, Corporación Universitaria Minuto de Dios, Bogotá, Colombia

[4] Interdisciplinary Development Studies, CIDER, Universidad de los Andes, Bogotá, Colombia

[5] School of Economics, Universidad de los Andes, Bogotá, Colombia

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Introduction

In 2015, the United Nations, during its annual summit, made an urgent call to every country to intensify their efforts in the search for sustainable development of our planet. Looking to continue the work guidelines established in the Millennium Development Goals, the UN invited the nations of the world to follow 17 Sustainable Development Goals (SDGs) for long-term planet sustainability. One of these objectives, the sixth one, emphasizes the value of water for communities, not only regarding sanitation but also in relation to their search for sustainable development. This natural resource, on which all humankind depends, requires an efficient management system that guarantees its availability for future generations. Finally, thanks to the coordination of the SDGs with the public policies of each country, humankind can think on water management in terms of community participation, whether they are urban or rural.

In the Colombian context, the conservation of the natural systems has become a necessity. According to the Departamento Nacional de Planeación (2012), Colombia has exceptional natural and cultural diversity and richness. This premise has been the basis upon which the nation and its regions have built their development strategies. The natural resources, soil, water, forests, hydro-biological resources, minerals, hydrocarbons, landscape, etc., have been used and exploited for creating economic growth and social welfare (Botero 2009). Even though the economic growth has significantly contributed to the improvement of Colombian citizens' income and welfare, it also has been marked by clear environmental deterioration and by the aggravation of problems such as deforestation, biodiversity loss, and water and air pollution (Ramírez Hernández 2015).

However, little research exists in the Colombia context about the management of natural resources using participatory approaches. In consequence, the objective of this article is to integrate action research into the field of natural resources efficient management. This document is an example of how the design of proper technological solutions for conserving water in a Colombian rural region can be carried out. The technology, understood as a complex system of relations between artifacts, users and knowledge, does not create the change per se (technological determinism), but it rather allows the transformation process within the systems which it is implemented (Osorio 2003). The challenge that should cluster collective efforts, as Orlando Fals Borda used to say, is the communication between the research world and the real world. The understanding of social systems, and their close relation with the natural systems, gives sense to the collective research actions that lead to an efficient management of any natural resource (Rammelt 2013).

This paper is divided into four sections: first, authors present a brief theoretical review that introduces the concepts of participation in action research, systemic participatory design, and sustainable development. Second, a presentation of a systemic, participative, collaborative and integrative methodology for the construction of prototypes of technological solutions was made, highlighting the importance of this methodology for water consumption in a rural region. Third, authors include a description of the study case and of the processes that were carried out for the participative and prototyped design of a virtual learning community for sharing practices and experiences regarding water conservation. A final discussion presents several conclusions that generate relevant questions regarding the application of these approaches in different contexts.

Literature Review

Participation in the Action Research Context

The participative processes are an opportunity for social learning (Nokes-Malach et al. 2015) and innovation (de Guerre et al. 2013; Estensoro 2015), encouraging the community's commitment with social changes. For example, Cuéllar-Padilla and Calle-Collado (2011) show, in the context of organic producers in Andalucía, the importance of a collective identification of a common goal to generate, share and analyze information that allows them to establish priorities and to develop strategies. Moreover, these processes create new ways for accomplishing established objectives, as it occurs in the case presented by Langdon and Larweh (2015). There, the participants realize–individually or collectively– how they must change their behavior to have their priorities properly addressed.

This generates a stronger sense of belonging, which in turn encourages people to keep participating in the projects, especially when obstacles arise (Durston and Miranda 2002). A well designed participative process may help to solve or handle conflicts through the creation of a common ground for negotiation for every party involved (Al Lily 2013). Later, detecting and solving these conflicts in the initial stages of a project helps to reduce the costs of supervision (vom Brocke and Lippe 2015). Moreover, designing solutions for shared resources issues that reaches a consensus, demonstrate the advantages of the participative approach in research. Examples such as those of Trimble and Berkes (2013) and Rammelt (2013) show us the benefits of collective processes regarding decision making processes which are environmentally sustainable, just and rational, as suggested by Kemmis et al. (2014).

The empirical approaches in action research, from Kurt Lewin up to the present (Fals-borda 1987; Stringer 1999; Cuéllar-Padilla and Calle-Collado 2011; Mackenzie et al. 2012; Kemmis et al. 2014; Langdon and Larweh 2015), show the importance of grounding the development processes on systems of values and cultural norms that underlie the social fabric of communities. According to the action research theory, people participation is a continuous process, based on results and with a continuous identity construction by the participants, as shown in Arias et al. (2016).

Action Research and Participative and Systemic Design

The systemic aspects within action research look to keep the people in contact with the process, in a participative way (Flood 2001; Yu and Hong 2016). This characteristic allows understanding the intrinsic and structural relation of the social and natural systems. A tool that helps to understand this complexity is the actor-network theory (Latour et al. 1992). Using network representations, the actors of a social system (individuals or institutions) can be mapped inside the current situation of their communities, with the technology or the problems playing the mediation role (Sage et al. 2011). Additionally, it allows the professionals and theorists to understand the problems and the proposed solutions (Floricel et al. 2014).

Also, the design, from a collective perspective, favors the interaction among the different parties involved and the discussion regarding the design itself (Barcellini et al. 2015). For example, the design of the community of practice in Korea allowed effective problem-solving strategies through a common generation of root definitions (Yu and Hong 2016). Another case which exemplifies the benefits of participative design is the IDEA project (de Guerre et al. 2013) where, using design thinking and systemic thinking, a methodology for generating prototypes for solving problematic situations within companies is designed and applied. These examples show the importance of participation in the solutions design process, a key aspect of the experiences.

If, for example, technology is regarded as part of that participative design scheme, the idea of building it in a participatory way gains further sense. Also, this is in line with the action research guidelines, as it seeks that the actions being carried out achieve the objective of creating with a purpose (Whitehead 2005). This aims to accomplish designs that go beyond the device itself and are connected to the four domains of design and construction proposed by Laszlo (2014) and Rousseau and Wilby (2014). First, on an intrapersonal level, the design addresses the identity of the participants and their skills and expectations (e.g. Jimoyiannis 2010). Second, in the interpersonal level, it favors discussions and collaboration among individuals belonging to the same or to different contexts, leading to the development of solutions and prototypes that fit their own needs, culture and values (e.g. Asaro 1999; Ramírez et al. 2015). Third, if we think in the relation with other species, the design and construction also address the needs of the environment (e.g. Straussfogel and Becker 1996; Xi and Poh 2013), favoring a sustainable development perspective, the fourth domain, and envisioning the future as part of the design process (e.g. Ramírez et al. 2012; Barile et al. 2014).

Holistic Sustainable Development

A fast-economic growth of countries, access of products due to free markets, technology transfer, and growth in capital flows are some of the key aspects around which the sustainable development has been conceived (Espinosa and Walker 2011). The implementation of these proposals in the rural areas has shown the negative consequences of this neo-liberal position (Bardy et al. 2015), which ignores the role of the environment and the relations between the social and the ecological systems (Andrade et al. 2011). For Espinosa and Walker (2011), this is a consequence of the existence of non-holistic hypotheses regarding development, which assumes that the possible courses of action towards a state of development should be designed. Some of these hypotheses, such as finite knowledge, determinism in modelling, and calculable results, contradict the principles of systemic design itself. Therefore, a new source of fundamental values regarding sustainable development must be adopted, one that allows the design and redesign of the systems to be considered.

The complexity theory and different approaches of systemic thinking give us a broader look of the sustainability concepts, in contrast to the neo-liberal position. These approaches allow researchers to face some of the previous hypotheses through holistic lens. The first of these aspects, which opposes the basic premise of the neo-liberal sustainable development, is the existence of limits for growth and development. If the conditions for the conservation of consumable resources, such as water, are not met, it won't be possible to generate acceptable levels of basic needs satisfaction and therefore, to build viable and sustainable development roads (Espinosa and Walker 2011). Alternatively, from a complex adaptive systems perspective, the need to forge local relations has shown to cause an impact on the behaviors of the systems on a global level (Iñigo and Albareda 2016). Finally, and connected with the characteristics already mentioned, it can be argued that sustainable development is an emergent property because of the local and continuous interactions, which understand the characteristics of the surrounding context, and not only an assigned value. Summarizing, this perspective opposes the idea of economic growth and turns it into a qualitative unfolding of the systems' potentiality through the enhancement of their complexity (Bardy et al. 2015).

Thus, sustainable development is both a social process and a solution-development process, which may have a technological nature. According to Espinosa and Walker (2011), this can be understood under three different criteria. First, coevolution with the environment concerns the construction of an identity that allows addressing the changes in the environment and becomes a facilitating aspect in the decision-making process. Examples such as that of Imran et al. (2014) seek to generate these capabilities within an ecocentric identity, whereas others such as Mohamed et al. (2010) proposes ICTs (Information and Communication Technologies) as key elements in the generation of sustainable development knowledge. The second criterion, cohesion and autonomy, seeks independence through the generation of an organizational closure, while it simultaneously creates mechanisms for managing the information pertaining the critical aspects of its own sustainable development. For example, Fratini et al. (2012) show how the adaptation of the water management system depends of a transition towards the closure of the system, which, in turn, accounts for the micro, meso and macro patterns of consumption of the resource. Third, the generation of links in each level, from the individual decisions to the global level, creates sustainable governance. In this dimension, an interpersonal and intertemporal participation of the local actors is achieved, as well as a holistic approach (Bardy et al. 2015). In conclusion, by including these three criteria in our definition of sustainable development we can generate a governance process for sustainable development from a systemic perspective.

Methodology

Given the theoretical context analyzed above, a methodology is presented. This methodology integrates three major theoretical components for generating technologies with a social impact: i) the participatory dimension of action research; ii) a systemic design; and iii) a holistic view of sustainable development.

To develop this type of proposals, with low environmental impact and high social impact, the different stakeholders involved must participate in their design. Therefore, the proposed methodology could:

- Create value from the different participants' knowledges and experiences.
- Build collectively a sustainable technological proposal.
- Generate discussions about proper technologies given the socio-environmental context.

In other words, the design of a technology must be based on the principles of systemic design. This methodology considers identifying: i) the key social and environmental variables for the adoption of the technology; ii) the different interested stakeholders; and iii) the relations between the physical variables, the technology, and the stakeholders.

As a result, to create this systemic interaction it is important that, during the design process technologies are co-constructed by the stakeholders. Therefore, developing the projects actively and integrating every person interested through *Participatory Action-Research (PAR)* is fundamental. The community participates in the assessment of their problem and in the implementation of the projects, usually focused on natural resources and their sustainability. This is an appropriate method for working with the rural communities, as it encourages the emergence of sustainable solutions, it generates a progressive change in society, it increases the community's level of participation, and it allows feedback and amending the proposals (Ramírez et al. 2011). These principles are summarized in the Fig. 1.

The integration of PAR as a main feature of the research process in engineering projects allows the emergence of sustainable attributes previously mentioned, and the orientation of development inside this framework (Ramírez et al. 2011). Accordingly, to achieve a result that is also systemic and allows to integrate the visions and perspectives of the participants, a structured vision is required. For this, an integration of the SSM into the methodology development is proposed. This soft approach for system improvement emerges as an alternative to situations in which there are no clear definitions of system and problem modeling, usually unstructured, to provide participatory and active solutions (Checkland 1992). Furthermore, the feedback process of SSM is iterative, using systems concepts to reflect and debate the perceptions of the real world, carrying out an action in the real world, to reflect again on the events that caused the use of these systemic concepts (Checkland 2000).

This integration between SSM and PAR relies on two main characteristics of the system thinking. First, even when some of the theorists of system thinking believe that systems can be identified and improved without internal intervention, every activity in SSM is an action research process in which participants take part on purposeful actions (Checkland 2000). These group of purposeful actions, in addition, can be linked to understand the purposefulness of PAR interventions. Second, SSM include the participatory side of action research by including the people's perspectives, experiences and intentions in the social construction of reality (Flood 2001). These components are not only included but analyzed and legitimized through root definitions and conceptual models (Checkland 1997). Therefore, it is not only natural, but desirable, to link the systemic intervention methods with action research.

The classic model of the SSM has seven steps, divided into cultural and logic-based investigation. By cultural investigation, this model acknowledges the process of decoding the problematic situation into expressions of the system that permits its contextualization. In other words, the cultural investigation evaluates the intervention itself, as well as the existing social system and the current political moment. The logic-based investigation includes the understanding of the existing system, wherein the naming, the modelling of the solution, and the comparison of the chosen systems

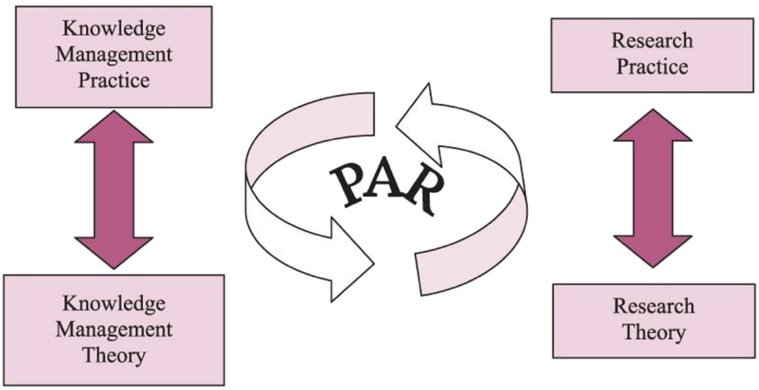

Fig. 1 Characteristics of Participatory Action-Research (PAR). Adapted from Fals-borda (1987)

takes place. Figure 2 shows the conceptualization of the seven steps of the methodology.

However, this proposed methodology for sustainable community intervention was adapted using actor-network theory (ANT). The use of conceptual models, according to Checkland (1997), is to accomplish what was included in the root definition. In our case, this relation of being and doing is a relationship between technology change and society. In consequence, the use of ANT reflects this structural change and complement the comparison with the real world by including both purposeful action and non-human actors in a single model. In addition, this methodology allows researchers to study deeply the learning process of SSM (Checkland 1995) by mapping and making effective distinctions between environment and society. Therefore, the adaptation and integration of the methodology into the sustainable and participative development model has the following steps:

Undefined Problematic Situation

As a starting point for understanding the development of projects, it is important to consider the formal visions of development on the national, departmental and municipal levels. Sometimes, collecting information about personal development could be helpful to meet their expectations during design process. To make this possible, it is required to design and develop a series of individual meetings with the relevant stakeholders, with the purpose of building a basis of knowledge that allows to structure the root definitions, and, at the same time, that provides a starting point for the conceptual models. This process allows the identification of relevant stakeholders regarding technological proposals with social impact. The information gathered with the community can be summed up in a series of key questions that lead to a full understanding of these visions of development and their expectations about possible technologies, without arriving to the problematic situation in detail.

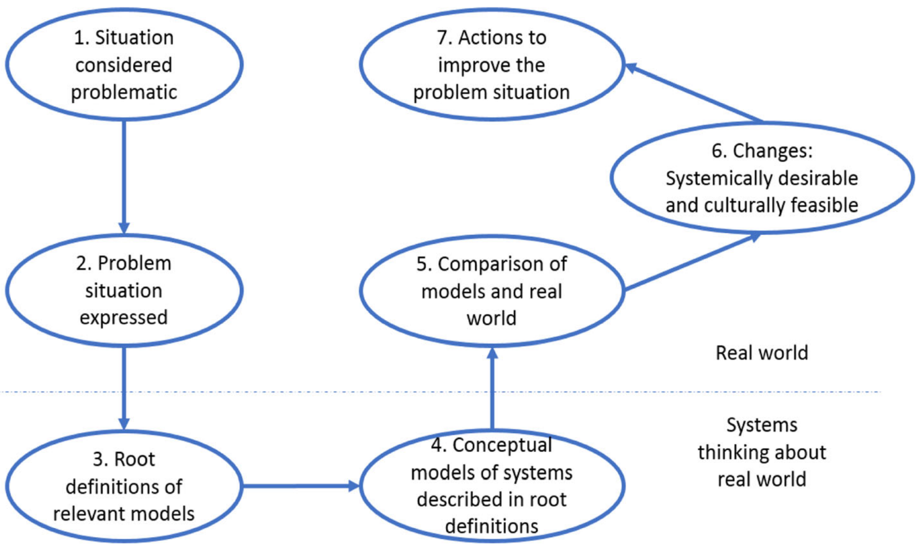

Fig. 2 The SSM process. Adapted from Checkland (1995)

Problematic Situation Expressed

Once the interviews are completed, the idea generation process begins, and the initial sketches of the situation are made. These pictures must be the result of representing real life situations that have been abstracted throughout the research and of the active participation processes of the community.

Root Definitions

After having obtained the information required for an appropriate knowledge of the problematic situation, the root definitions are built. These tools will be used for understanding the problematic situations, incorporate the necessary systemic objectives, and build an identity for each one of the problems presented. These root definitions should show the concepts of technology, development, sustainability and community. These definitions show, in addition, what relationships of the previous concepts should have within its context.

Systemic Design of the Proposal

Throughout process, the objective has been to achieve an understanding of the problematic situation, and to compose the diagnostic core of the SSM. The gathering of this information, the "embrollo entendido" (Aldana and Reyes 2004), is used to implement an intermediate work tool that will conduct to a precise formulation of the project to be implemented. Therefore, a model must be created with the highest capability of adaptation to the context possible, resilient to the characteristics of the surroundings, and able to capture in an integral way the socio-environmental context.

The tool with the aforementioned characteristics is the actor-network theory (ANT), and specifically the socio-technical networks (Sayes 2014). Bruno Latour and other researchers developed this theory inside of the area of Science and Technology Studies (STS) to understand the interaction of the actor (Latour 2005), whose activity consists in intertwining heterogeneous elements, and simultaneously coevolving with the environment (Ing 2013). This approach implies not only the resolution of techno-scientific problems (e.g. technological design), but also changes in the social structures. Furthermore, ANT could be useful to understand that the design must not become a science fiction experiment but an achievable result, can be redesigned and assure continuity throughout time or context (sustainable). In order to accomplish this, innovation is defined here as a process of development of socio-technical networks whose nodes are human (social) and non-human actors, implying the integration of different dimensions of a social reality (Latour et al. 1992). This type of networks allows seeing the attributes of the complexity that will be studied, as well as the key aspects of its relationship with a sustainable development, as it is proposed by Righi and Saurin (2015) on Table 1.

This tool will allow the researcher to visualize the non-explicit complexity of the relations between the actors, the projects of the communities, the devices existing within its context, and, above all, the influence of the products or results of the science, technology and innovation projects on the contexts that make part of the research. Thus, reflection and debate are structured through the use of SSM methodology, which allows a clear diagnosis of the situation, while the action of the methodology will be guided by

Table 1 Attributes of the complexity seen in ANT

Attributes	Key characteristics of the attributes
A considerable number of elements interacting dynamically	Systems change over time. Interactions may not be lineal. Interactions take place between pairs of elements that are close from each other.
Great diversity of elements	The elements may be differentiated according to several categories such as hierarchic level and specialization. The nature of the relations between the elements display diversity in terms of aspects such as level of cooperation or degree of shared goals.
Unexpected variability	Complex systems are open, which means that they interact with their surroundings. Emergence refers to an unexpected manifestation of the variability. An emerging phenomenon arises from the interaction of the elements, regardless of any design or central control.
Resilience	The performance adjustment is guided by feedback from recent events and from the early organizational history. Self-organization allows a complex system to develop or change its internal structure in a spontaneous and adapting way, to deal with its surroundings.

the interaction of the community with their socio-technical networks, which allow them to see problematic situations such as the convergence of complex material and social influences.

Desirable Changes and Improvement Actions

Once the problematic situation has been considered and negotiated with the stakeholders, and the conceptual model has been created, it is necessary to consider which change actions the system requires to accomplish the expected goal. These changes are possible through the identification of feasible actions with the stakeholders and the consequent evaluation of these actions in terms of the socio-technical networks previously developed. Given the nature of the project, these changes may be of three types:

- Structural: The structural changes take place in the static elements of the system, such as the agents' arrangement. In the case of the socio-technical networks, these changes are noticeable through changes in the relationships or the existence of new nodes.
- Procedural: The procedural changes take place on the dynamic elements of the system. They can be, for example, the information systems within the system. In our socio-technical network, these changes are noticeable in the existence of intermediaries between the agents.
- Attitudinal: This type of transformation is the hardest to identify and to achieve, because it regards changes in the intangible characteristics that compose the individual and collective conscience of the human groups, such as modifications in the expectations of the system.

Through the understanding of the dynamics of the network proposed, the improvement actions to be carried out are determined; these actions will be accompanied by the expected social processes.

Case Study

Project Background

The Sabana Centro and Guavio provinces have substantial water abundance. The Guavio province, a major producer and water supplier for Bogotá, has a frail ecosystem, and factors as the demand of land for housing and its proximity to the city lead to a mining over-exploitation of large volumes of building materials and to the deforestation, gravely deteriorating the environment (Cámara de Comercio de Bogotá 2010). This region, comprised by the municipalities of Guasca, Gachetá, Ubalá, Gachalá, Junín, Guatavita, La Calera and Gama, is characterized by its natural resources and by the diversity of its topographical elevations, providing 70% of the water consumed in Bogotá and 20% of the energy for the country (Instituto Alexander van Humboldt 2011).

This has led to a general misperception of the availability of the water resource, as several factors such as the climate change, the extensive stock farming, the mining activity, and unregulated economic development, among others, are affecting considerably the hydric sources of these regions and endangering its water sustainability. In effect, bad practices among the local population in the management of the water resource can be identified (Corpoguavio 2012), leading to its inefficient consumption and waste.

Undefined Problematic Situation

As a starting point for understanding the dynamics of the population, technology involvement and the relationship of the community with their surroundings, we established a series of questions pertaining the information gathered during the exploration visits. From this experience, the principal result is that educational institutions and students have a key role on their context as change makers.

The first strategy to integrate this result was to define how the students should be integrated into a possible project for water protection and the required participation process. The educational institutions manifested their interest to participate actively and support the process, which was essential for motivating the participants. After researchers completed an initial agreement with nine educational institutions, the process to get to know the perceptions of the academic community. Students fulfilled a survey that provides a baseline for about their ideas about technology, educational systems, perspectives about their future, and their relationship with the environment. Meanwhile, different stakeholders were contacted, such as the mayor offices, the governmental secretaries and the environmental authority of the region, Corpoguavio.

The topics that oriented the process and the results of the inquiry process were as follows:

Stakeholder Identification

A total of 1214 students participated in the first stage, from 10 educational institutions from nine of the municipalities involved. 50.6% of the participants were between 14 and 15 years old, while 72.2% were between 13 and 15 years old. Most of the students were in their last 2 or 3 years of high school and the distribution between males and females was almost equivalent. Regarding family composition, most of the households had between one and two children, and very few had over four children; for around 30% of the families the mother is the head of the household; and the level of education of the parents is predominantly medium, most of them having finished elementary school and a considerable part high school.

Resource Availability

The main aspects to be considered for the participation of the students were:

- Regarding connectivity, it was found that 90% of the students have a cell phone. Half of these cell phones are smartphones. The students use their cell phones mainly for listening to music, taking pictures, playing and texting.
- Only 1/6 of the surveyed students do not have access to the Internet. Those who do, connect to the Internet mainly through their cell phone, or at their homes, or from a cybercafé. Facebook is the preferred social network. Although having Internet access in the towns where the project was to be carried out was an initial requisite, after the initial visitations, it was found that most of the schools lacked the Internet service.
- Moreover, not every student had a water meter. A strategy had to be designed so these students could measure their consumption. The strategy consisted in taking an approximate measurement of the consumption water based on volumes and times.
- Regarding the teachers, it was found that they had a great autonomy. They decide factors such as time, spaces, and internal and specific strategies for each school. Therefore, the communication with the teacher will be fundamental for the success of the intervention in each school, because the acceptance process begins with the teacher that wants to become a supporter of the project.

Expectancies and Shared Ideas

Given the advancement and the needs of the community, the participant and researchers point out that their main concern is to achieve the sustainability of any initiative through:

- Participation of the relevant actors to generate a social appropriation of the project.
- Empowering students with tools that allow them to manage properly the water resource.
- A central question throughout the initial process was how a constant environmental education can relate to the proper management of the water resource be sustained in the educational institutions.

Measurement

Given the complex set of situations, and not only the technological aspects, three approaches for evaluation were considered:

- Sustainable technological development: The search for new technological tools must be in harmony with the cultural, social, and economic context of the students; furthermore, the interactions with the environment must be taken as a major concern.
- Personal and institutional appropriation: The impact of the effective implementation of these technologies must be measured, both for the students and for the institutions in order

to identify the organizational component of the technology applied, as well as the knowledge generated.
- Participation in the projects: Finally, it is also important to determine how participation influences students' perception of water consumption; therefore, it is important to know their perceptions regarding the efficiency of participatory process in their own consumption.

Other aspects considered fundamental for implementing a solution that has applicability within the described context, and pointed out by the participants during the inquiry phase were:

- The project will take advantage of the science, the culture and the technology to provide an integral education that favors sustainable development. Indeed, there are contemporary tendencies toward the application of knowledge in these areas, which the students must use for their benefit. Therefore, these tendencies on environmental teaching will be exploited in the project.
- The formation of students has a vocational and social basis. Therefore, including an educational focus oriented to the current and future life, it will be vital for any project that includes ICTs to support the development of basic and applied competences which are regarded as necessary for a future success in their academic and professional lives.

A possible project to tackle the problematic situation with water consumption should seek to foster the water resource management capabilities in the 10 municipalities of the Guavio and Sabana Centro provinces (Cundinamarca), through a social appropriation of the proposed innovations (Universidad de los Andes and Corporación Universitaria Minuto de Dios 2014). This proposed project will work with 1500 high school students from the region. In the project, students must be considered as major actors, and it will envisage their active involvement using participation techniques and information and communication technologies (ICTs). The goal is that the students gain technology and innovation knowledge related to the water resource, which will conduct to interactive participation through information systems, technological competences, development of prototypes for water conservation, and management of the generated knowledge.

The modelling and general definition of the current project took place during the second semester of 2013 and 2014. During 2015 and 2016, the project was carried out in all the participant high schools. Afterwards, the project should be sustainable and have continuity over time, both in the technological and in the human resource.

Situation Problem Expressed and Root Definitions

A series of specific interviews were conducted with different actors of the community who take part in productive, educational and political activities, to characterize accurately the perceptions of the community. As support material for the idea generation process, initial sketches of the rich pictures were presented, along with situations in which the participants could see the needs, strengths and concerns regarding the problematic situation. It should be noted that, although the different interviews, workshops and visits revealed several problematic situations, the analysis of this material suggested that the most important subjects for the community could be classified into three groups, given the characteristics that the community itself attached to each problematic situation. For our case study, it is sought that students are the main actor and change makers, so problematic situations are expressed in terms of the relationship of students with their social systems. Below are presented the rich pictures made with the community throughout the research.

Problematic Situation: from the Students to the Institution

The following rich picture (Fig. 3) presents the problematic situation perceived regarding the environmental and social education given by the school, the education that the students consider necessary, and their relationship with technologies. It is built based on the information gathered during the interviews and it allows seeing the opinions of each of the relevant group of actors.

The objective intended to ascribe to the current problematic situation can be summarized in the following root definition:

> The participating schools could integrate their study plans and aim them to the continuous improvement of the students, to help them achieve their motivation and take advantage of their capacities. This must be mediated by the available technological tools.

Problematic Situation: the Students, the Government, and the Non-governmental Organizations

The following rich picture (Fig. 4) presents the problematic situation perceived regarding the government and non-government institutions, the perception of the

Fig. 3 Rich pictures of the problematic situation related to the educational institution

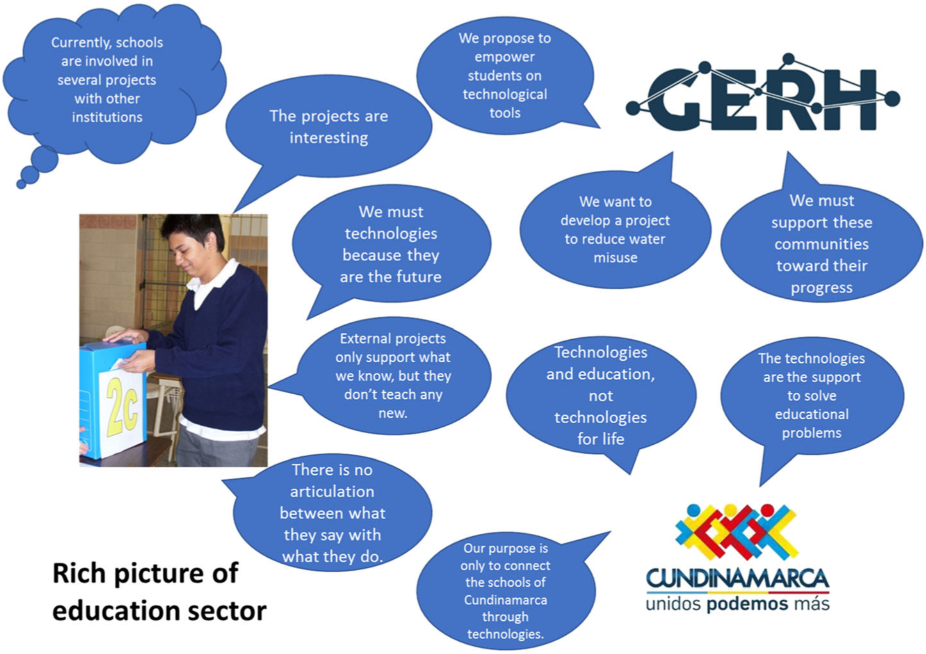

Fig. 4 Rich picture of the problematic situation related to inter institutional relations

students about the utility of these relationships, their response to the proposed projects from this institution, and their relationship with sustainable development. In the following image, GERH (Efficient management of water resource, by the acronym in Spanish) is the name of the main project, and it will represent the opinions of two non-government institutions: Universidad de los Andes and Corporación Universitaria Minuto de Dios.

The objective intended to ascribe to the current problematic situation can be summarized in the following root definition:

> The schools of the region, along with other educational institutions, whether public or private, must provide the tools that support the learning, the development of science, technology and innovation capabilities, and the construction of life projects for the students; this should lead to the empowering of these projects among the institution, the students, and the community.

Problematic Situation: the Students, the Educational Institution and the Productive Sector of Guasca

The following rich picture (Fig. 5) presents the problematic situation perceived regarding the practical education they are receiving at school, their life plans, their response to the situation in the Guavio and Sabana Centro regions, for the local producers as well as for the public entities and their relationship with the current educational model.

The objective intended to ascribe to the current problematic situation can be summarized in the following root definition:

Fig. 5 Rich picture of the problematic situation related to the region

> The participating schools, the civil society and other educational institutions must seek to provide the students practical knowledge, as well as opportunities for the community to build themselves the future of their region. The ICTs could also help in this process of transformation.

Based on these rich pictures, participants created a root definition where those three controversies were included. This root definition was written with the community by using the mnemonic CATWOE. This selection of the actors and clients was also framed using ANT, where technology and non-human actors are essential and have agency for the model. The results were:

- Clients
- The students from K8 to K12 of the public institutions of the Guavio and Sabana Centro regions.
- Professors and administrative staff of these institutions
- Actors
- Technology: Laptops, mobile phones, water saving prototypes
- Professors and students of these institutions
- Universities and research centers involved
- Civic organizations and environmental protection departments
- Transformation
- Using participatory design and engineering tools, create initiatives for the appropriate management of the water resources. These proposals must be related with technology, science and innovation, and each activity must be oriented on developing capabilities for the students and the future generations. Finally, every element of the initiatives is related with the community by creating cultural and social bonds.

- Worldview
- Improve the use and access for the future generations for clean and safe water. This must be achieved through active participation of the community, workshops about engineering tools for water saving, and technology development.
- Owners
- One of the greatest achievements of this process was that students and professor feel owners of changing their habits as much as owners of the technological initiatives. Additionally, the local and state government are owners because the schools are public.
- Environmental Constraints
- Technological constraints: Access to computers, internet, technical knowledge.
- Budget constraints: As every public school in Colombia, the participant institutions only have a limited budget for materials, time and access to the students.

Conceptual Models and Comparison with the Real World

The design process of the work to be done with the students and teachers regarded the participation in activities that lead to the common construction of knowledge as the central aspect of the process, looking for initiatives and solutions of the community to problematic situations that they considered important. To determine the way the relationships between the different parties should occur, the students, teachers, and participating organizations mapped, along with the members of the team, the relations among the social actors (for example, students) and the expected dynamics (for example, knowledge appropriation).

In this way, the result of the analysis was an initial socio-technical network. This network has in each node an actor or a relevant aspect, and the distance between them represents their proximity as perceived by the participants. Thus, it could be seen that the actors were deeply polarized between the government institutions, schools, expected results and the projects' activities. Figure 6 shows the graph resulting from this process.

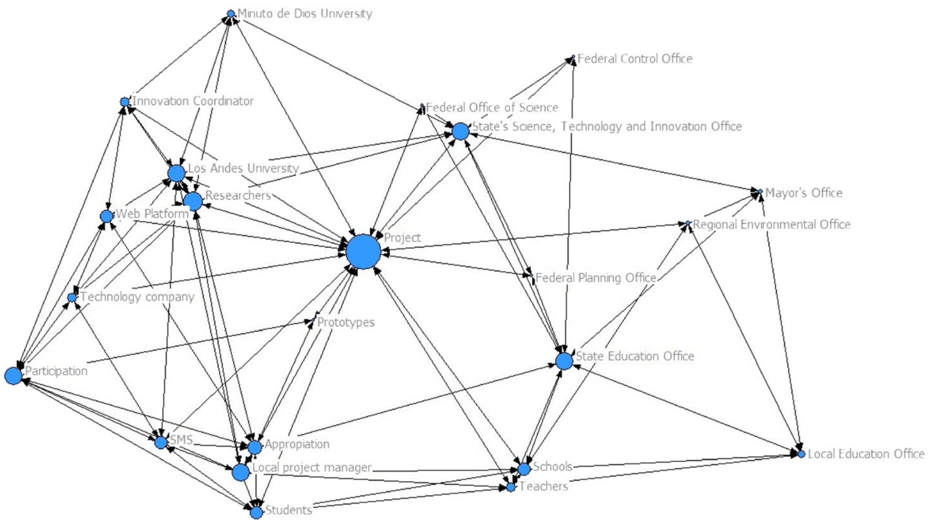

Fig. 6 Socio technical network from the GERH project, first network

This socio-technical network shows the actual state of the system and allow researchers to understand visually the dynamics of the project. From this analysis of the graphics, three main conclusions can be derived. First, the proposed project is the main node in this network, having a great node centrality and betweenness centrality. This a consequence of the level of disconnection between the government, the educational institutional and the research in our specific context. The project, therefore, is a bridge to connect these three topics for water saving. Second, both universities and schools do not have a direct relationship. Finally, the use of the technology is disconnected. Because of these three dynamics, students and researchers proposed two strategies to create engagement and awareness about the use of water (attitudinal changes), which makes possible to connect the actors (structural changes): participation using cellphones and a technological platform.

Desirable Changes and Improvement Actions

Participation Using Technologies

The first stage for conducting the design of proper solutions was for every student to become aware of his own water consumption at home. To accomplish this task, this first stage included the use of mobile technologies. The students (with and without water meter), notified the daily water consumption of their households via SMS (Short Message Service). Thus, week after week the student knew the quantity of water consumed and took decisions seeking to reduce its consumption.

The next step was to generate motivation regarding the learning of specific dynamics concerning the water resource and to raise awareness about its proper use. Interacting with a flexible technological platform, the participating students became “heroes” in order to conserve the water resources. The design of the technological platform started with the participation of the students through strategies of multiple choice questions related to water resources. The flexibility established by the methodology allows having a change dynamic that adapts to specific realities. Finally, it was possible to integrate motivation and design strategies to obtain the expected levels of participation. This specific co-creation model creates a new set of relationships between the actors to share knowledge, experiences and practices. Each student is a hero who collected information and imagine pertinent solution for own reality, and eventually created with the team.

Joint Construction of a Prototype for Reducing Water Consumption

Considering these ideas and the previous dynamics, a new socio technical network was created with the community (Fig. 7). This network represents the results of the awareness stage, where the actors integrate (Community, researchers and government institutions) and align them using technologies. However, students and community want to implement their technological ideas for water saving. Therefore, a first model of this prototype was designed with the community, a dry toilet.

One of the key elements of the project was the production of prototypes for reducing water consumption. Consequently, a research work was undertaken, along with the community, to find out which technologies could be implemented in the rural sector, where most of the students live. To select what kind of technology the community wanted to implement, a participatory selection process was carried out. The community decided that the building of a

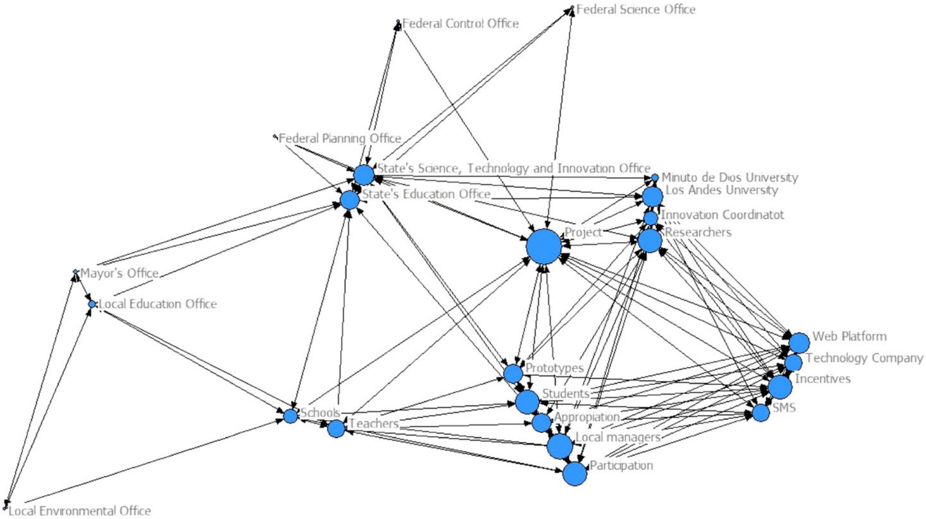

Fig. 7 Socio technical network of the GERH project, second network

dry toilet was the best option to achieve the objective of reducing water consumption, considering the easiness of construction, the replicability and the potential benefits for the community and the environment. A dry toilet is a technology that can be easily adopted anywhere, because it does not require a source of water for cleaning up, since in this type of toilets the liquids and the solids are divided, generating a process of feces composting that is useful as fertilizer. Furthermore, the urine becomes useful as bio-fertilizer. Thus, the residues are used to avoid that they become a source of pollution for the environment (Flórez 2015).

Students, teachers, and partner organizations were invited to participate in the building of the dry toilet, as well as representatives from the territorial organizations, as shown in the Fig. 8. All the participants made activities intended to explain the advantages of these devices, as well as the proper manner to build them in their houses. Thus, the participants

Fig. 8 Students and teachers in the dry toilet building activity

acquired the required empiric knowledge to build the dry toilet in their own homes. Furthermore, based on the SSM process, the stakeholder contributed to create a technological purposeful solution for the region with a strong collaboration between the participants. From this process, a book, with specific instructions and several recommendations for the self-construction of dry toilets, was distributed with the students and their families.

Co-Design Laboratories: Green and Sustainable Technology

After building the first prototype, a new exercise was proposed. This exercise involved the participation of university students with students and teachers from the participant schools. It consisted in assembling work groups, setting out real life problems and asking them to come up with solutions that were later evaluated by a group of national and international experts. Looking to encourage the active participation of the students, some challenges were posed related to the efficient use of resources such as water, energy and wind, which led to improvement proposals and actions represented in prototypes. One example of this technologies was a wind turbine, built with recycled materials, as presented in Fig. 9.

Design of the Learning Community

Initially, there was not an effective mechanism for communicating and sharing the knowledge between the participating schools in the GERH project. This absence affects the promotion of ideas, solutions and experiences among the students, teachers and other participants of the project. Looking to promote a constructivist learning approach, especially in the guidelines of the social constructivism, a prototype system was proposed. This system will offer virtual and technological channels for spreading interactively the information among the participants and the people interested in the project, including those that may want to replicate this type of projects in other contexts, such as natural resources preservation.

One of the results of a workshop held with the teachers from the educational institutions that participated in the GERH project was the proposal of designing and building a prototype

Fig. 9 Participatory construction of prototypes of wind turbines

of a learning community that uses a virtual education approach. By learning community, we refer to a technological tool that allows sharing a group of successful educational experiences oriented to social and educational transformation (Pavía et al. 2010) of the teachers and principals that participated in the GERH project. This initiative addresses the need of giving continuity to the work being done by the participants, as well as to their interactions around the water conservation issue. It is also a response to the call from several actors from the community who asked the research team to prolong the work done in their region by all.

This learning community has the following characteristics:

- To guarantee that the participant actors of the GERH project had access to the information, this learning community is hosted in the La Liga del Agua Platform. In this way teachers, students, principals and researchers have access to this tool, favoring horizontal relations among the participants (Lleras 2002).
- Knowledge is dynamic; therefore, each participant may contribute in this community.
- It intends to give voice to every participant; to this end, several videos, infographics, interviews and other tools for visualizing the knowledge generated were created. All of this is sorted by modules and theories, as it is used in virtual education courses.

The system developed is a graphical and interactive web application that provides information about the organizations, collaborations and resources in the form of graphs. It facilitates, through an administrator module, the management of all the existing information as integration project and social learning. To this end the following objective was established: analyze, design, develop and implement a technological solution that facilitates the integration, interaction and communication among the organizations and partnerships related to the GERH project.

The “Learning Community” prototype is a social construct, conceived collectively for everybody’s benefit, and accessible for everyone. To this end, a new module was added to the application that the actors of the project already know and have appropriated to some degree: the Liga del Agua Platform. Finally, the socio technical networks used in the process are explained and implemented in an interactive interface (Fig. 10).

Fig. 10 Socio technical network representation in the Liga del Agua platform

Discussion

Three main achievements resulting from this research must be highlighted: first, the processes of action research allowed the members of a community to make relevant their relationship with technology, social systems and educational systems. This was achieved through the understanding of social constructions using a participatory evaluation of the relations between students, teachers and institutions, and making them visible for everyone using socio-technical networks. Second, the process of imagining, creating and prototyping a technological solution, carried out using the Soft Systems Methodology (SSM), is also an action research process in which the participants, particularly the students, play a leading role. Therefore, the design is also systemic, and it accompanies the research of the participants in the social, ecological and technological levels. Third, the technology is cross cutting in the development of a vision of sustainability. The importance of the relation between the technological systems and the environment by using ANT was fundamental, since it encompasses almost everything, from the way people use their cell phones, to the possibility of designing a platform that improves the management of natural resources.

During the set-up of the proposal four big challenges were identified. These challenges must be faced by anyone who conceives a social project that, among its goals, aims to generate a positive social impact, minimizing the harm on the environment. Properly addressing these challenges is fundamental for successfully accomplishing this objective:

i. Changing the context conditions (adaptability)
ii. Integration of small efforts to create attitudinal changes
iii. Determining the focus of the research (the people or the science?)
iv. Empowerment and sustainability

The constant and continuous implement of SSM methodology shown that working and learning through collective actions increases the chance of transforming a given situation, enables the development of a creative thought – through learning-by-doing– and it encourages the individuals of the community to develop autonomous thinking, while motivating them to actively engage in the system. In addition, this made it possible to articulate some recommendations related to functional, structural and attitudinal issues, with the purpose of addressing the systemic problems that emerge in human activities and that interfere in the actors' functions, and in their relations. It is important to point out that the SSM permitted to identify collectively the principal opportunities and to co-design the solutions sharing the different stakeholder knowledges.

Also, there is an emerging need in the social project generation framework to define structurally the role of the community and their participation, because as it was mentioned through this document, omitting or poorly addressing this subject may entail fatal consequences for the projects. Nevertheless, it is important to remark that this is not an imposing methodology, on the contrary, it seeks the integration of both formulators and participant actors involved in the project, building robust social structures that correspond to the common goals, which are defined collectively based on the individual aims.

Likewise, the integration of a vision of soft systems with an identification of material and social actors is key to the design and implementation of systemic solutions for socio-environmental problems, such as community water management. On the one hand, that the use of the soft systems methodology allowed to identify the key aspects of the problematic situation of the community with respect to water consumption, using both technology and systemic methods. On the other hand, the use of socio-technical networks not only focused on creating representations of the problematic situation, but also on a tool to visualize viable solutions together with their interactions with existing social and material actors. Moreover, by integrating a structured vision of an environmental problem through ANT with the participation of the community through SSM, the methodology focused on a practical work that was transformed into community proposals and prototypes for the management of natural resources.

Finally, it was possible to identify a problematic situation concerning the projects with a social nature that may be approached from the perspective of operations research, but also from the action-research perspective, structuring projects society-oriented, without neglecting the research predominance. It is noteworthy that engaging in social projects from an engineering point of view requires nonetheless a support and knowledge of the different social components that are not implicit in the engineering referential models.

By using the different steps of SSM, the participation of the young people (students from the public schools) allowed not only to increase the possibility to design appropriate technology, but to increase the commitment of the schools in the rational use of water. The major lesson for the researcher is that the young students can participate with real solution to establish good practices to follow, but also think in environmental problems by coming up with innovative and appropriate solutions. Other learnings outcomes could be highlighted: during the project, on average, 11% of normal water consumption in the students' households was reduced, and it was possible to create effective synergy between real problems of the communities and educational school to design appropriate technology and reinforcing the participation. Consequently, SSM allowed identifying strong environmental problems by creating a context where the community identifies opportunities and possibilities to co-create and to participate. In conclusion, the SSM methodology is a systemic methodology suitable to improve environment problem throughout participation.

The results and findings presented in this paper could be replicated if the study's limitations are considerate. The limited time to work the students and, sometimes, its low response rate is a major opportunity. Because this study includes both members of the community, social and environmental institutions and schools, authors encourage a further additional research between those institutions, their power structure and their sharing mechanism. The inclusion of this information will be useful to understand if the use of a critical social perspective has different implications on the outcomes of this study. In addition, the relationship between action research methods and soft system methodology needs further validation. The exploration of this project and complete studies about the use of SSM and PAR could lead to confirm the results presented in this paper and to create a standard method. Furthermore, further research in three results is required: the relationship between SSM and technology usage, the technical dimension of being part of a social-oriented project and the implications of technology usage for environmental problems.

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