# RAINWATER HARVESTING SYSTEM FOR MEDELLIN'S BOTTOM OF THE PYRAMID COMMUNITIES LOCATED ON SANTO DOMINGO SAVIO

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# 1. PROJECT GENERALITIES

## 1.1 INTRODUCTION

Water reuse is considered as an option to decrease environmental impact, an issue that has become everyone´s concern. The following report exposes the results of a graduation project which has been built from a process which took a year and has potential to decrease the hydrological impact of Medellín´s BOP[1] communities, by designing a water reuse system based on *Santo Domingo Savio*[2] context. In addition, the project seeks for a social impact and considers the economical and political situation of the population.

## 1.2 BACKGROUND INFORMATION

The inadequate use of natural resources has led to a critical period, which is reflected in serious weather changes, lack of natural resources, diseases caused by air pollutants among others. However, this phenomena has also led to a new way of thinking in many scientific, academic, social, political and environmental fields around the world. For instance, by 2010 the European Union aims at a 12% decrease in total energy consumption as well as a 21% decrease in Electrical energy (GERMÁN, 2007). Spain is a clear example; the country expects to have 12.1 % of their energy sources to be renewable. This growing and green way of thinking gives the Green Construction Industry a total of 60 billion USD by 2010 which leads to a market of 30 to 40 billion USD the same year (GERMÁN, 2007). As for Latin America, developing countries expect at least 10% of their energy to be renewable by 2010 (RODRIGUEZ MURCIA, 2009).

Access to water for developing daily activities has become one of the main concerns because of its importance for the socioeconomic activities of the nations and individuals themselves. Water availability for human consumption represents less than 1% of the total water on earth. 1.1 billion people lack access to proper drinking water supply. 88% of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. 94% of these diarrheal cases are preventable through modifications to the environment, including access to safe water (World Health Organization, 2007).

[1] BOP: Bottom of the pyramid. In economics as well as many other fields, this phrase refers to the poorest socio-economic group.
[2] Santo Domingo Savio (SDS): Is a neighborhood located on the north-east part of Medellín. It belongs to one of the many city subdivision called ¨Comuna 1¨; its inhabitants belongs to the BOP communities of the city.

Colombia is one of the richest countries when it comes to water, but its distribution is heterogenic (Ministerio Colombiano de ambiente, vivienda y desarrollo territorial, 2009). Because of its location and geographical condition, Colombia has an annual precipitation of 3,000 mm, which represents a high availability of water compared with the world's average level of 900 mm and South America's with 1,600 mm (IDEAM, 2009). Colombia takes the 24$^{th}$ place among 203 countries but by the end of the 20$^{th}$ century was positioned on the 4$^{th}$ place. The drop in position is the reflection of a population growth and the consequent growth of the productive activities which affect the quality and availability of the resource (UNESCO, 2006). In conclusion, the water availability is decreasing; about 50% of the Colombian urban population is exposed to a lack of water due to the available conditions, regulation and impact over the water sources (Ministerio Colombiano de ambiente, vivienda y desarrollo territorial, 2009). In Colombia, the highest water consumption rate is in Bogota, the capital city (20%), followed by *Antioquia* and *Valle del Cauca* (18%) (Ministerio Colombiano de ambiente, vivienda y desarrollo territorial, 2009). Domestic usage represents 29% of the water demand in the country taking the 2$^{nd}$ place ranking after agricultural usage, which represents 54% (IDEAM, 2008). in Medellín the average house consumes 1.48 $m^3$ of water per day (Sistema único de información de servicios públicos, 2009) .

During August 2009, EAFIT University developed a project named HelpManuel; it was the result of joint efforts between students of EAFIT (Medellín), TUDelft (Netherlands), Universidad Técnica Federico Santa María (Chile) and the Technical University of Denmark. During the project development, through observation and contact with Santo Domingo Savio inhabitants, the lack of access to clean water was found in some areas located specially in the higher areas of the neighborhood. The Help Manuel group found places where people have to collect rain water in pots for domestic and personal use, despite of the 99.08% water supply coverage from EPM (Alcaldía de Medellín, 2005). Not having water supply is the result of poor infrastructure, low income, governmental regulations and the lack of common water meters (CARDONA, 2010).

Medellín is investing up to 190 billion pesos (63 million euro) to increase quality of life on the lower income areas of the city by implementing policies like *Medellín Obra con Amor*[3] and *Medellín Solidaria y Competitiva*[4] and created the ISVIMED[5]. The administration is

[3] Medellín Obra con Amor (Medellín acts with love): administration policy aiming to improving infrastructure on the city.
[4] Medellín Solidaria y Competitiva (Medellín Solidary and Competitive): administration plan oriented to improve life quality for vulnerable areas of the city.
[5] ISVIMED (Medellín´s Housing Social Institution): created on 2008 by Alonso Salazar´s administration.

developing the program *Viviendas con corazón*[6] which aims to build 15,000 dwellings between 2008 and 2011 (ISVIMED, 2009), this program includes the MIB[7] plan consisting on building 6,000 new homes and improving up to 2,000 more. In addition, public entities such as the EDU[8] and nongovernmental organizations like *Habitat for humanity* are being part of this social transformation. The *Comuna 1*[9], including *Santo Domingo Savio*, will be benefited with the *Parque Habitacional Cerro Danto Domingo* where, on its initial stage, 250 new dwellings will be built and another 200 will be improved (ISVIMED, 2009).

## 1.3 PROJECT JUSTIFICATION

Over the past few years, environmental issues have increased the economical investment on projects which aim to decrease the impact on natural resources and lead to their better use. On a global and national level, new policies have been created to regulate the use of the resources without compromising population needs. The use of water is one of the main concerns due to the importance of the resource. Despite the water richness of the country, Colombia´s available water sources have been decreasing due to the human activities and the population growth. In addition, this resource is not equally distributed through the territory that represents the lack of water on some areas.

Medellín is the second largest consumer city in the country. This is consequence of the amount of population and the water coverage from the public service company. Nevertheless, social aspects attribute to a lack of water in some areas and the people´s will to save the resource. The *Comuna 1* reflects that the area has water richness but some of its inhabitants, for many reasons, present shortage of it. However, the administration is developing plans aiming to improve quality of life of vulnerable areas. Much as in the context as we are designing for.

This graduation project pretends to work on a solution for the water access difficulties in *Santo Domingo Savio*, taking advantage of the administration policies being implemented, by designing a water reuse system based on the community´s characteristics.

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[6] Viviendas con Corazón (Houses with heart): Development plan belonging to the Medellín Solidaria y Competitiva and Medellín Obra con Amor policies. It aims to increase the life quality by improving the housing situation.

[7] Mejoramiento Integral de Barrios (MIB): Neighborhood improvement plan developed by the administration.

[8] Empresa de Desarrollo Urbano (EDU): Medellín's urban devolpment company

[9] Comuna 1: Medellín city is divided in 6 zones and these are subdivided into 16 communes or ¨Comunas¨. The ¨Comuna 1¨ is also called Popular and is subdivided into 12 neighborhoods called **Santo Dimingo savio # 1**, Santo Domingo Savio # 2, El popular, Granizal, Moscú #2, Villa de Guadalupe, San Pablo, El compromiso, Aldea Pablo VI, La avanzada, La esperanza and **Carpinelo**.

## 1.4 GENERAL OBJECTIVE

Design a system capable of providing water according to the *Santo Domingo Savio*´s needs, in order to ensure the resource availability for the execution of daily activities and getting the best of the surroundings and the environment aiming to decrease the impact over this resource.

## 1.5 SPECIFIC OBJECTIVES

1. Identify water consumption habits and social conditions, in Santo Domingo Savio, Medellín, that may turn into new product development opportunities.
2. Register some water provisioning and collecting systems for domestic use, that have been successfully used in developed and developing countries, aiming at similar issues, to use as possible references.
3. Enunciate product design technical specifications to develop and design the new system.
4. Generate a number of alternative solutions (minimum 3, maximum 5) which could fulfill the product design specifications, in order to evaluate and select the most appropriate one to develop further.
5. Develop a detailed design of the product using 3D modeling techniques and technical drawings
6. Elaborate of a functional model

## 1.6 SCOPE OF THE PROJECT

This project aims to improve the water use in the domestic activities of *Santo Domingo Savio* community by developing a system capable of fitting the community's needs as it makes the best use of the resource.

By the end of the project, a functional model of the system will be built based on the results of the research phase and the following design stages. To summarize, the project can be divided into three main phases: Research (“Hear”), analysis (“Reflect”) and design (“Create”). Each of these stages is described in detail in the Methodology.

## 1.7 METHODOLOGY

The graduation project seeks to bring a solution, regarding water consumption needs, to the base of the pyramid (BOP) communities located in Medellín's neighborhoods, centered on the *Comuna 1*. With such a goal in mind, the project methodology is based on the IDEO's *Human Centered Design Toolkit*; this tool presents a methodology which helps organizations connect better with the people they are designing for; it transforms data into actionable ideas and it helps to see new opportunities and solutions.

IDEO divides the methodology into three main stages: "Hear, Create and Deliver" (HCD – which also stands for Human Centered Design). Each of these phases aims at a different goal by the use of diverse methods. First, throughout the "Hear" phase the design team collects stories and inspiration from people. Secondly, during the "Create" phase, people's desirable situation, which includes needs, dreams and behaviors, is translated into opportunities and solutions. Finally, the last phase, "Delivery", realizes solutions making them feasible and viable by planning the further development and implementation.

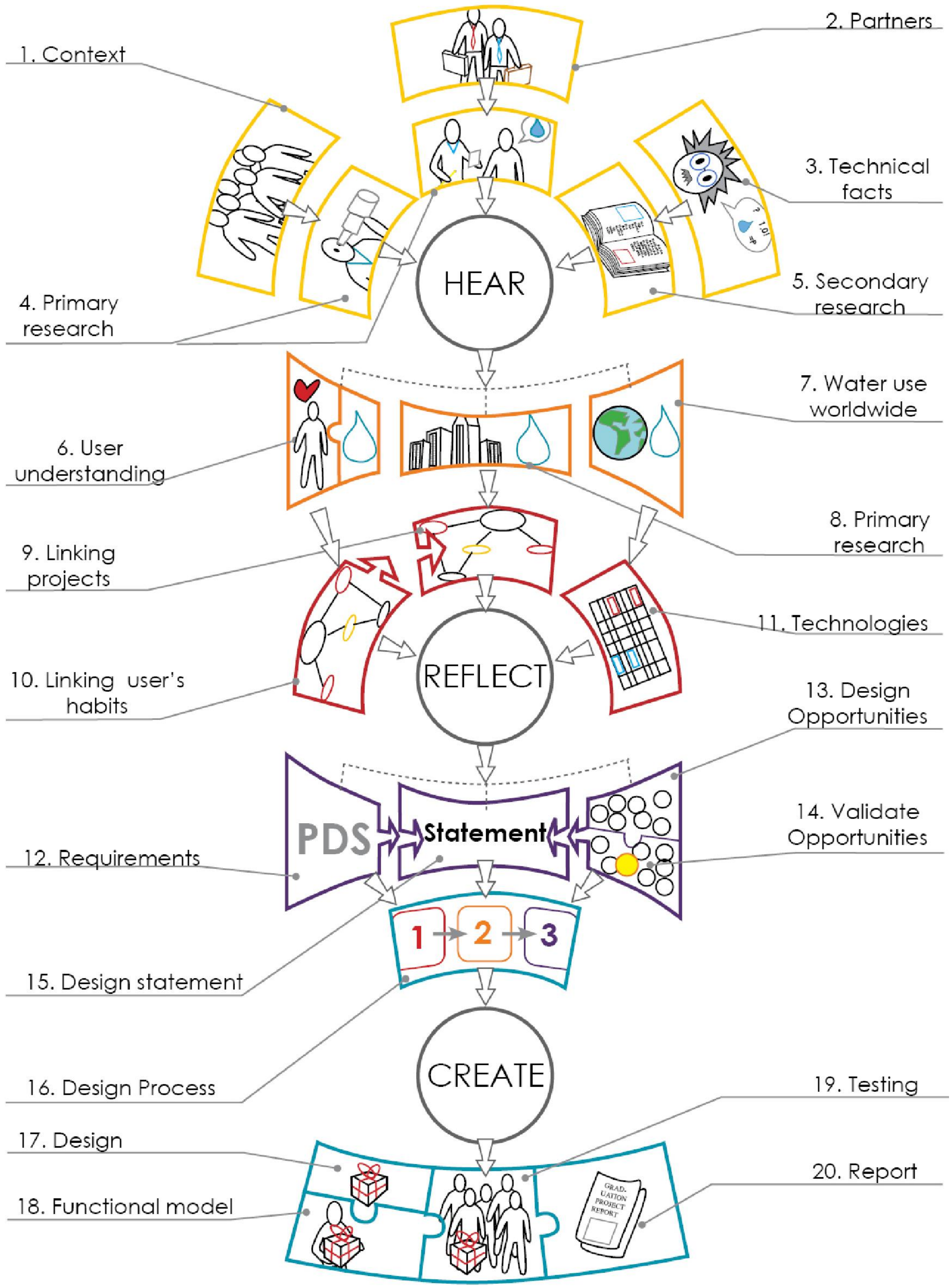
Based on the 3 stages of IDEO's HDC methodology, the graduation project is developed into three main stages: "Hear", "Reflect" and "Create". The project's three phase methodology is described below and illustrated in Figure 1. It is important to note that the graduation project does not include IDEO's "Deliver" stage since the specific objectives and the scope of the project are met with the first two steps of the HDC method

### 1.7.1 "Hear"

This phase of the project can be described as the research stage. The purpose is to obtain information from three different sources: context/community, partners/institutions and technical data. To explore the context, the main tool to use is primary research, in which observational visits to the neighborhood are made, as well as individual interviews (IDEO, 2009). With the use of these qualitative methods, deep empathy for the people is developed and new solutions are inspired.

Experts will also be interviewed in order to understand the situation from different perspectives as well as support and increase knowledge about related topics (IDEO, 2009). In Figure 1, these individuals are named "partners" due to their relevance on all project stages. These interviews seek to understand local water management and politics. Together with primary research, the first step of the project is supported by secondary research to explore technical facts.

Figure 1. Project's methodology.

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The “Hear” phase seeks to collect as much information about the community needs, expectations and behaviors and establish relations between people, places, objects and institutions surrounding a specific topic: water use in BOP communities. In addition, collected data, which includes existing technology and similar products, is used to have an idea of what is available in the market. This data serves to elaborate on state of the art technologies, which allows minimum product requirements based on existing products which solve similar issues (Baxter, 1995).

The outcomes of the first step of the project represent the inputs for the next stage “Reflect”. The “Hear” phase allows gathering information about the context, partners and technical data which influence the project. What’s more, it gives the team an emotional connection with the community which will allow emphatic design on the posterior phases.

### 1.7.2 “Reflect”

The second stage of the project consists on synthesize and interpret the research outputs. It seeks to translate the found insights into design opportunities; the filter to do so, is to keep in mind the user’s desirability. The IDEO method includes the “Reflect” stage into the “Create” phase. On this case, the “Reflect” step is considered as an individual phase due to its importance and the team’s need to clearly identify design opportunities.

Security issues represent “imaginary community policies” which make it difficult to select individuals to work with and for the team members to constantly meet up with the community during the “Reflect” and “Create” steps. The emphatic design technique consists on creating solutions by connecting rational and emotional insights; this method asks the team to design by keeping the user in mind and not judging (IDEO, 2009). Furthermore community members can be included, especially when they possess skills needed for the design and to validate the ideas generated by the design team. Emphatic design uses frameworks to illustrate relationships links between ideas and actors in one same issue and finding common themes from key insights.

From the reflect phase water consume patterns will be established, product design specifications (Pugh, 1991) will be driven and new design opportunities will be stated and validated by partners, community and the design team in order to define a design statement which will be the start for the last stage: “Create”.

### 1.7.3 “Create”

The final stage of the project, “Create”, is centered on developing solutions from the found opportunities. This phase includes a design methodology, a functional model building and a model testing. The design methodology is based on Phal and Beitz methodology which is divided in four main stages: task clarification, conceptual design, embodiment design and detail design. Each of these steps uses different tools in order to achieve a solution for the design statement established in “Reflect”.

- **Product design methodology**

Designing the product has a method of its own based on Phal and Beitz methodology. It consists of 4 stages which aim to bring the design team one step closer to the problem solution (Cross, 1999):

- Task clarification: gather information about the requirements and restrictions to be incorporated in the solution.
- Conceptual design: establish functions and solution principles and combine them in several concepts. Select a principle solution.
- Embodiment design: from the concept, the designer determines shapes and a technical product or system according to the technical and economic considerations.
- Detail design: shapes, dimensions, materials, technical aspects and economical feasibility are stated or developed as well as the blueprints and documents necessary for production.

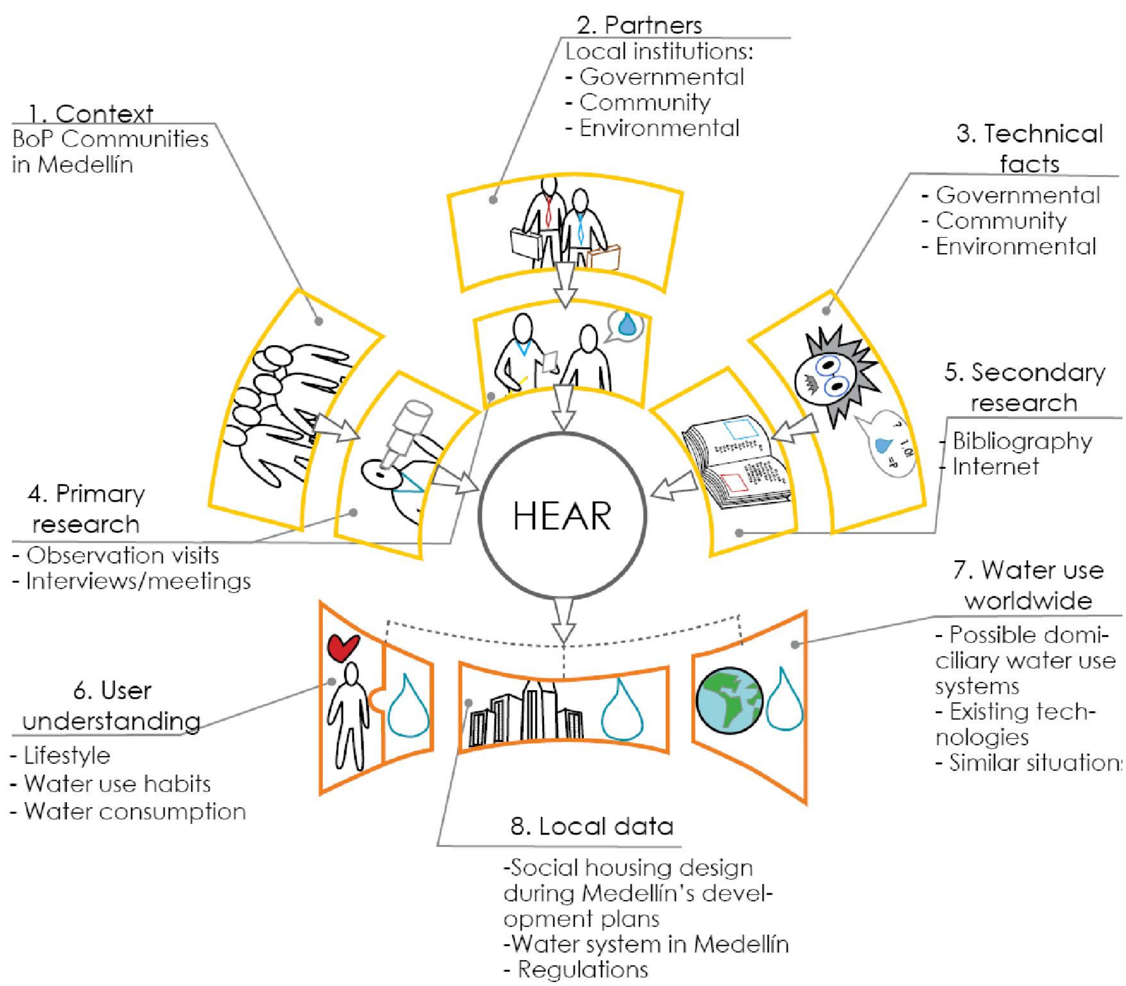
Throughout these four stages, different tools are used in order to obtain a feasible solution meeting the user’s needs. Each of the tools are described in detail in chapters 4 and 5 where the design process takes place.

## 2. “HEAR”

Qualitative methods were used as main tool for the second project phase; these research methods sought for “deep understanding instead of broad coverage” (IDEO, 2009) in order to uncover needs, desires and aspirations as well as establishing links and relations between people, places, objects and institutions around one specific topic: water use. It is to note that secondary research methods such as online and bibliography research were also a main source of information to support the on field primary research and the following design process described in the coming chapters.

The following Figure illustrates in detail the tools used during the research phase and its outcomes.

Figure 2. Hear phase.

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With this step the first two specific objectives of the project are fulfilled. Domiciliary activities where water is used are identified and similar situations and technologies research resulted on a state-of-art development. Both of these outcomes will be analyzed during the next step ("Reflect") in order to generate design opportunities.

## 2.1 PRIMARY RESEARCH

### 2.1 .1 Observation visits and Individual Interviews

Observation visits and interviews aimed to enable deep and rich view into the context; first, observation allowed us to get involved and familiar with the context. The visits were done in parallel with individual interviews in order to establish the user's lifestyle and consume habits; the main goal of these interviews was to let the community talk in their own words in order to achieve information which could help understand what they really need and/or desire. In contrast with the observation visits, interviews were done to gather concrete information from the user's perspective instead of the observer point of view.

- **Visits and interviews description**

The observation visits included a neighborhood walk with the community leaders, six house visits in the *Comuna 1* neighborhoods *Carpinelo* and *Santo Domingo Savio 1* (SDS) and one social house visit in *Pajarito*[10]. Due to security issues of these areas of the city, observation visits had to be done with community and governmental institutions accompaniment.

The hike with the community leaders consisted on visiting 5 neighborhoods of the *Comuna 1* in order to get to know the context. The walk was part of the neighborhood communication plan which aims to get the whole community involved.

Six house visits were done in the area; each visit took an hour. Four of them were done to houses located on *Carpinelo* and two of those located on SDS. *Carpinelo* homes are part of a group of houses illegally built in a high risk area. The other two houses are legally built with access to the city's infrastructure.

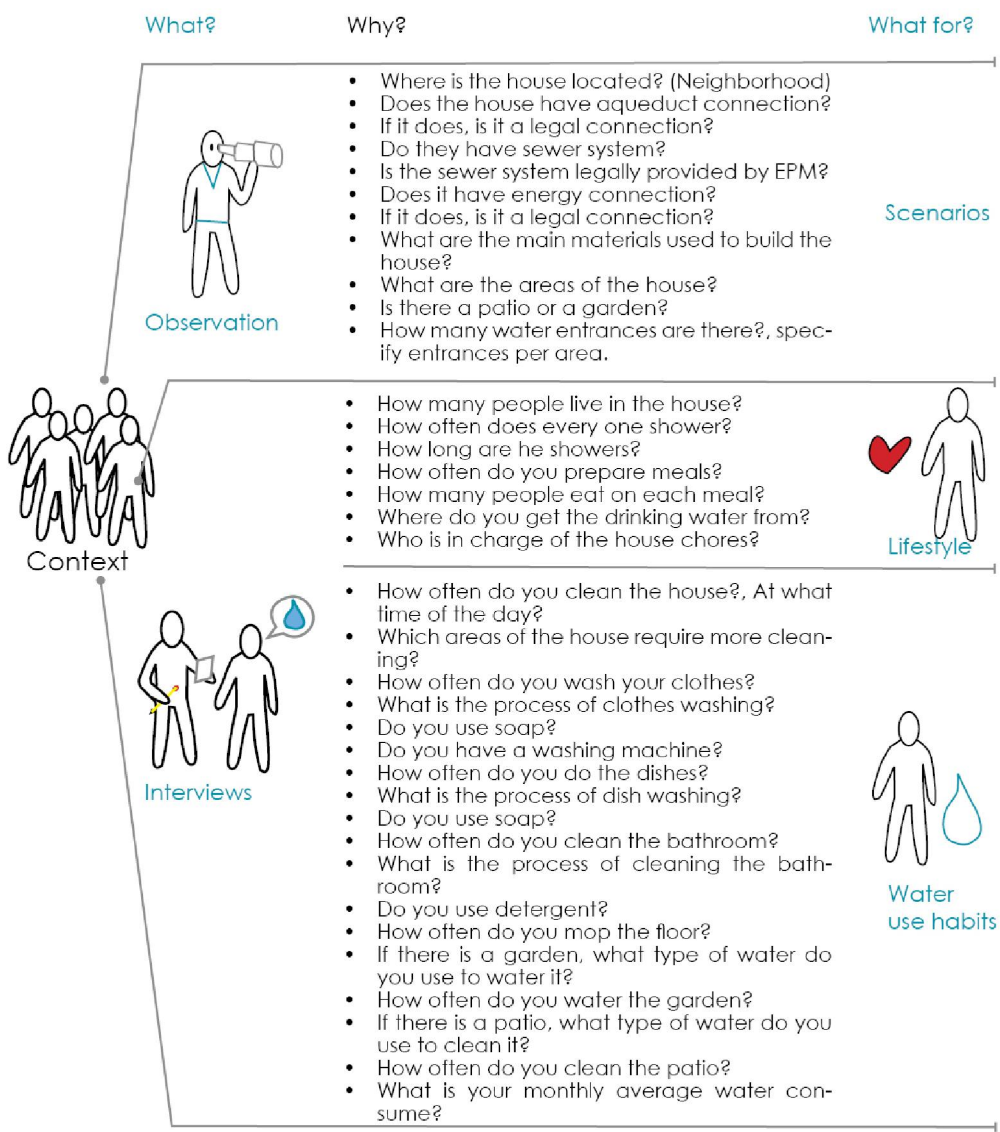
[10] Pajarito: In the same way that Colombian cities are divided in Comunas or Localidades, the rural areas close to urban zones are called ¨Corregimientos¨ and these are also subdivided into ¨Veredas¨. Medellin at North-West borders with San Cristobal Corregimiento and specifically with Pajarito vereda. Due to the lack of space into Medellín´s borders, Pajarito was used by Medellín´s administration to build new social housing complexes and is about to become Medellín´s new 17$^{th}$ Comuna.

The last observation visit was done in *Pajarito* to a social housing complex; it aimed to find differences between the previous two types of neighborhood houses and a social house model in Medellín built into the administration's development plan.

In parallel to the observation visits interviews were done to the women head of household in charge of the house chores at each of the visited homes.

The following Table illustrates the questions for both the observation visits and the interviews and the main outcome of these two activities.

Figure 3: Observation visits and interviews guide and questions

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- **Results**

From the observation visits, general aspects of the context and the houses were noted. Due to their nature and the differences between the houses, observation enabled the team to witness common water consume habits among highly visible differences on socio-economical conditions. From individual interviews, details about water consume habits and lifestyle were found and clarified. Detailed photographs were taken to illustrate the context, living conditions and water consuming areas of the houses. Appendix 1 contains observation guides and interviews for the six houses which were visited.

According to the nature of the houses visited, they can be classified on three scenarios: non-formal houses, formal houses and social housing complexes. In order to understand and show these three scenarios generalities, collages were elaborated. Collages help to illustrate context and lifestyle in order to understand user's situation (Baxter, 1995).

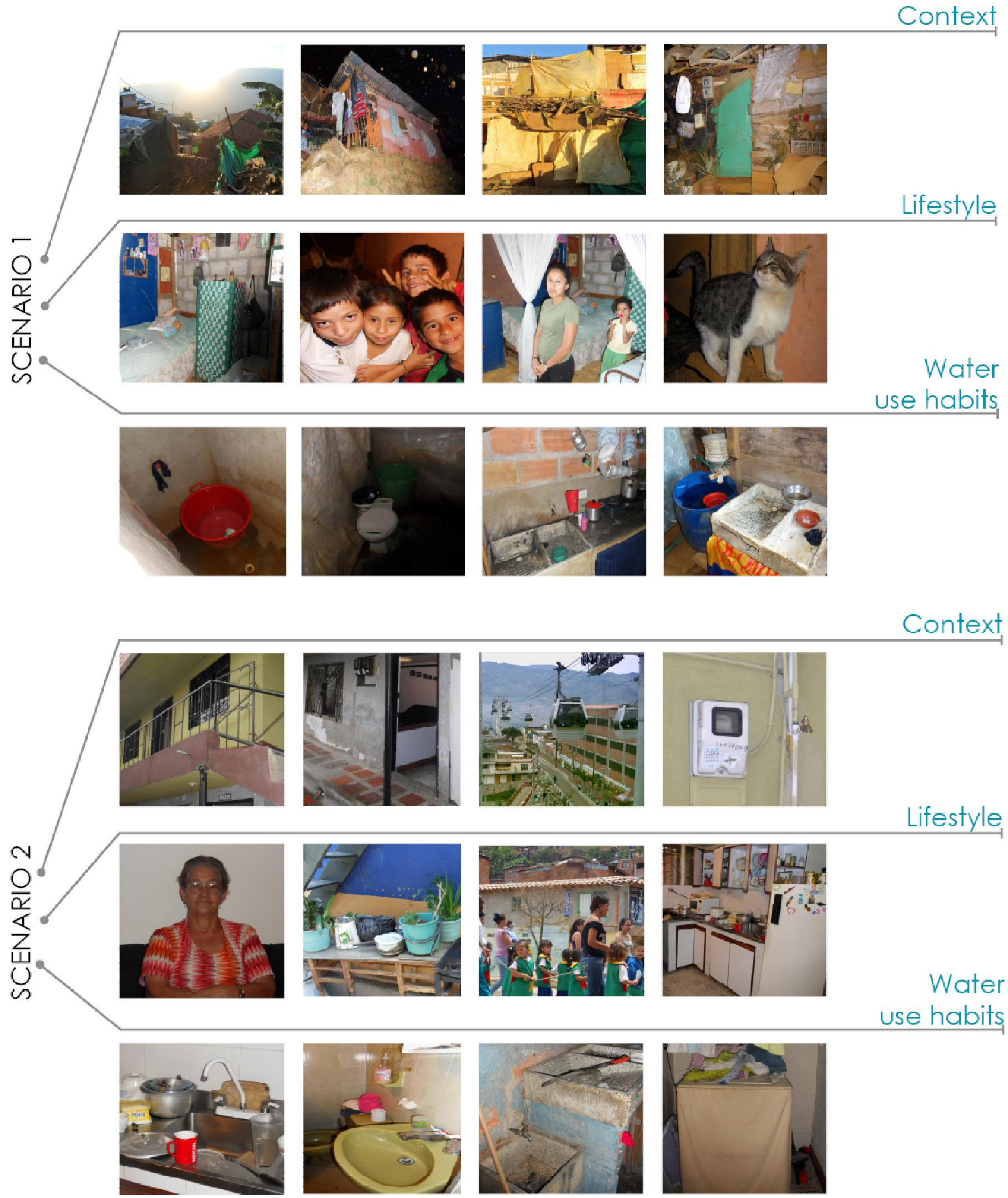
Non-formal houses consist on illegally built homes with unusual construction materials found in their surroundings, such as carton, plastic bags, PVC pipes, metal sheets and bricks; they are not catalogued on any level of the socio-economical *estrato*[11] scale (*Carpinelo* houses). Its inhabitants are low income families victims of forced displacement. Typically, these houses are built on high risk areas and current regulations forbid EPM[12] to provide public services. Therefore, they have built their own illegal connection to EPM's water and electricity services. Figure 4 shows this first scenario.

Formal houses are properly built with common construction materials such as cement, sand, pvc and bricks; they are catalogued as *estrato* 1 or 2 on the socio-economic scale (SDS 1 Houses); they have legal connection to public services. Its inhabitants usually work for a minimum wage salary. Social housing complexes are built by the administration (*Pajarito* houses); its inhabitants were relocated by the administration because of their vulnerability. These complexes have legal connection to public services. Figure 4 also shows these two scenarios.

[11] Estrato: Is a Colombian governmental Socio-economical tool to classify properties taxation, public services charges, lifestyle, etc. It is based on Colombian national administrative department of statistics –DANE- guides and considers properties owners´ poverty level, domiciliary public services availability, urban or rural location, among others. There are 6 estratos where the poorest communities belong to estrato 1, and the richest ones belong to 6.

[12] EPM: Empresas públicas de Medellín or Medellin's public services company; It is in charge of provide aqueduct, sewage, electricity and telephony services to Medellín and its ten municipalities.

Figure 4. Scenarios found in the Comuna 1.

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### 2.1.2 Group interviews

Group interviews helped to learn about the community life and general issues related to them; three interviews were made in order to get insights from diverse community actors: youngsters, community leaders[13] and community urban planning and environmental committee. Each group interview required different planning and guides due to the difference of age and activities to be done and the expected outcome from them.

- **Group interviews development**

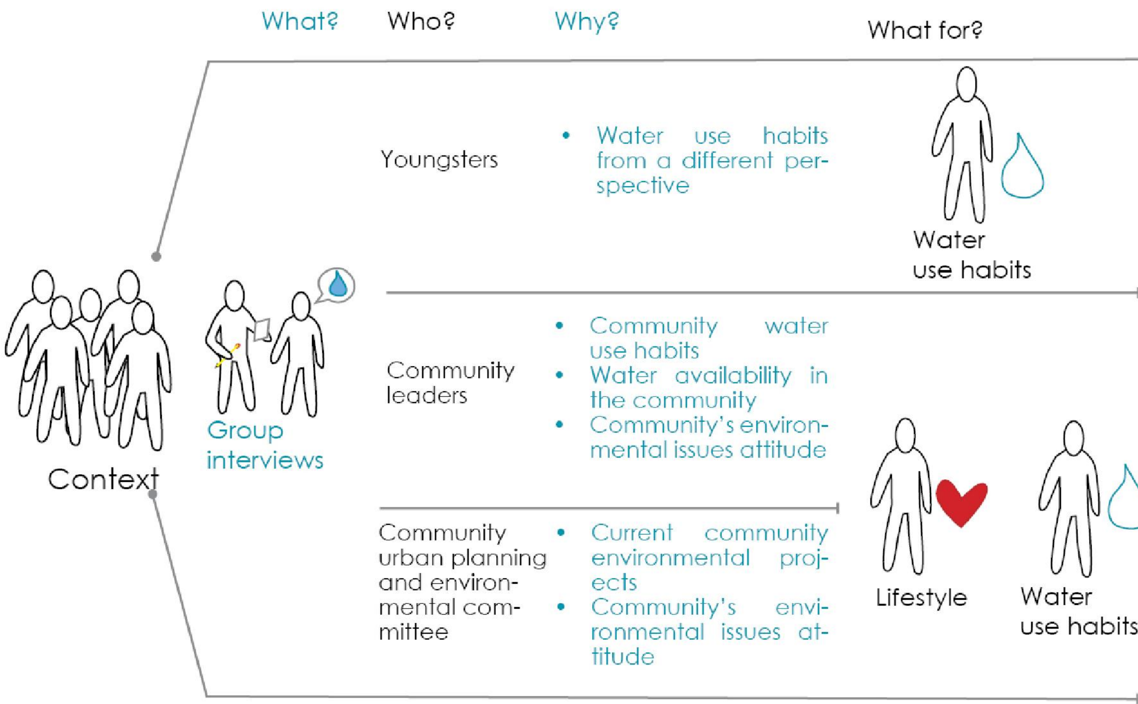
A creative session was done with 9 students from the *Institución Educativa La Candelaria* located on SDS 1. The purpose of this group session was to get information from a different age group. The creative session allowed the kids, on the ages between 16-18 years old, to express their habits and behaviors related with domiciliary water consume.

Community leaders and the environmental committee represent an important source of information since they are elected by the people and are in charge of taking the voice and speak up for the *Comuna 1* inhabitants.

[13] Community leaders: According to Medellín´s politic division, each neighborhood must elect a leader so that he can speak up for the community and care and fight for its interests. The Comuna 1 has its own community leaders´ board with leaders from each of its 12 neighborhoods. These leaders include an environmental committee.

The Figure below summarizes the group interviews done together with their purpose and expected result.

Figure 5. Group interviews.

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- **Results**

- Hiking around Comuna 1 neighborhood helped to understand common community´s lifestyle and organization aspects. It enabled to get deeper insights about the *Comuna 1* space distribution, political organization, *Presupuesto participativo* (PP)[14] importance, transportation problems due to the topography, and imaginary borders created by gangs and feared by the community.
- Talking with the community leaders helped to get connections which served in a later project stage such as community inhabitants for posterior observation visits and interviews.
  - Mrs. Rosalba Cardona was one of the community leaders who showed more interest on this project. Therefore, many other visits such as the creative session

[14] Presupuesto participativo (PP): Is a program created in 2004 sponsored by Medellin´s administration. Based on Medellin's administration definition it is seemed as a democratic citizen participation process. Each year the administration must assign a budget for the community leaders to decide according to its basics needs, which projects pursue and invest on.

with youngsters were possible with her help. Important outcomes need to be highlighted from the interview with her:

- Mitigation projects are a good option for the neighborhood; it is also a way of presenting the project to the PP or the governmental organizations to support it.
- The neighborhood leader has tried to start water use projects in the neighborhood, especially to mitigate the risk in some areas consider to be dangerous and which don't have the resource.
- The use of rain water is a solution already implemented by some families in the neighborhood, and it is an accepted idea. They think is not only important because of the economy, but because of the environment.
- Reasons for not having clean water in the *Comuna 1*:
    - Not paying because of the lack of income.
    - They use water by building illegal aqueduct systems.
    - Community water meters are not enough.
    - The use of water from small rivers has decreased because of the conditions of the resource.
- The public services price is still too much for some of the families of the neighborhood, especially the ones living on houses with poor infrastructure.
- For details about the outputs of her interview see Appendix 1.

- Creative session with youngsters left many insights about how they see ecological issues and logically, water use. Youngsters creative session highlights are presented below:
    - They are well informed about environmental issues such as global warming, greenhouse effect gases and water importance.
    - Young women use to help with house chores so they have a good understanding on how water is used at their homes. Consequently, they exposed some activities done with rainwater such as cleaning the sidewalk or their front yards.
    - Both, girls and boys, are concerned about saving water; not only for economical reasons but for environmental aspects
    - Some of them have heard about vanguard water treatment processes such as reverse osmosis and desalination processes
    - It is important to note that, when youngsters were asked for better water use systems, they immediately came up with Rainwater Harvesting (RWH) solutions; It is at their top of mind

- From the urban planning and environment committee meeting the authors got an insight about the importance of environmental care on the community. They have developed different projects on this matter such as streams cleaning.
- The committee also highlighted RWH importance as an additional water source. This organization could serve as the management committee for this new water source.

### 2.1.3 Experts' interviews

Diverse aspects needed to be covered to increase governmental and environmental knowledge. Governmental knowledge includes: political information about development plans taking place in Medellín, especially in the *Comuna 1*, average water consumption and Medellín's water system. As for the environmental knowledge, information included impact measurement techniques and cleaner production practices as well as current regulations to take in account when designing for water use. Besides the interviews, experts were also consulted for specific data and future advice and connections, as well as possible participation in the project.

- **Experts' interviews development**

In-depth and technical information was found by interviewing experts from different areas related to governmental policies taking place in Medellín and environmental issues associated with water consume and water treatment. The organizations which were interviewed are: EDU[15], CNPML[16], EPM, SAG[17], and the community leaders; these meetings, their purpose and expected outcomes are shown on Figure 6 below.

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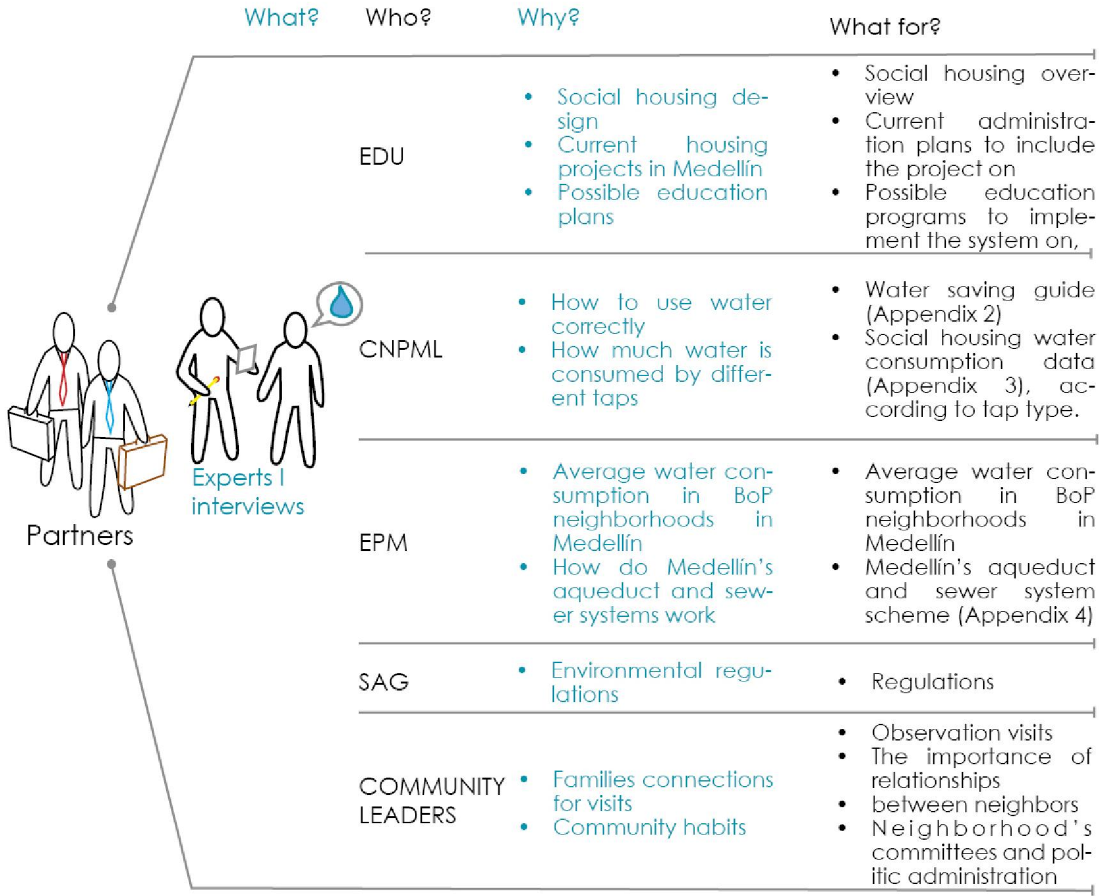
[15] EDU: The Enterprise of Urban Development in Medellin, -EDU-, is a State industrial and commercial enterprise, of the municipal order, whose main object is the development of Integral Urban Projects which seeks to improve citizens life quality, by means of urban treatments of renewal, urban extension, neighborhood improvement, consolidation, redevelopment, as well as, the conservation and recovery of the environment, which involve public space, housing, mobility, and equipments. Taken from: http://www.edu.gov.co/Figures/stories/articulos/brochureingles.pdf. Consulted in July 2010.

[16] CNPML: From its initials in Spanish is the ¨National cleaner production center¨. It is a joint of institutes, entities, public and private companies aimed to improve the economical and environmental performance of Colombian productive sector. It is a nonprofit organization founded in march of 1998.

[17] SAG: Geographical and environmental services (from its initials in Spanish). It is a Consultancy company dedicated to advice infrastructure and development projects in environmental issues.

Figure 6. Experts interviews.

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- **Results**

o EDU's interviews

From the EDU's interviews the team was able to understand social housing complexes design in Medellín. Typically, these complexes consist of 8 floor buildings with 6 apartments per floor connected by a corridor for a total of 48 apartments per building. These apartments have a total area of 35 m2.

The building itself consists of an impermeable flat roof with no tiles. Rainwater is evacuated by a PVC pipe which goes from the rooftop down to the ground and into the sewer system. The complexes have common areas such as gardens, parks, sidewalks, children's playground and football fields. There is extra water consumption on these complexes for the common areas maintenance.

The EDU has current plans to improve the *Comuna 1* infrastructure by building new social housing complexes. It is important to highlight that among their goals, rainwater systems are being considered. They are also implementing "urban plantations" which are areas where people could get together to cultivate their food; they will be in charge of taking care of the plantation.

In addition to social housing building, the *Comuna 1* is eligible for house improving as part of the administration plans; these plans (MIB) focus on house improvement in order to give better life quality and decrease earth slide risks in the neighborhoods. There are several organizations such as EDU and NGOs like *Habitat for humanity* which, together with the ISVIMED, lead the initiative.

o CNPML

From the interviews at the CNPML information about water management was found; the GAUEA[18] plan is the main source of information; Appendix 2 summarizes this plan together with a possible implementation for domiciliary activities. From it, the following steps are to be outlined:

- List process stages: process stages and which activities consume water
- Identify waste generators: which activities generate waste and which type
- Process diagram: identify water inputs and outputs
- Analyze the process and identify facts: which type of water is being used, which activity consumes the most water
- Evaluate options: evaluate from diverse perspectives the options available for better water use

In addition the CNPLM served as source for information for water consume according to the type of tap being used. They also have a previous study for consume patterns, this means, how much water and time are expended on each house activity. These Tables can be found on Appendix 3.

o EPM

An interview with EPM's aqueduct department employee, Luis Eduardo Londoño, who has been working at the company for over 20 years, clarified how the resource is managed in the city; from obtaining it until bringing it to each home and charging for it. EPM does not

[18] GAUEA plan: ¨Guía de ahorro y uso eficiente del agua¨ or Water saving and efficient usage of water guide. It is a document published by the CNPML for some industries willing to decrease its water consume.

make a distinction among gray and black water coming from the houses but they do separate rainwater from domiciliary water. Domiciliary waste water catalogued as black goes straight to the treatment plant and then to the river. Further details about how water system works in the city can be found in Appendix 4.

Medellín's aqueduct has coverage of 98% and the sewer system of 96 %. EPM has a *non countable water percentage*[19] of up to 80% on BoP neighborhoods in the city; this high percentage is the result of water leaks but mainly, on these communities, it is because of the illegal connections built in those neighborhoods.

In addition, EPM gave data about average water consumption in Medellín's BoP neighborhoods. For the *Comuna 1*, the average water consumption is 13 $m^3$ (Sistema Único de Información de Servicios Públicos, 2009) per month; for details about water consumption in Medellín see Appendix 5.

- SAG

SAG interview was the main source of information to clarify which regulations were relevant for our project; although there are no specific laws for RWH in Colombia, there are several regulations about water; the most relevant are listed below.

- Decretory 1594 of 1985: water use and liquid waste
- Colombian resolution 2115 of 2007
- Law 373 of 1997: efficient potable water use program
- PORH (*Plan de Ordenamiento del Recurso Hídrico*): water resource management plan

- Community leaders

From the community leaders meetings a broad understanding about how the community works was born. The *Comuna 1* as well as the other *Comunas* in Medellín, has its own committees which are in charge of relevant aspects such as: education, public services, constructions, health, environment, among others. Each committee is elected by the whole neighborhood and their mission is to gather community's needs on each of the topics and distribute the annual budget, given by the administration, for them to invest according to their priorities.

[19] Non counTable water percentage (NCWP): It is the indicator which shows ppublic services companies´ water losses percentage during its normal operation.

The community leaders were our first contact with the community and it opened doors for the observation visits previously mentioned. In addition, the leaders were an important validation source for the posterior “Reflect” and “Create” phase.

## 2.2 SECONDARY RESEARCH

Online and bibliography research allowed the project team to understand worldwide used home water systems made for two different purposes: RWH and water re-use. In addition, similar situations in different context inspire new ideas bringing new insights to mind. Countries with similar economical and social conditions than Colombia and how they take the best of water were the basis of this research.

- **Research development**

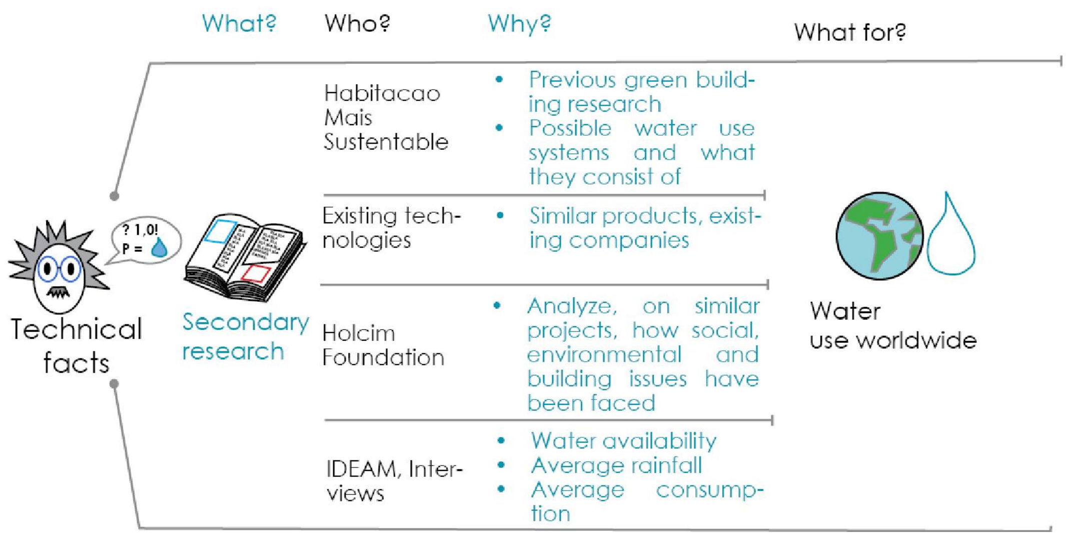
This step of the project included contact with *Habitacao Mais Sustentavel*, a Brazilian project developed by the University of Sao Paulo which consists of an elaborate study about green building. The study includes the use of water on domiciliary activities and it describes the alternatives for an environmental friendly home on this matter. This research is summarized on the document *Levantamento do estado da arte: agua* (Politécnica da Universidade de Sao Paulo, 2007) provided to us by Luz Helena Oliveiro.

In order to achieve information about similar cases related with the project´s topic, *Holcim* awards were consulted. As the *Holcim*[20] foundation explains, this is a contest which recognizes “innovative projects and future oriented concepts on regional and global level“. Related topics such as civil engineering works, urban and infrastructure design and construction technologies are the main award’s subject.

Figure 7 below explains the diverse research contacts done during this step and its outcomes.

[20] Holcim Foundation: The Holcim Foundation for Sustainable Construction promotes sustainable responses to the technological, environmental, socioeconomic and cultural issues affecting building and construction at the national, regional and global levels.

Figure 7. Secondary research.

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- **Results**

From online and bibliography research three main outcomes are to be highlighted: possible domiciliary water use systems, existing technology according to the system type, similar situations from an environmental, context and type of building point of view.

o Domiciliary water use systems

From the *Habitacao Mais sustentavel* previous research, two sustainable water use possibilities for domiciliary consumption are catalogued: water re-use (WRU) and rainwater harvesting (RWH) (Politécnica da Universidade de Sao Paulo, 2007). The first option consists on those systems which use domiciliary gray water as input and after being treated it is again used for domiciliary activities. The second system, RWH, consists on using rainwater as input to be also used for domiciliary activities. Both of the alternatives aim to decrease potable water use. Table 1 shows these two types of water use systems. Appendix 6 summarizes water use systems according to Habitacao mais sustentavel research.

Likewise the research allowed the authors to understand which subsystems are necessary to implement on each of these two types of water use systems; this is illustrated on Figure 8.

Table 1. Water use systems for domiciliary use.

| WATER USE SYSTEMS | | |
|---|---|---|
| **Types** | **RE-USE SYSTEM** | **RWH SYSTEM** |
| **What are they?** | Use water over one time on domiciliary activities | Collect rainwater for domiciliary activities |
| **What type of water they use?** | Grey water from domiciliary activities except for water coming from the toilet and dish washing activities | Rainwater |
| **When is it used?** | When there is a wish to decrease water consumption | When there is a wish to decrease water consumption |
| | | When there are no marked extreme dry seasons |
| | | When it is helpful to decrease soil water |
| **Final water use** | House activities which do not require potable water. Such as: toilet flush, cleaning, gardens | |

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In addition of the two possible water systems to be used to decrease potable water consumption in domiciliary activities, several requirements related to performance, safety, water quality and possible implementation on social housing could be inferred from the mentioned research and are illustrated on Figure 9.

Figure 8. WRU and RWH basic components.

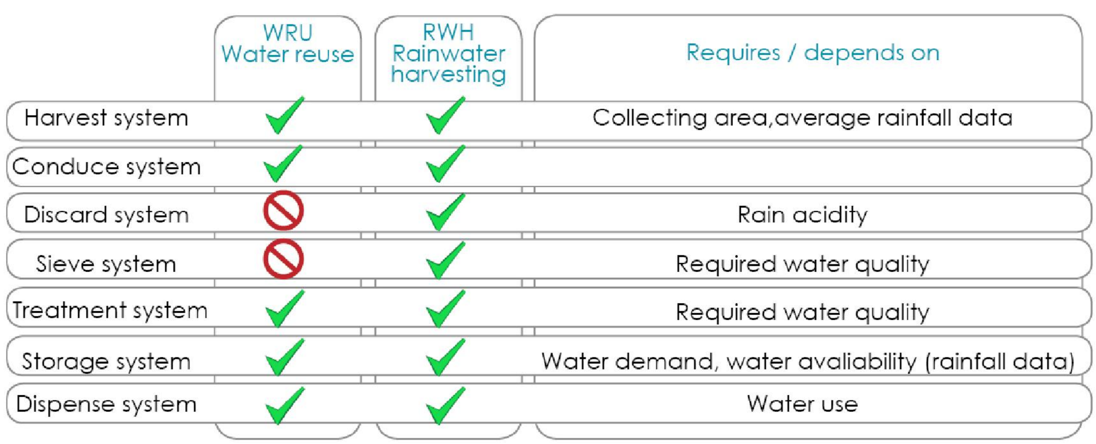


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Figure 9. Water systems common requirements.

| | Common requirements | Includes |
|---|---|---|
| Water use systems | Performance | Ensure water amount for at least 2 high consumption hours<br>Easy to operate, monitor and maintain<br>Guarantee water quality for the activity being used on<br>Separate from potable water |
| | Water quality | Determined by the activity where it will be used on<br>No odor nor taste<br>No foam precence |
| | Safety | Prevent miss interpretation and missuse by the user<br>Include a functional manual<br>Continuos monitoring<br>Include education programs |

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- State of art: existing technologies

Existing technologies analysis helps to analyze similar products and situations and what they have to offer. The main points to analyze include their advantages, how they solve the issue, and their disadvantages in order to come up with design opportunities and requirements (Baxter, 1995). The state-of-art was developed based on the two, previously described, possible water use systems in order to increase knowledge about similar situations and existing technologies. Figure 10 summarizes the state of art whereas the complete document can be found in appendix 7.

Figure 10. state of art summary.

| System | Water from | Water for | Energy used | Treatment or filtration | Context | Disadvantages |
|---|---|---|---|---|---|---|
| WRU | -Washing machine/<br>-Washtub<br>-Shower<br>-Bathroom taps | Usually for irrigation | -Electricity (Pump)<br>-Gravity | Usually used. Water is polluted from the activity where it comes from | -Domiciliary<br>-industrial<br>-farms | Expensive due to treatment used because of the pollutants.<br>Intervention of house infrastructure to rearrange pipes.<br>Usually water is not stored |
| RWH | Roof collecting systems | -Cleaning<br>-Toilet flushing<br>-Irrigation | Electricity to pump water from the storage system to its final destination | Not commonly used. | -Domiciliary<br>-industrial<br>-farms | Water should be at least filtered because it will be stored to prevent hygiene problems.<br>A lot of the systems are just concepts. |

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- Designing for BoP

As well as the systems used worldwide, the authors found important information to keep in mind when designing for BoP communities like the *Comuna 1* in Medellín; eight *Holcim* awarded projects were chosen to analyze in depth. This selection was based on concepts which were related with water, trying to find out if they treated, managed, reused or saved the resource and how these innovative solutions would add insights to the graduation project not only because of the technology used but because of their application in BoP communities. A list with the eight *Holcim* Awarded projects is presented below with its main output for the graduation project:

1. River remediation and urban development scheme, Fez, Morocco
- Integrating existent infrastructure to possible solutions could mean:
  - Decrease costs
  - Old areas revitalization and embellishment of neglected ones
  - Less primary sources demand
  - Easier community´s acceptation
- Using local materials is very important because local inhabitants know how to use, acquire and handle them.
2. Post earthquake reconstruction project, San Lorenzo de Tarapacá, Chile
- The community itself has knows how to set up solutions for their own needs
- Research, observation and understanding will make possible to found and embody the correct solution.
3. Coastal fog-harvesting tower, Huasco, Chile and Heart of Suzhou creek ecosystem revitalization, Shangai, China
- It is not always necessary to come up with complex technology artifacts, in many cases the most effective solutions are easy, simple and practical. It is not necessary to invent what the nature has already done, it just can be used.
4. Water for all. Solar water heating and rainwater tower, Florianópolis, Brazil
- Flexible and adaptable solutions are very important in an environment such as SDS with a large variety of dwells and construction processes.
5. Autonomous alpine shelter, Zermatt, Switzerland
- In spite of suffering big shortages, SDS inhabitants live in a rich food and water area. It is not always necessary to live in a harsh and isolated area to think on self-sufficiency, when people have no money at all, it becomes an extremely important issue
6. Low impact environmentally-responsive house, Cape Town, South Africa.

- As other projects developed in Medellin, the aids for the community should harmonize with them in most of their culture costumes

7. School infrastructure from local resources, Vale and Vryheid, South Africa.

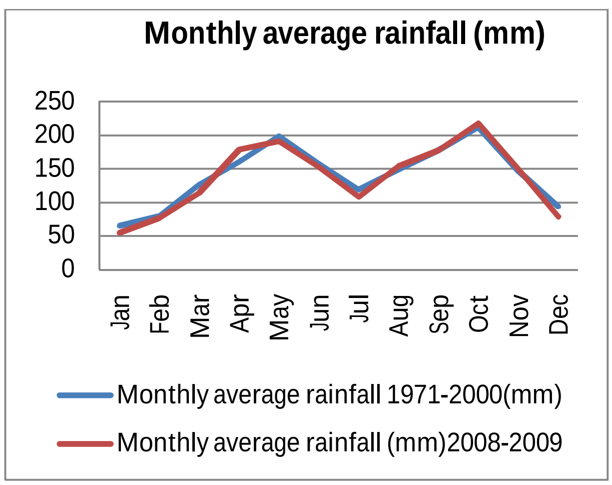
- As projects latter explained, education is sustainability´s main core and our graduation project must seriously consider it

After a suitable research about these projects, a detailed report was done and can be found on Appendix 8.

- Water availability

Since two types of water systems are to be considered as possible design paths, water availability must be calculated for both systems. For RWH a research about Medellín´s rainfall was necessary in order to achieve insights about this matter. Figure 11 shows the average rainfall based on collected data from 1971 to 2000 (Organización meteorológica mundial, 1971-2000) and from 2008-2009 (Wikipedia, 2010) by the IDEAM[21]. The total rainfall for the period 1971-2000 is 1687mm and for the period 2008-2009 is 1656mm. For detailed information see Appendix 9.

Figure 11. Medellín's monthly average rainfall

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In addition, for WRU systems, the information gathered on house visits and interviews will be the input to establish how much water is used, therefore available, by house per day.

[21] IDEAM: Instituto de Hidrología, meteorología y estudios ambientales or Institute of hydrology, meteorology and environmental studies from Colombia.

This analysis can be found on the next chapter, “Reflect”, where data from the interviews is crossed with the CNPML information.

## 2.3 “HEAR” CONCLUSIONS

- **Context:**

- From the visits and interviews 3 different scenarios were found in BoP neighborhoods of Medellín like the *Comuna 1*, non-formal houses, formal houses and social housing complexes
- On Medellín’s BoP communities illegal water connections are common due to the lack of water, despite EPM’s high coverage; this situation is mainly the result of the non-payment of the public services
- Just like with illegal water connections, BoP communities in Medellín build their own houses with materials locally available which do not represent high cost.
- The *Comuna 1* homes are constituted by an average of 5 people
- *Comuna 1* houses consist of one kitchen, one bathroom (with sink, toilet and shower), two rooms and one dining room/living room area.
- Water consume activities in the *Comuna 1* are as follows:
  - Shower: one daily per person
  - Dish washing: three times per day
  - Clothes washing by hand: once per day (with washing machine: 2 times per week)
  - House cleaning: once per day
  - Outdoors cleaning: once per week
  - Toilet flushing: three times per day, per person
- House chores are usually developed during morning hours and the use of regular products such as buckets and plastic recipients is common. These utensils are also used when they lack of water connection and the resource must be stored
- The average water consumption in BoP neighborhoods in Medellín is 13 $m^3$ per month according to the public service system
- The community leader boards could be in charge of managing a system with communal purposes due to their ability to work together
- The need for extra water is notorious; in spite of EPM´s excellent coverage because illegal aqueduct systems are common among houses as well as the non-payment of the services
- Generally speaking, when water connection is illegal, water saving comes more from the will to save products related with water than the will to save water
- The community, from children to elders, is aware of saving water

- When asking the community about water use systems, RWH is on the top of their mind
- Because of their rural origin, *Comuna 1* inhabitants know the advantages of RWH
- The system must be designed taking in account the context we are working for: its water use habits and lifestyle
- Some people in the community already use RWH systems built by themselves
- BoP Communities in Medellín pay the minimum required water quantity. As long as the consumption is below 32 $m^3$

  - **Partners:**

- The community of SDS 1 has money to invest in a project such as the one being presented. This would be possible through the PP
- The EDU has shown interest on integrate a water use system in one of their social housing projects. Therefore, the project it is feasible to Medellín´s context.
- The current administration plans include better use of rainwater together with community activities such as urban plantations
- The CNPML has elaborated a plan (GAUEA) which explains diverse activities to give water a better use
- When implementing water systems for BoP communities it is necessary to include educational plans and manuals to ensure their proper use
- Administration plans such as *viviendas con corazón* and "MIB" are some examples of development plans in Medellín where systems could be implemented
- It would be attractive for EPM to implement plans and systems to decrease the NCWP which can rise up to 80% in BoP neighborhoods.

  - **Technical facts:**

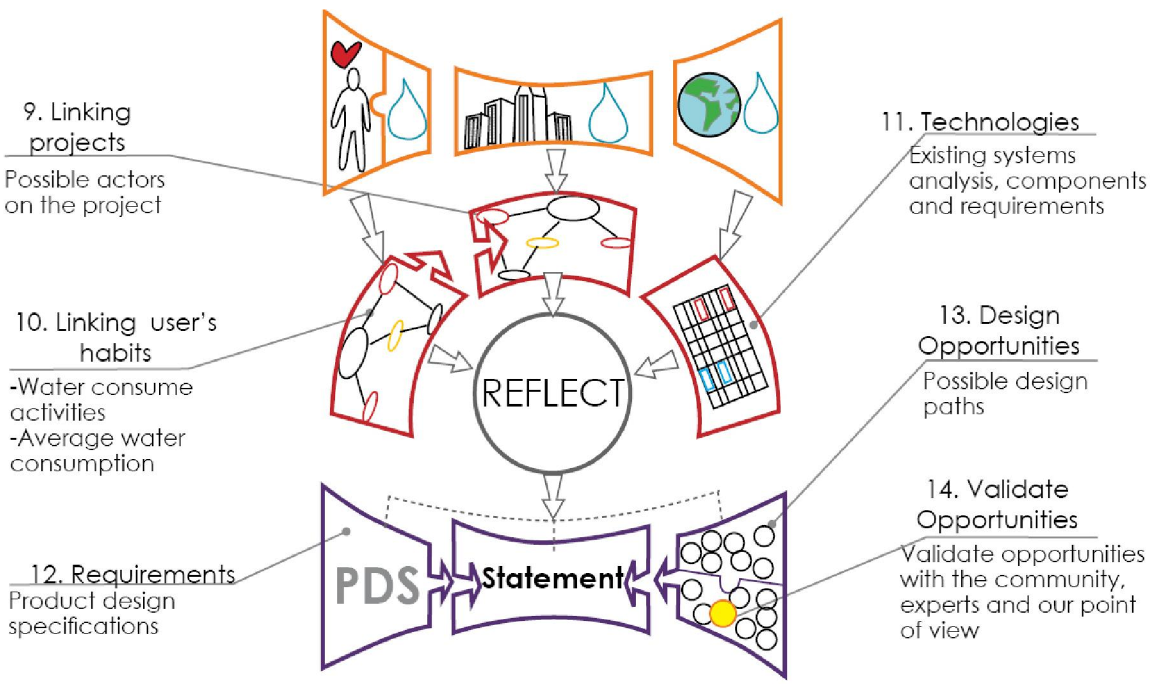
- There are two water use systems to implement for domiciliary use: RWH and WRU
- WRU systems are commonly used worldwide for irrigation purposes; they have a high cost of implementation because of the need to rearrange water pipes
- WRU systems require water treatment due to where water comes from
- Excising RWH systems are commonly homemade or concepts which use water for activities such as cleaning, toilet flushing and irrigation
- RWH systems include a storage system and don't always include treatment system, especially when they are homemade which could cause hygiene issues
- Medellín is a suitable city to implement RWH systems due to an average annual precipitation of 1656 over the past two years
- RWH systems could decrease earth slides risk because of less soil moisture
- Water treatment depends on which activity the resource will be finally used.

## 3. "REFLECT"

The second step of the project consisted on analyzing "Hear" outputs; by linking them and creating relationships diverse frameworks were elaborated; finally, design opportunities came to life. At the end of this phase, requirements are established and the opportunities are evaluated by different instances: community, partners and the graduation project team, in order to come up with a concrete statement to start designing the system. With these, at the end of the "Reflect" stage the second and third specific objectives are achieved.

Figure 12 illustrates in detail the tools used during the research phase and its outcomes.

Figure 12. "Reflect" phase

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### 3.1 ANALYSIS DEVELOPMENT

#### 3.1.1 Water consume habits in BoP communities in Medellín

From the observation visits and interviews, consume habits and lifestyle could be concluded on the previous project phase. By implementing some steps from the CNPML plan, GAUEA, domiciliary water consuming activities were seen as a whole process;

therefore, it was necessary to list process stages activities, or in this case every house activity that implies water use, and identify waste generators in order to develop a process diagram to illustrate water imputes, throughputs and outputs.

The following scheme, Figure 13, illustrates the daily activities on a regular house in the *Comuna 1* as well as the type of water used for each activity. The pollutants and the type of water exit are also shown on the Figure below. The scheme illustrates water inputs, throughputs and outputs on a regular BoP community in Medellín based on the *Comuna1.*

In order to deeply understand consume habits and patterns it is important to analyze not only the house as a whole system but each activity as a sub-system itself. To do so, process schemes were elaborated to describe in detail each activity as illustrated in Figure 14; Appendix 10 contains the complete process chart analysis.

Figure 13: Water consuming activities on a typical BoP community in Medellín

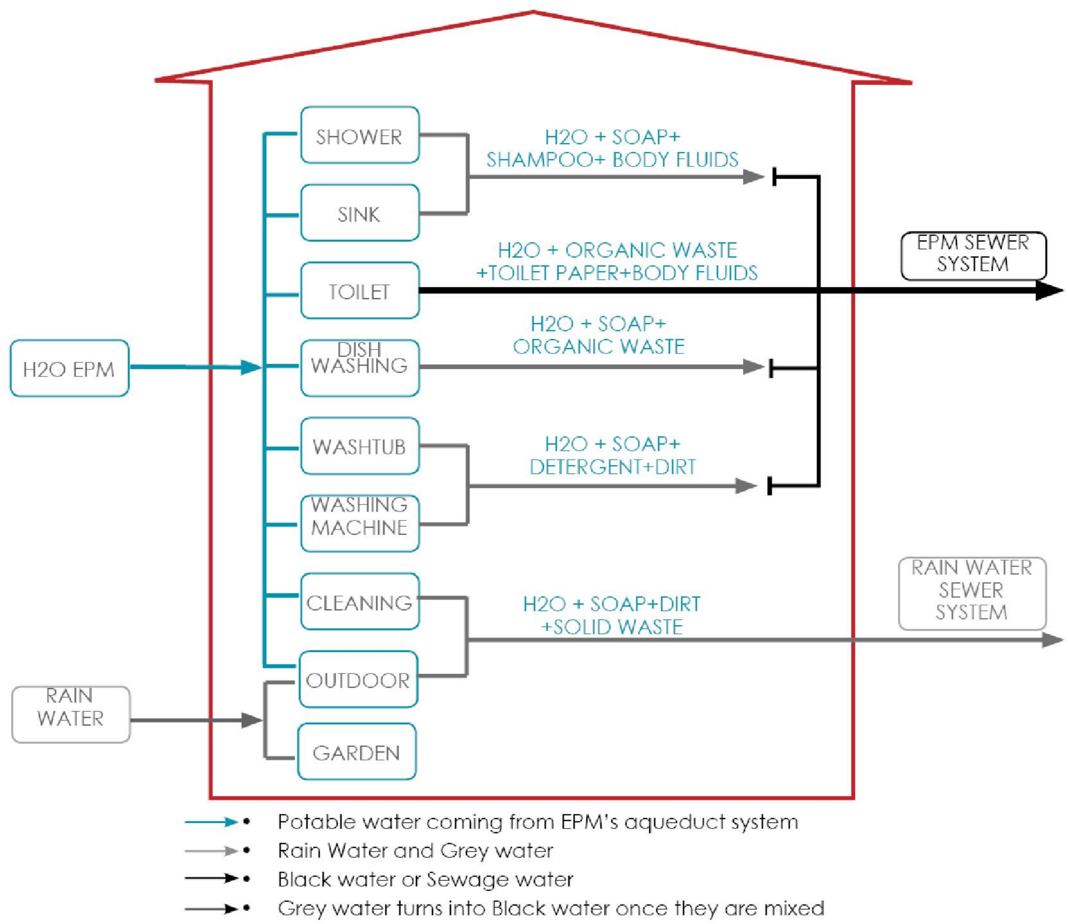


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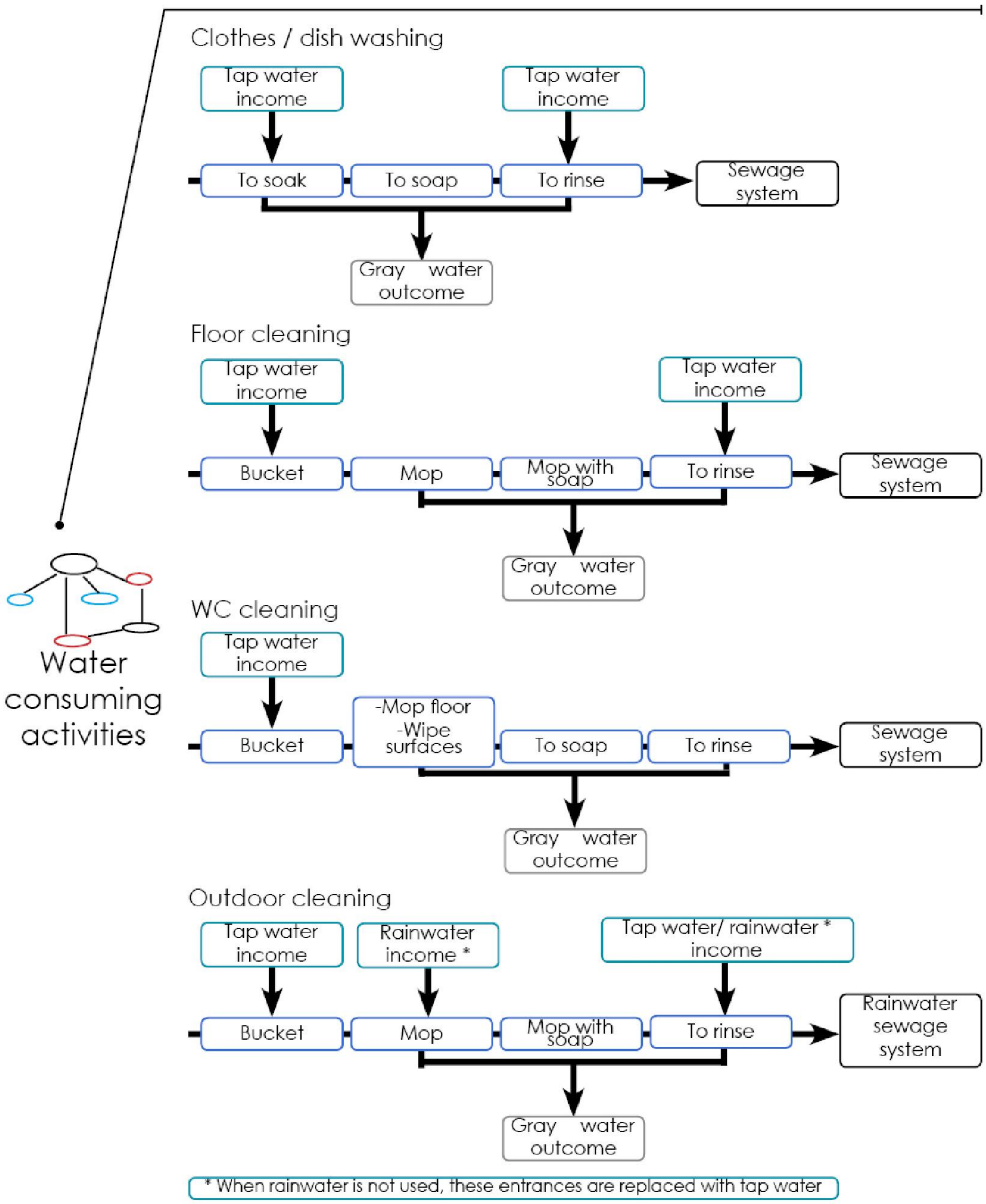
Figure 14. Water consuming activities schemes.

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- **Average water consumption in BoP homes in Medellín**

In order to implement a system to give water a better use, it is necessary to analyze which of the activities mentioned before consumes the most water. This information is the result of the interviews done in different houses in the *Comuna 1* as well as the data which the CNPML has gathered after their own studies; these data gives an idea of the average consumption per activity according to the water tap and the amount of time each activity requires. Table 2 summarizes water consumption for an average BoP house in Medellín whereas the whole report is contain in Appendix 11. Activities were divided in two categories: those done by each individual such as toilet flushing, showering and tooth brushing, and those done for the whole house members like cleaning, dish washing and clothes washing.

According to the analysis, there is a total consumption of 14,9 m3 per month, which could be compared to EPM's consumption data of 13 m3 per month for BoP neighborhoods. The difference is not considered as representative. The individual activities which represent higher consumption are showering and toilet flushing; as for the common activities, dish washing represents the higher consumption because it is done three times per day; cleaning indoors and outdoors also represent high water consumption.

Table 2. Daily water consumption according to activity in BoP homes in Medellín.

| Activity | Lts | % | Activity | Lts | % |
|---|---|---|---|---|---|
| **Shower** | **120** | **24,50%** | **Shower** | **120** | **24,55%** |
| **Toilet** | **240** | **48,99%** | **Toilet** | **240** | **49,11%** |
| Clothes washing (hand washing + rinsing) | 44,00 | 8,98% | Clothes washing (washing machine) | 42,86 | 8,77% |
| **Dishwashing + rinsing** | **39,00** | **7,96%** | **Dishwashing + rinsing** | **39,00** | **7,98%** |
| Cleaning | 32,00 | 6,53% | Cleaning | 32,00 | 6,55% |
| Outdoor | 1,12 | 0,23% | Outdoor | 1,12 | 0,23% |
| Faucets | 13,75 | 2,81% | Faucets | 13,75 | 2,81% |
| Total/day | 489,87 | 100,00 % | Total/day | 488,73 | 100,00% |
| Total m3/day | 0,48987 | | Total m3/day | 0,488727143 | |
| Total m3/month | 14,6961 | | Total m3/month | 14,66181429 | |

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## 3.2 DESIGN OPPORTUNITIES

After analyzing context, partners and technical facts on the first stage of the project, diverse opportunities to design were found. These opportunities are categorized according to the domiciliary water consuming activity and shown on Figure 15.

Figure 15. Design opportunities

| | Opportunity | Present situation | What could be done | Ideal situation |
|---|---|---|---|---|
| RWH | RWH system to provide water for domiciliary activities | -No rainwater harvesting<br>-Water shortage<br>-High risk areas<br>-Earth slide cased by presipitations<br>-Administration concern to use rainwater | Implement RWH systems on each house or as a common system.<br>The community must be included on the process | Use of rainwater for house chores which do not imply human consume.<br>It decreases water consumption and earth slides risk |
| RWH | RWH system for urban plantations | -No rainwater harvesting<br>-Low income families<br>-Current administration programs to implement urban plantations<br>-Community knows how to cultivate | Implement RWH systems to use water on urban plantations in order to provide the community of an extra food source | Use of rainwater for urban plantations gives people food and decreases slides risk; in addition it is part of the administration plans |
| WRU | Reuse water from/for clothes washing | -High water consumption on clothes washing<br>-Water is disposed as black water<br>-Clothes are commonly washed by hand | -Implement WRU systems to decease water consumption to wash clothes.<br>-Water coming from clothes washing could be used for other activities<br>-Implement common laundry areas with water saving machines in social housing complexes | -Less water consumption by reusing water.<br>-By having a common laundry houses could be designed different with more area for other activities such as an extra room or a business |
| WRU | Reuse water from dish washing | -High water consumption on dish washing<br>-Water is disposed as black water<br>-Requires tap water because dishes are in contact with food | -Implement WRU systems to decrease tap water use in other activities by using water from coming from dish washing<br>-Design different devises to decrease water consumption on dish washing | -Less water consumption by reusing water.<br>-Water must be treated because its polluted with food<br>-Redesign of houses by rearranging water pipes |
| WRU/RWH | Outdoor Cleaning and plant's watering | Use of rainwater and tap water for gardening and cleaning of patios | -Implement RWH or WRU systems to clean outdoors and water plants | -Use of rainwater or recycled water; no need of using tap water for these activities |
| WRU/RWH | Bathroom | Use of tap water for toilet flushing | -Implement RWH or WRU systems for toilet flushing | -Use of rainwater or recycled water; there is no need of using tap water for these activities |
| WRU/RWH | House cleaning | Use of tap water for cleaning | -Implement RWH or WRU systems for floor's cleaning | -Use of rainwater or recycled water; there is no need of using tap water for these activities |

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- **Design opportunities validation**

After elaborating the opportunities scheme, each of the possible topics to work on was scored and graded according to four issues: personal opinion, administration plans, community and environmental impact. For each of these categories, different criteria were graded:

1. Personal opinion:
   - o Project's importance: it evaluated if the topic was relevant enough for a graduation project
   - o Importance for people: it evaluated weather the team considered it would generate positive impact on the community
   - o Good use of water: it evaluated from the team's perspective, if the topic would imply a better use of water
   - o Feasibility: it evaluated if the graduation project team has the abilities to develop the design; also, if the team considers it will generate an economically viable design according to the context
   - o Personal: the graduation project team grades this criteria according to how proud they would feel working on the topic
2. Administration plans
   - o Development plans: it is graded after evaluating the topic with the EDU; it represents if the topic would be feasible and meets the administration development plans
3. Community impact
   - o Lifestyle: it evaluates, by discussing it with the community, weather the possible solution meets the community current lifestyle and improves it
   - o Management as a community: it evaluates weather the community feels it is possible to implement the solution according to their own policies
4. Environmental impact
   - o Environment: it evaluates, with the CNPML advisory, if the topic would reduce environmental impact in two ways: less potable water consumption and decrease of earth slides

In order to grade the last three issues, it was necessary to consult previously interviewed partners/experts; in addition, architect Carlos Alberto Montoya, EDU´s housing and habitat manager was also interviewed. It is important to note that he showed a great interest on rainwater harvesting systems for the new social housing complexes to be constructed in the short term and are planning to include environmental sustainable solutions. In contrast, WRU systems are not being considered among the administration plans because social housing complexes apartments already have a finished design; therefore, WRU systems would be expensive to implement since implies new pipe design for those complexes yet to be built and pipe rearrangements for the already built ones.

On the other hand, the community leader Mrs. Rosalba was interviewed as community member. The opportunities were introduced and explained to Mrs. Rosalba so that she could explain which of them was more useful and feasible considering her context knowledge. As a conclusion, she pointed out the relevance of rainwater usage arguing that she, and the community in general, already uses this source for cleaning the front yard and sometimes for house cleaning. As for WRU, Mrs. Rosalba didn't show much interest in this area; she believes the community is more likely to accept RWH than WRU because of their idea of polluted water coming from house chores in contrast of rainwater which is considered clean.

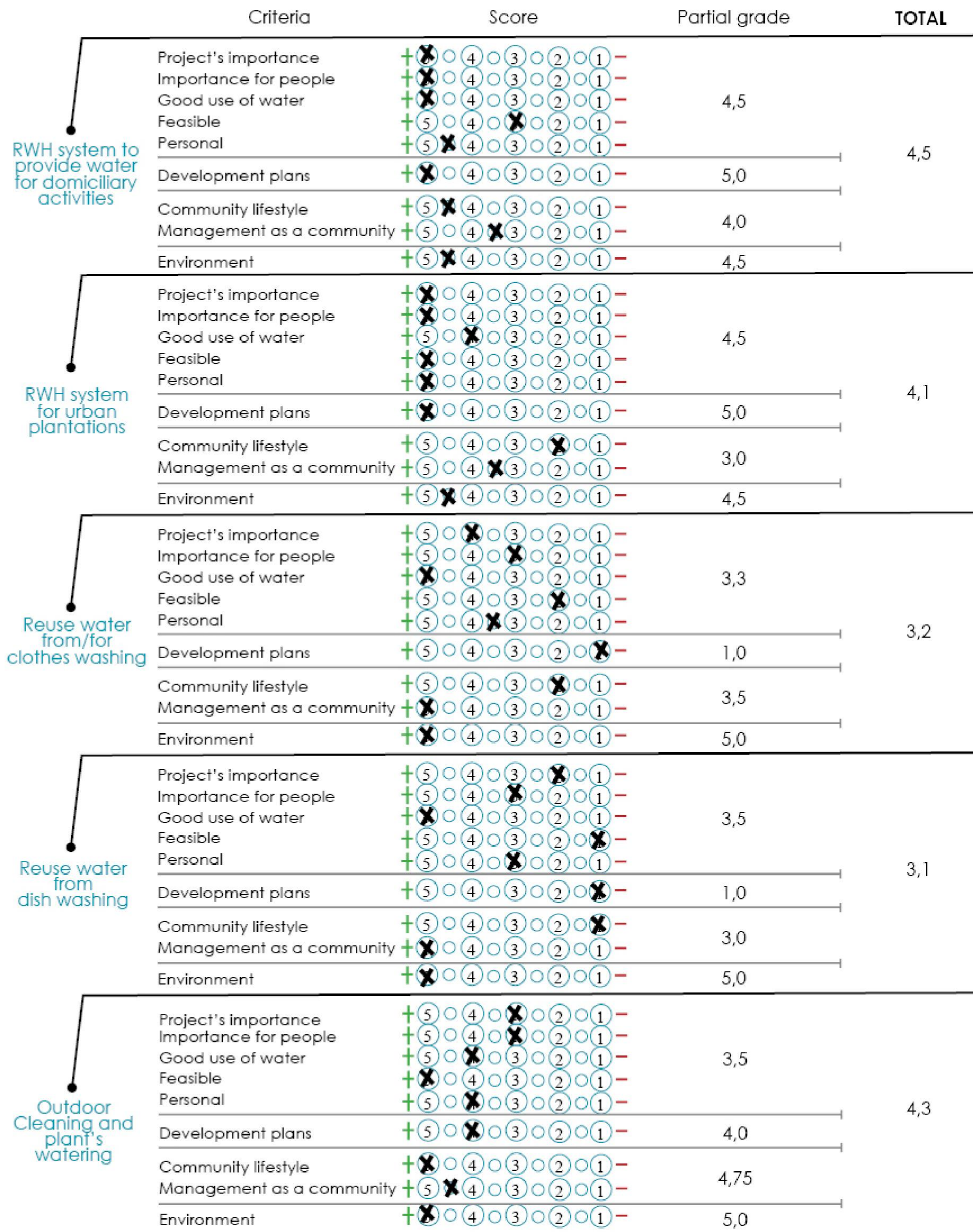
Likewise, the civil construction and environmental community leaders' committee was consulted in the same way described above. They also interpreted the water use systems as harvesting rainwater for human purposes. They suggested to implement this kind of system in those areas were public services connections are forbidden because of the illegal and high risk location. The detailed information is contained in Appendix 12

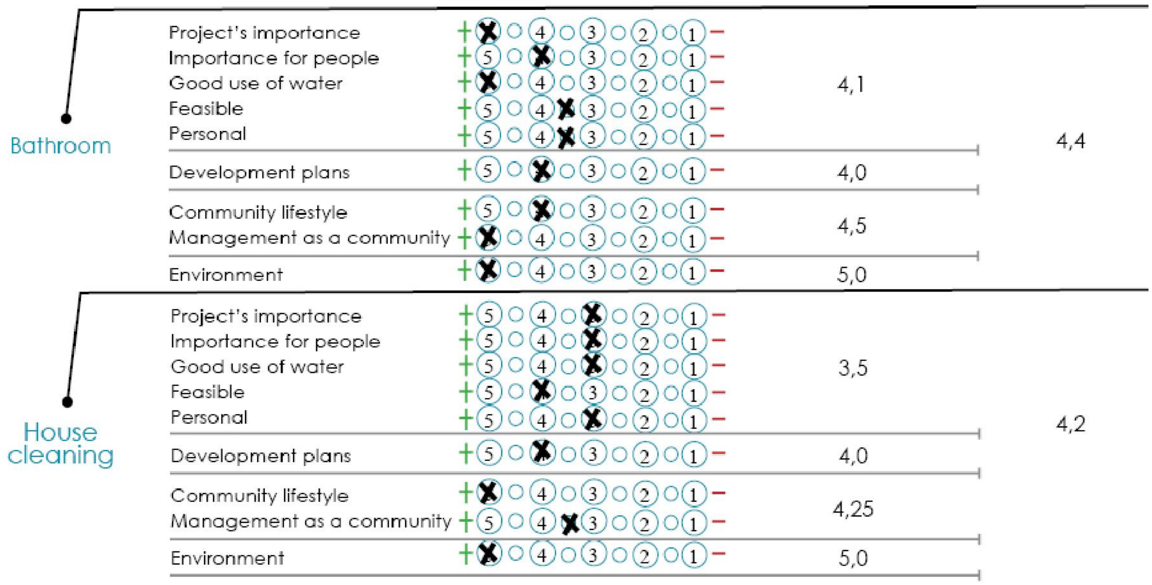
Finally, the CNPML was again consulted. Domiciliary activities such as dish washing and clothes washing represent a high water consume and would highly decrease potable water use if WRU systems were implemented for this topics; nevertheless, the pollutants contained on dishwashing require extra treatment for water to be recycled. As of other house chores like cleaning and outdoor activities, there is no need of using tap water; therefore implementing a system to replace potable water for recycled or rainwater will also decrease environmental impact. On the other hand, RWH would decrease earth slides, which also represents less impact.

- **Design opportunities evaluation**

As it was mentioned before, after validating the possible design paths to follow, an evaluation chart was elaborated with the four mentioned issues. Each issue has the same weight when giving a final/total grade; this means each issue is worth 25% of the whole grade. In order to evaluate them, a scale from 5.0 to 1.0, where 5.0 represents the higher value, was used. Figure 16 shows the evaluation chart with the given grades.

Figure 16. Design opportunities evaluation chart.



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After evaluating the alternatives, the chart shows RWH as the highest graded opportunity because of the possible applications in diverse domiciliary water consume activities which do not require potable water.

WRU systems no longer represent an option because of the low scores; these grades are the result of low acceptance among the community and low interest among the administration development plans.

As environmental solutions, both RWH and WRU seem to be a viable option; nevertheless, RWH represents an extra environmental and community impact due to decrease of earth slides because of good water channeling.

Outdoor activities, house cleaning and bathroom also obtained high scores due to the importance of reducing tap water for these activities, as well as community acceptance to do so; however it must be considered that in case of using an extra water source for toilet flushing, it would represent an extra cost because of the need of redesigning or rearranging water pipes.

Clothes' washing represents high water consumption; although the community doesn't fully accept using rainwater to replace tap water for this activity, when properly treated, rain water doesn't damage or bleaches clothes.

Clothes washing, cleaning and outdoor activities consume almost 100L of water per day (during morning hours) and they don't require potable water, as well as toilet flushing which represents 240L per day.

The use of rainwater for urban plantations was not accepted by the community because they rather ensure water for those activities already being done, such as cleaning, instead of using it for extra activities; in addition, most of the BoP neighborhoods in Medellín lack of space to locate the plantations due to the unplanned building.

### 3.3 DESIGN STATEMENT

The design statement points out the design challenge, consequence of both "hear" and "reflect" steps. The statement is considered the main input for the posterior project phase: "create". The statement should answer four basic questions:

1. What type of system should be used?
2. Which is the final activity where water will be used?
3. Which scenario are we designing for?
4. How will the system be delivered to the user?

RWH systems are the best option to be implemented on BoP communities because they have higher acceptance and do not oblige pipe arrangement. The collected water can be used on those activities since they don't require potable water (toilet flushing, clothes washing, cleaning and outdoor activities) which represent a total of 201 liters of water per day. Nevertheless toilet flushing (120 liters of water per day) requires pipe rearrangement which may increase installation costs and decrease user's acceptance.

Non-formal houses are not considered as a design scenario because they have illegal connection to public services which implies legal aspects to be involved. In addition, they have poor infrastructure which represents higher risk for the inhabitants and more complexity for the system to be implemented. As for social complexes, on-roof collecting should be used for community activities, such as plantations; since these options has been ruled out, they are not considered as a scenario. Nevertheless the designed system aims to be modular in order to make it possible to implement in these two situations (non-formal houses and social complexes) as a long term option.

Development plans taking place in Medellín as well as community leaders and committees are the best option to get to the user. The plans are accompanied by educational programs which will result into proper use of the system and the resource. Therefore, partner organizations can be the mean to deliver the system and implement it in context. It can also mean that these organizations include the user into building and installing the system themselves as part of improvement plans and teaching programs.

After finding answers for the three issues expressed on the questions above, the design statement is as follows:

**"Design a modular RWH system for formal houses in BoP communities in Medellín, in order to provide 100 liters of water daily; this water will be mainly used for the following non human consume activities: outdoor, indoor cleaning and clothes washing. The system will be delivered to the user as part of development plans taking place in the city"**

## 3.4 PRODUCT DESIGN SPECIFICATIONS (PDS)

The PDS (Table 3) establishes products requirements, this means, what the product shall accomplish; in addition, it gives an extra tool for future product evaluation (Pugh, 1991). From the links done during the "Reflect" phase in order to understand "Hear" outputs, different requirements were found. These requirements are catalogued in categories based on Pugh's elements.

Table 3. Product design specifications (PDS)

| Category | Requirement | Wish or Demand |
|---|---|---|
| Consumer | The system helps improve relations between community members | W |
| Consumer | The system is combined with an educational program aimed to improve sustainability in the community | D |
| Consumer | The education program includes kids in order to ensure the future of the system and increase their awareness towards sustainability | W |
| Consumer | The system represents higher income for the community due to at least 10% less water consumption | D |
| Consumer | The system includes an user manual | W |
| Environment | The system decreases tap water consumption at least 10% | D |
| Installation | The product can be assembled regardless of the context, in less than ten steps and it should take no more than 45 min | W |
| Installation | The system is flexible enough to be adapted in the 3 scenarios | W |
| Installation | The system is modular in order to allow its transport to the areas where the houses are located | D |
| Maintenance | The system requires no more than a monthly maintenance | W |
| Materials | The storage system is made with low porosity materials to ensure water insulation | D |
| Materials | The materials used are wear resistant | D |
| Materials | The system is built with materials available at the context which are | W |

| | | |
|---|---|---|
| | commonly used by the inhabitants | |
| Performance | The system is easy to operate | D |
| Performance | Potable water is well separated from the water being used by the system by implemented separate pipes | D |
| Performance | The system stores at least the amount of water equivalent to two hour peak consume hours = 50 L | D |
| Performance | The system's connections have hermetic seal in order to decrease leaks to less than 1 | D |
| Performance | Stored water maintains its conditions and properties for at least 4 weeks | D |
| Performance | Stored water is kept at room temperature between 15 to 20 °C | W |
| Performance | If harvesting rainwater, the system must include a discard system | D |
| Performance | If using domiciliary waste water, the system must separate gray water from black water | D |
| Politics | Water to be used must meet the quality requirements dictated on regulations "Classificação dos parâmetros de qualidade da água segundo os reúsos previstos. (NBR 13969, ABNT, 1997)" according to its final use. | D |
| Politics | The stored water is kept in good hygiene conditions. It follows the Colombian water quality regulation: "Resolución 2115 de 2007; Decreto 475 de 1998 ", Decreto 1575 de 2007. | D |
| Politics | Every part of the system is properly marked and identified in order to prevent miss interpretation and wrong use by the user | D |
| Price | The product has a price suitable for estratos form 0 to 2 | D |
| Production | The system should be feasible according to the local resources an processes | W |
| Production | The system is simple and it can be homemade | W |
| Quality | Before stored, water must be filtered at least one time | W |
| Quality | Water coming out from the system into the house for domiciliary activities must not be used for human consumption | D |
| Quality | Water does not have odors nor taste | D |
| Size | The products has a volume no more than 40,50,100 cm according to its more general dimensions | W |

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### 3.5 "REFLECT" CONCLUSIONS

- **Consumption habits**

- Nine water consuming domiciliary activities were identified after visiting the BoP communities: shower, sink, toilet, dishwashing, washtub/washing machine, cleaning, outdoor activities (cleaning of patios) and garden. All of these activities use potable water from EPM weather they have legal or illegal connection.
- Average water consumption in BoP communities (*estrato 1-2*) in Medellín is 13 $m^3$ per month.
- The higher water consumption is generated by showering and toilet flushing.
- Higher water consuming activities are usually developed during morning hours (from 6 am until 12 m) when shower and house chores take place.
- Showering, dishwashing and faucets (which include water for drinking and cooking) require potable water due to direct contact with user and its possible ingestion.
- Toilet flushing is the highest consumption activity (240L/day) because they use an average of 10L of water per flush. Some houses could have less consuming toilets.
- Shower is the second water consuming activity with 120L per day.
- Over 300L of water per day are being used on those activities that don't require potable water (toilet flushing, clothes washing, cleaning and outdoor activities).
- Clothes washing can be done both by hand or using washing machine. Although washing machines consume more water, they are not used daily but once or twice per week. This makes the consumption about the same.
- When measuring the amount of water consumed per activities a bucket (8 - 10L) of water was the basis because is the most used element when developing house chores.
- There is a community committee to ensure an appropriate water use in BoP neighborhoods; this represents an opportunity to implement education plans when distributing the system among the community.
- BoP communities are able to get the best of the environment, therefore, the system should reflect this lifestyle, providing rainwater as an extra water source, by ensuring the use of common materials and taking advantage of their actual skills to build and repair their own homes.

- **Design opportunities**

- Design opportunities represent 7 scenarios where water use systems could be implemented in BoP communities; weather the system uses RWH or WRU.
- Based on the evaluation criteria, RWH is a feasible option when it comes to water use systems due to its current use in BoP neighborhoods for some activities such as cleaning.

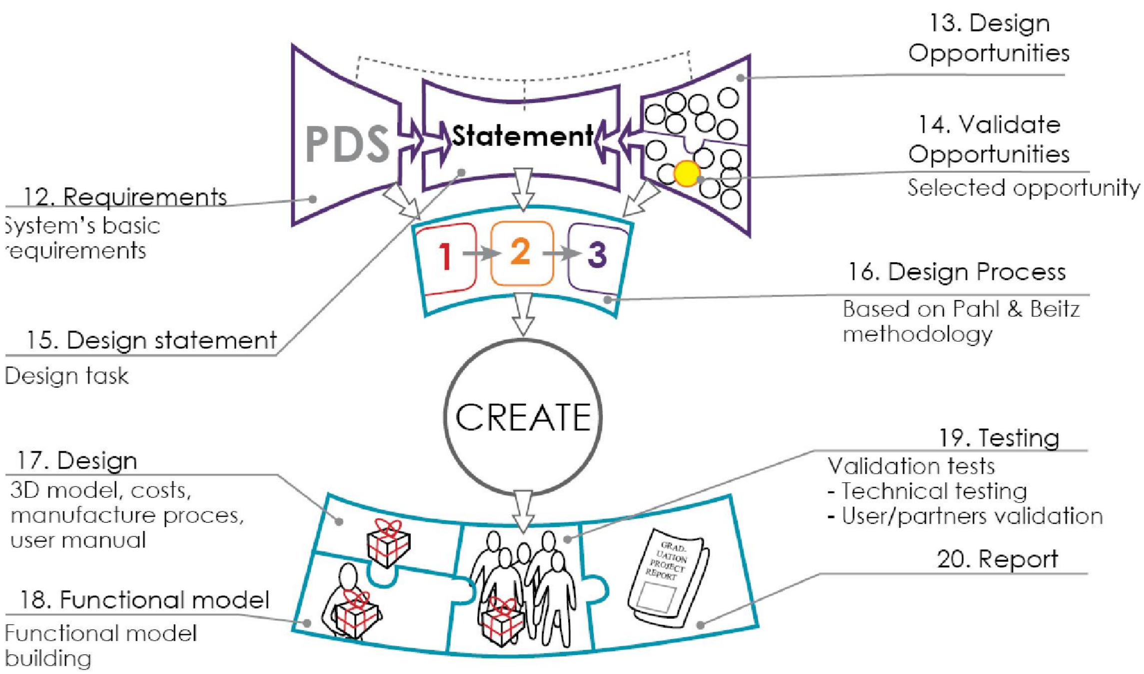
- RWH has been on the current administration plans to implement in BoP neighborhoods.
- RWH decreases earth slide in this areas due to the proper water channeling.
- WRU systems are not being considered among the administration plans because social housing architectonic design is restricted by economics and the lack of interest in new design due to the social and political pressure of building the amount of houses in the stipulated time.
- WRU systems, on formal or informal houses scenario, implies remodeling because pipes infrastructure has to be rearranged which increases costs. For this reason, BoP neighborhood inhabitants do not contemplate it as an option.
- WRU systems imply more specific treatment than RWH because of the pollutants from the previous activity where the water was used.
- For BoP communities, WRU systems represent less hygiene than RWH.
- House cleaning, outdoor cleaning, garden watering and toilet flushing represent the most feasible opportunities to use an extra water source.
- Urban plantations represent an option for development plans; however, they also represent extra water consumption for the community.
- Using a different water source for toilet flushing implies rearranging pipes; therefore, extra costs.
- Existing RWH systems are the base for the design; the challenge is to develop a system which can be adapted to BoP communities in Medellín according to their consumption habits.
- It is fundamental to implement an education plan when providing the community with the system in order to ensure its proper use.
- As found on the Hear phase, there are current administration plans and institutions aiming to implement water systems in BoP communities in order to improve the use of the resource; therefore, the system's distribution could be throughout these institutions and the final user will be the community itself.
- Taking in account that the user itself has built and installed their homes and current water infrastructure (illegal water connections), this ability could be used in order to manufacture the system. This means the solution has to be simple with the possibility of being homemade with the use of common materials.

## 4. "CREATE"

The final stage of the project consists on designing, building and testing the system. The main input for this step is the design statement developed in "Reflect" which is fed by the specifications and the selected opportunity. Phal and Beitz's *Engineering design a systematic approach* is the base of the design methodology (see chapter 1); it presents a step by step analysis and synthesis plan as a guideline for a rational approach into problem solving.

In addition from the design itself, "Create" is also about developing a prototype, or in this case, a functional model, which will serve to test technical aspects of the product and come up with conclusions and suggestions for its further implementation. "Create" stage is described and illustrated in Figure 17.

Figure 17. Create phase

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By the end of the "Create" phase, a solution will be designed taking in account technical and social characteristics. A SolidWorks 3D model will be elaborated as well as technical drawings which will be the base for the functional model also built during this step. With these outcomes, specific objectives 4, 5 and 6 are fulfilled and validation testing can be done.

## 4.1 DESIGN PROCESS

### 4.1.1 Task clarification

The design task is presented as a statement which responds to the objectives to be satisfied, the properties that the product must have and those that it must not. The result of the task clarification is a requirement's list. As it was mentioned on the project's methodology, the outputs from the "Reflect" stage will be the inputs for the last step of the project "Create"; both, the statement and the requirements were elaborated on the previous project stage.

### 4.1.2 Conceptual design

The conceptual design phase determines the basic solution; this is achieved by systematically analyzing the functions executed by a product (Baxter, 1995). Once the general problem has been formulated (design statement) it is possible to indicate an overall function which can be broken down into sub-functions. The goal is to understand and project a products functioning, link the user's needs and expectations with the product functional characteristics and divide the main design challenge into sub-challenges which could be easily or separately solved (Martínez, 2009).

- **Understanding the system: Black box (overall function) and Function's tree (sub functions)**

In order to simplify the system and look at it as a whole two tools were used: the black box and the function's tree. The first one aims to analyze the systems inputs and outputs by defining the main product's function. The second technique, function's tree, helps to represent and understand the system as a whole by dividing it by functions, ranking them by hierarchy and linking them. Figures 18 and 19 illustrate the result of these two tools.

Figure 18. Black box.


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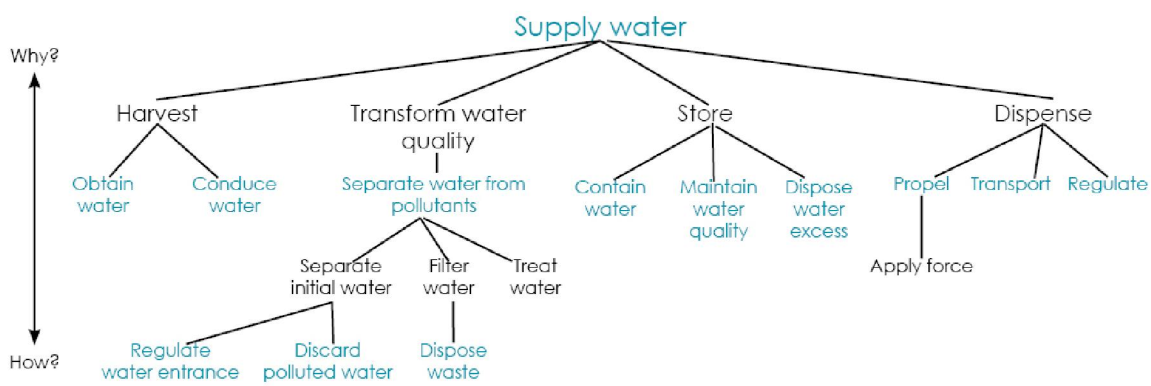
Phal & Beitz method defines adaptive designs as those that do not represent a radical invention, but are based on existing technologies (Phal & Beitz, 2007); hence, the RWH system follows into this category because it seeks to implement the concept for BoP communities. In this case, functions can be obtained easily by analyzing similar technologies and situations (see chapter 2)

The function's tree states four system sub-functions: Harvest water, Transform water's quality, store water and dispense water. These four items along with their own sub-functions are to be analyzed in order to include them on further design stages.

Figure 19. Function's tree.

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- Decisions making: "Stop and Go"

Although every function is irreplaceable for the system to work out, based on the information contained in the state-of-the-art, there are functions that may include variety of solutions already available on the market which do not require further design. Therefore, a self made exercise called *Stop and Go* took place; It aimed to determine which functions are to be designed further. However, the exercise does not aim to neglect those functions put aside or in *Stop* state but to increase the attention for those in *Go* state.

- Functions considered as Stop: There are several reasons to set up a function in a *Stop* state. Firstly, some functions cannot be controlled by the design team; it is necessary to include them within the whole analysis due to their relevance for the project, but there is no need to think about them as elements to design. Secondly, those functions which don't represent a design challenge or step out of the technical field which the team has skills for. Finally, those functions with several solutions, as products or services, already available in the market which can be directly implemented into the system regardless of the context the system is designed for.

- Functions considered as Go: Functions can be categorized as *Go* when they require an ad hoc process; this means, they have to be specifically design for the context or functionality. Those functions with a solution already available in the market, but must be analyzed, redesigned and adapted to the aimed context.
- Functions considered as *Analyze*: Those functions which require further analysis on coming design steps are considered as *Analyze* functions.

  - **Results**

Each of the functions were analyzed and categorized as stop, go or analyze depending on its characteristics. Figure 20 shows "S*top and Go*" analysis and Figure 21 shows how it is reflected on the function's tree

Figure 20. Stop and Go analysis

| | Function | What does it mean? | Why stop or go? |
|---|---|---|---|
| GO | Conduce | Surface or element to collect rainwater and take it into the system | This element depends on the context in terms of:<br>- Consumption habits (How much water needs to be collected in order to meet the user's needs?)<br>- Collecting capacity: depends on average rain fall for Medellín and the material being used to collect it. |
| GO | Filter | Retain solid particles | There are existing technologies to be applied which must be analyzed and adapted to the context depending on water quality. |
| GO | Store | Store water | Storage system selection depends on the context in terms of:<br>- Water demand: How much water needs to be stored to fulfil domiciliary activities<br>- Water availability: How much water could be collected |
| GO | Dispense | How to take water out from the tank and bring it to the different activities to be used | It represents a design challenge |
| STOP | Obtain water | Water source | Rain; It is a phenomenon. There is no control nor design involved |
| STOP | Treat water | Micro biological treat-ment | Depends on the required water quality. Because the activities do not require potable water, there are simple solutions existing on the market which can be implemented. |
| STOP | Regulate | To allow or block water flow | Existing products on the market to be implemented |
| ANALYZE | Discard | To avoid the first 5 minutes of rain to enter the system | Rainwater acidity testing to be done in order to decide weather or not inmple-ment the system |

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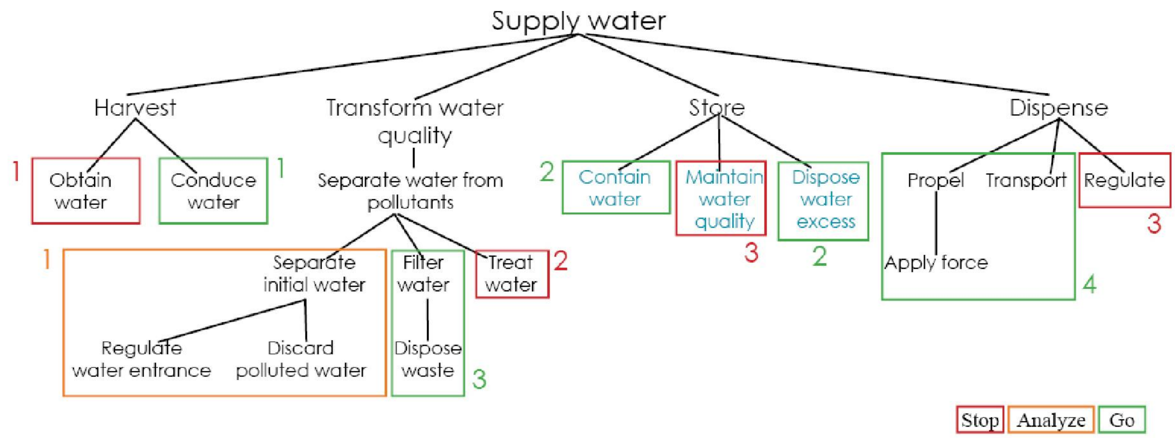
These decisions were made taking in account aspects coming from the design and reflect stages, Figure 21 illustrates the analysis.

Figure 21. *Stop and Go* function's tree

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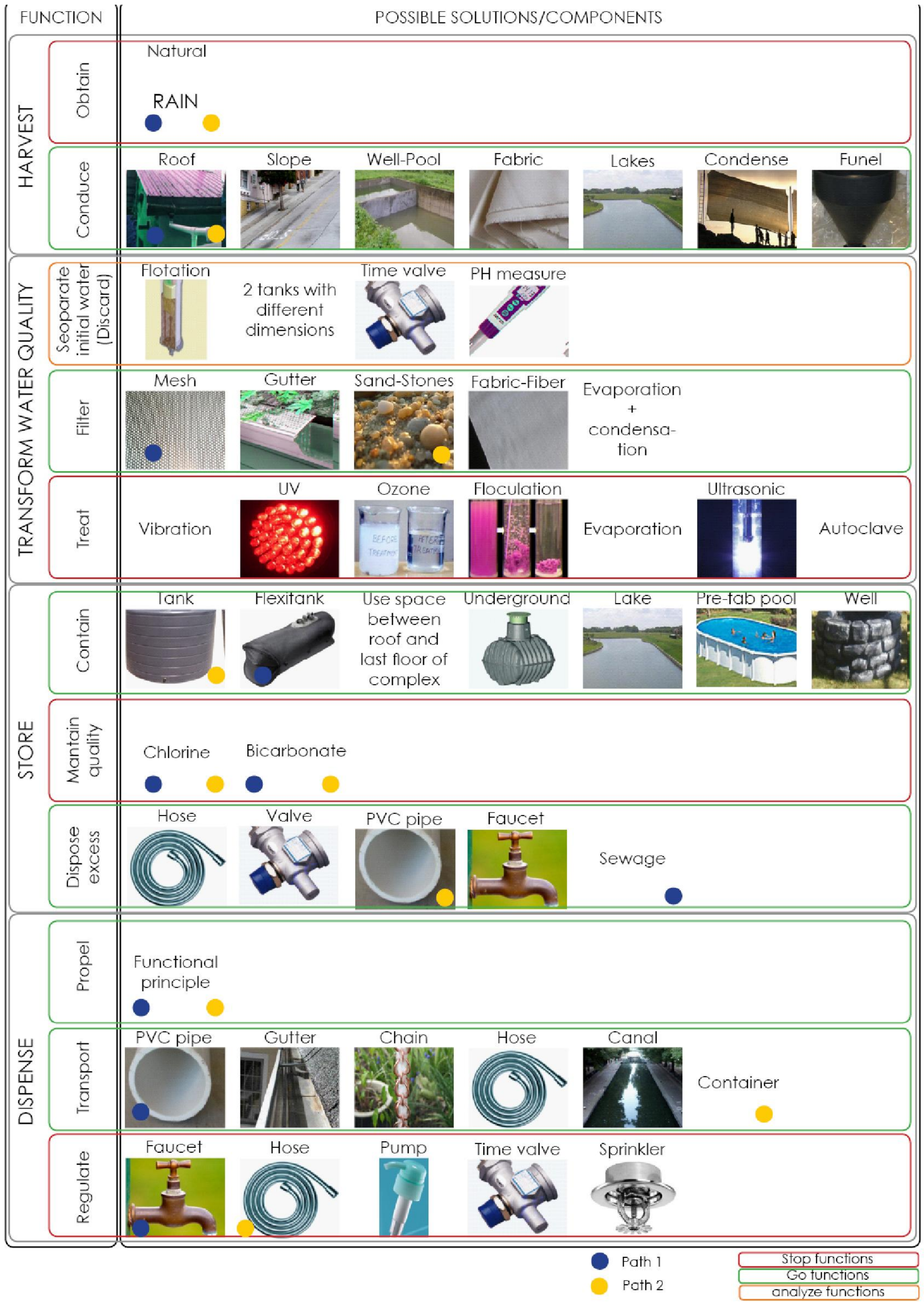
o How these definitions will affect further steps in the project?

*Stop and Go* exercise determined which functions are not determined by the context itself; therefore, existing products available on the market can be used to fulfill the function. On the other hand, those functions stated as *Go*, shall be further designed.

- **Morphological scheme**

Once the sub-functions are determined, different solutions are to be found for each of them; therefore, and in order to generate different ideas, possible solutions for the product's sub functions (components) were arranged on a morphological scheme. Although the functions classified as *Stop* are not to be further designed, they are contained in the scheme in order to analyze and select them when designing the others. The morphological scheme allowed to broad possible solutions for each of the functions executed by the system whereas these solutions are existing products, concepts or technical facts. Figure 22 illustrates the scheme.

Figure 22. Morphological scheme.

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o Morphological paths

Because of the amount of components and possible combinations of them, paths must be selected (Cross, 1999); this means, choosing possible combinations which are feasible, practical or promising, as well as discard those which include functions that are already contained by others. In this case, two paths were selected and they served to create ideas when generating concepts. In order to select the components included on each path, Hear and Reflect steps were kept in mind as well as the *Stop and Go* exercise. The paths are illustrated on the morphological scheme image (see Figure 22). When selecting the components, some of them where already determined by the context, required water quality or because they represent a phenomenon to be further studied. For this last case, it doesn't mean design its not to be done, but technical facts have to be considered first in order to select a proper component. Figure 23 illustrates which components are already determined and the specific reason.

Figure 23. Already determined components.

Selection

| Function | Component | Why? |
|---|---|---|
| Obtain | Rain | RWH system design where rain is the source of water |
| Conduce | Roof | Roofs are the most efficient way of collecting rainwater; the infrastructure is already available in the context and can be used for this purpose, therefore it doesn't represent extra costs for the system. |
| Treat | Not necessary | There is no need of treating water due to the use that will be given to it (Appendix xx) |
| Maintain quality | Chlorine + Bicarbonate | The amount of each of these elements depends on posterior water quality testing, but they are the easiest, cheapest and most available techniques in the local market. |
| Propel | Functional principle | It represents a design challenge to be further studied and analyzed in posterior design stages |

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In addition to those solutions already selected which shall be adapted to the context, two components are to be individually designed in detail:

- Filter: in both paths, filter turns out as a material, which shall be included in the component design itself.
- Propel: this principle is to be studied and designed in further stages.

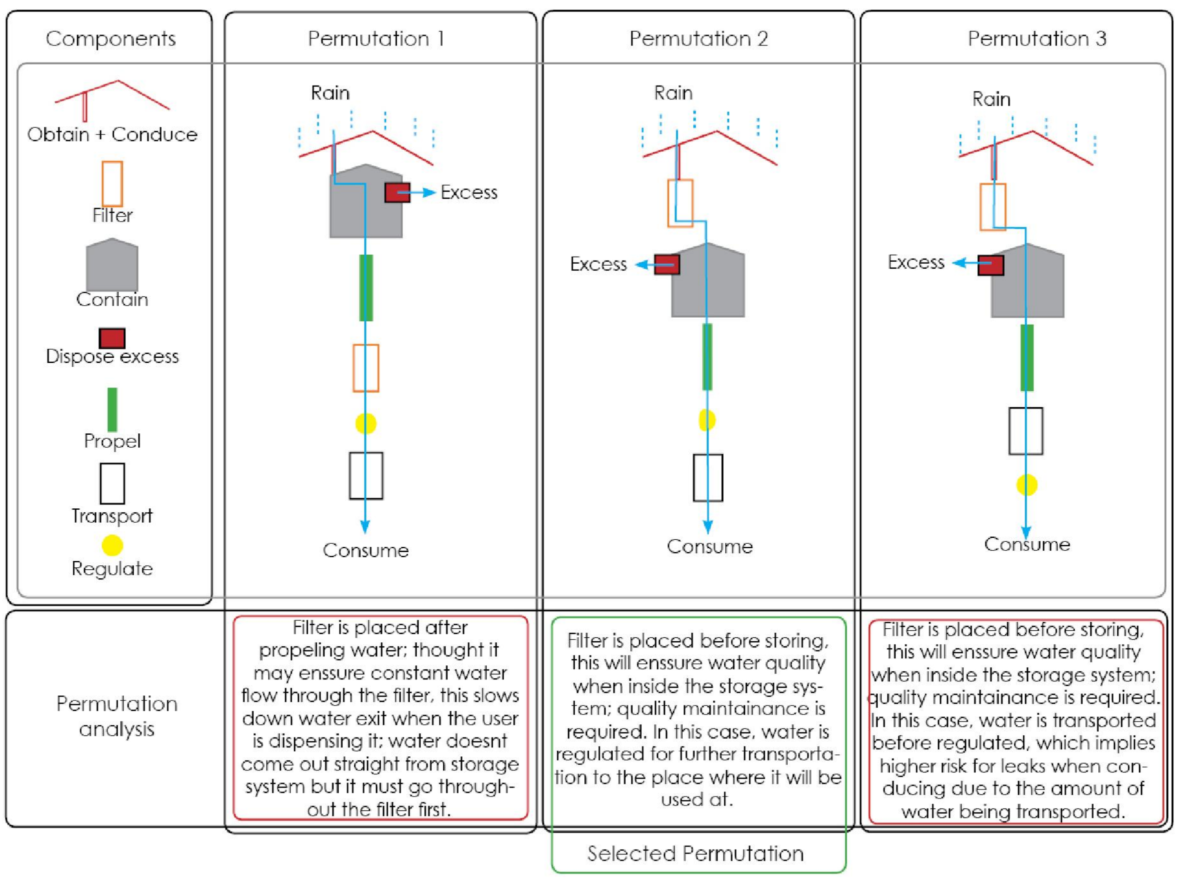
On the other hand, initial water separation will be designed in case it is needed since it depends on water quality testing.

- **Product permutation**

Product permutation aims to systematically locate product components taking in account possible arrangements (Baxter, 1995); this technique allows to generate ideas based on how parts have to be located in order for the system to work properly to avoid incidental relations that will result on mal functioning of the product.

From the selected components and the state of art, only few combinations can be arranged since RWH require certain steps in a stated order; water harvesting and dispensing are necessary the first and last component. The most notorious difference between the variations is achieved when storing and treatment system as well as their sub-functions are placed in different orders. Three permutations were generated (Figure 24) and analyzed in order to select one which wouldn't compromise water quality or system's functionality.

Figure 24. Possible permutations for the RWH system being designed and their analysis.

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Permutation 2 was selected because it ensures water quality before entering the storage system; therefore, water being propelled to be used in the activities already has the required water quality. In addition, water is regulated first and dispensed afterwards which reduces the risk of leaks when transporting it.

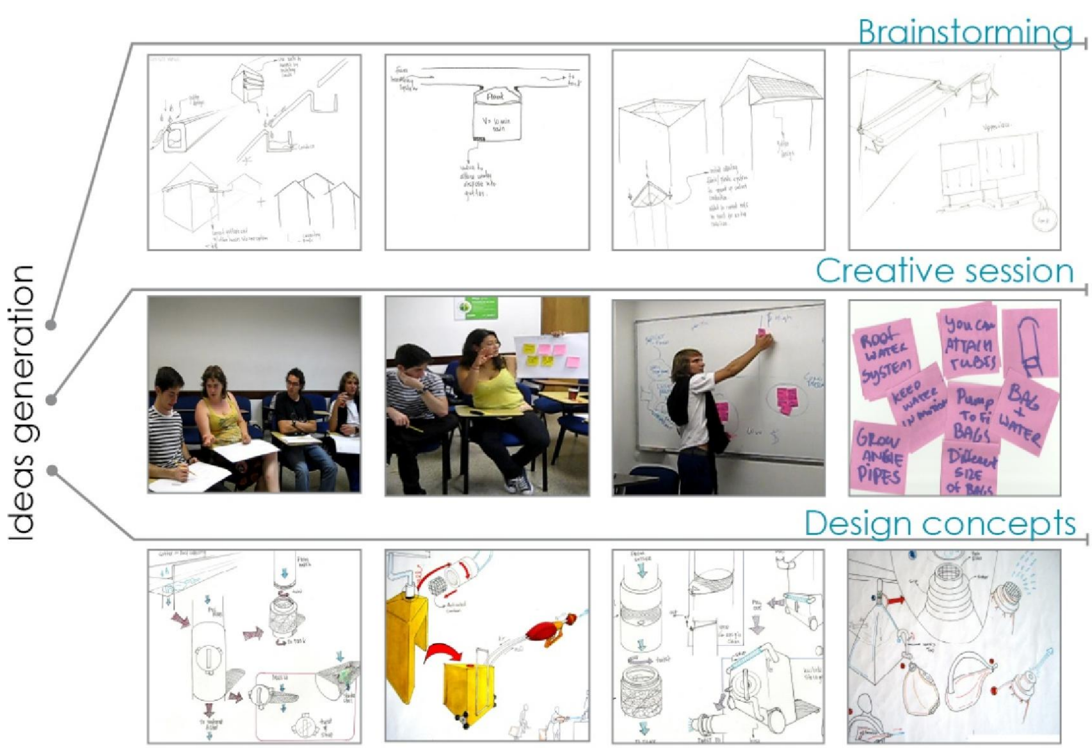
### 4.1.3 Embodiment design

During this step the overall layout of the product is determined (general arrangement and spatial compatibility) as well as the preliminary form design (shapes and materials); in many cases several preliminary designs are needed before a definitive design (Phal & Beitz, 2007). Therefore, different "idea generation methods" were used in order to develop different preliminary designs and refine them in order to achieve a definitive final concept to be designed in detail.

- **Ideas generation**

In order to begin generating solutions for the design statement, different methods were used to broad the possibilities. Images from all of these methods are shown in Figure 25 while each of them is briefly described in following paragraphs.

Figure 25. Design concepts.

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- Brainstorming

By using the different components from the morphological paths, and the final permutation, several ideas were generated by the team members. A brainstorming was used to develop a first approach to the solution; this method stimulates people to present different ideas in a short amount of time. Therefore, the solutions generated are drafts and a final concept was not intended to be obtained; the goal was to initiate the creative process which will evolve into the final concept and solution.

From initial brainstorming, it was evident that dispensing was a key factor for the design; the goal is to bring water to different areas of the house without compromising the infrastructure and ensuring low cost components. Therefore, a creative session was done with Industrial design engineering students in order to broad the possible solutions for this particular component.

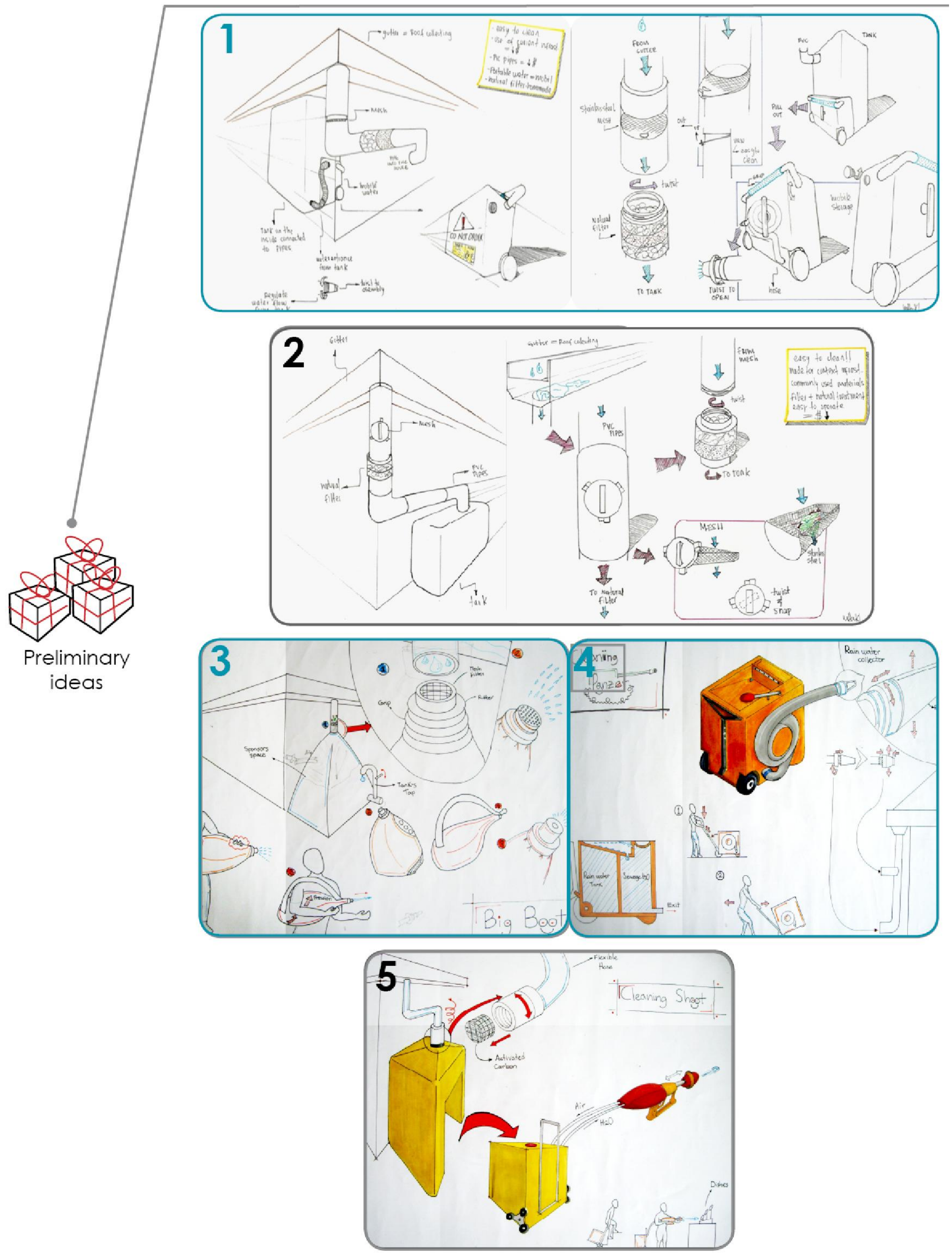
- Creative session

From the morphological path selection and after brainstorming the need to diversify the way of dispensing water to be used by the community was found. Therefore, a creative session with Industrial Design Students from EAFIT University and TUDELFT was planned and developed. From the session different ideas were born: using bamboo pipes, using a bag filled with water with a pump in order to carry water around, using the roof as a storage system in order to distribute water through the house by connecting PVC pipes, use manual pumps, use a sponge to filter and transport water and dispense it by wringing it out, design different buckets whit diverse volumes in order to use the exact amount of water, use common materials such as PVC and plastic bags with lids, among others. These ideas were also basis for concept generation. The planning and development for the session can be found in Appendix 13.

- Preliminary ideas (design concepts)

From both the brainstorming and the creative session, the team had enough material and creativity boost to develop five design concepts which illustrate basic functional solutions to be further detailed once evaluated. These concepts are shown on figure 26 and gathered in Appendix 14.

Figure 26. Design concepts – preliminary ideas –

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- Concept evaluation

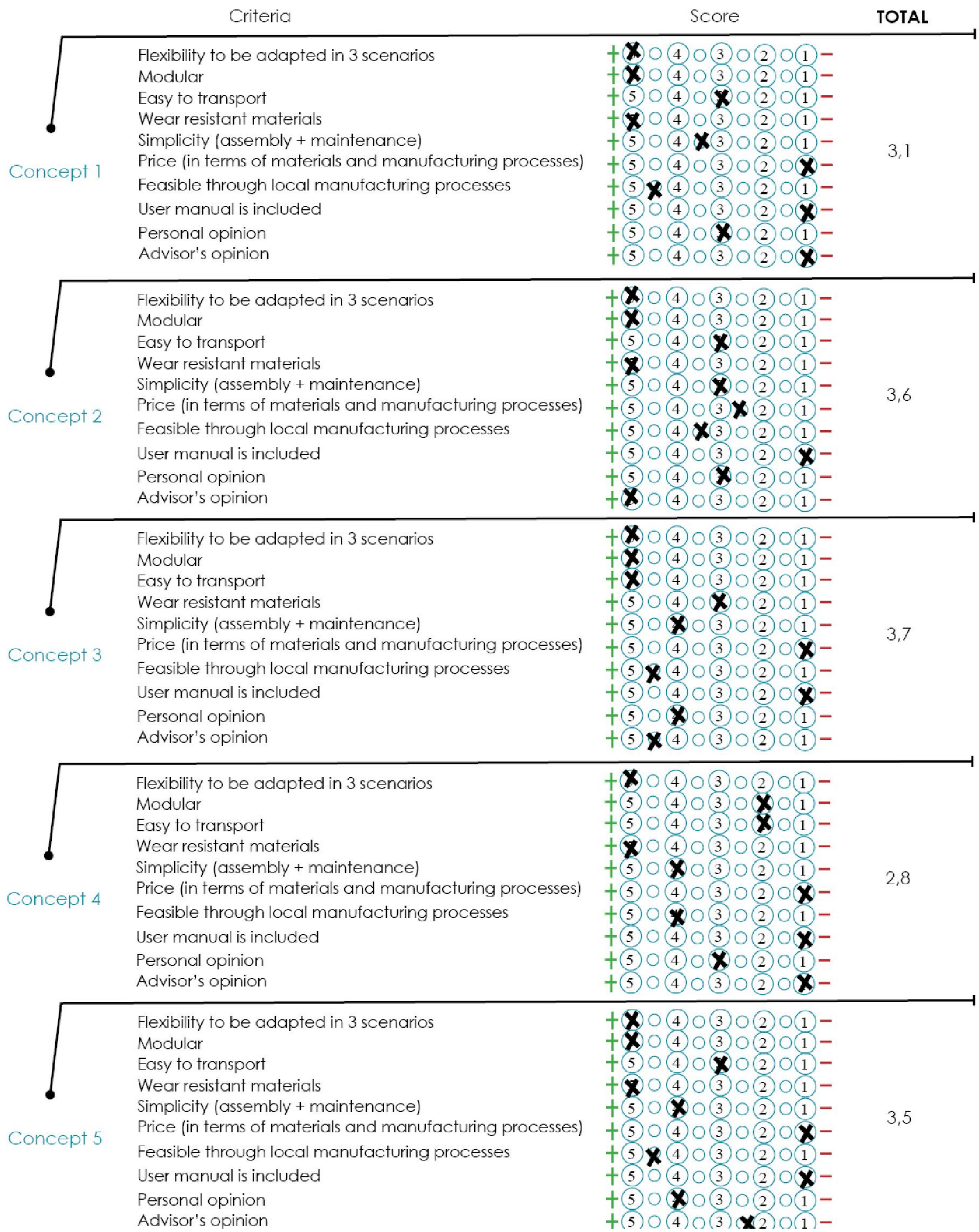
In order to select the specific components based on the different solutions generated on the preliminary ideas, criteria was determined based on the specifications stated on the PDS, personal and advisors opinion; the 5 preliminary concepts were evaluated according to it. Figure 27 illustrates the evaluation chart where the analysis to select the most appropriated idea or several parts from each idea was done.

- Concept evaluation analysis

From the concept evaluation, several conclusions could be made:

- There is not a concept which exceeds the others in terms of total score; therefore, the design will be a combination of components and ideas presented on the 5 concepts.
- Concepts were based on the four main components: harvest, transform water quality, store and dispense.
- It is important to include the context infrastructure and available materials such as PVC in order to decrease production costs and increase community acceptance.
- The storage system doesn't need to be designed because it will represent costs increment. Therefore, available tank materials and characteristics are to be analyzed in order to determine which type of component to use.
- Dispensing water continues as a key factor; not only transporting water to different locations but pumping it. Only one concept considered a pump design; this means, pumping principle has to be further analyzed when detailing.
- A portable bag is an option to carry and transport water to the different locations where it will be used; this alternative was also present in the creative session.
- Mesh and filter shall be easy to clean and operate; natural filters are the most feasible, according to the concepts and the team's personal opinion, because they can be homemade with low cost materials.

Figure 27. Concept evaluation

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- **Design concept**

From concept evaluation a final concept was elaborated (see Figure 28 and Appendix 15 for concept details); the concept includes each of the components: harvest, water quality transformation, storage and dispense. Each of these parts has to be studied and designed in detail through the final design stage (chapter 5).

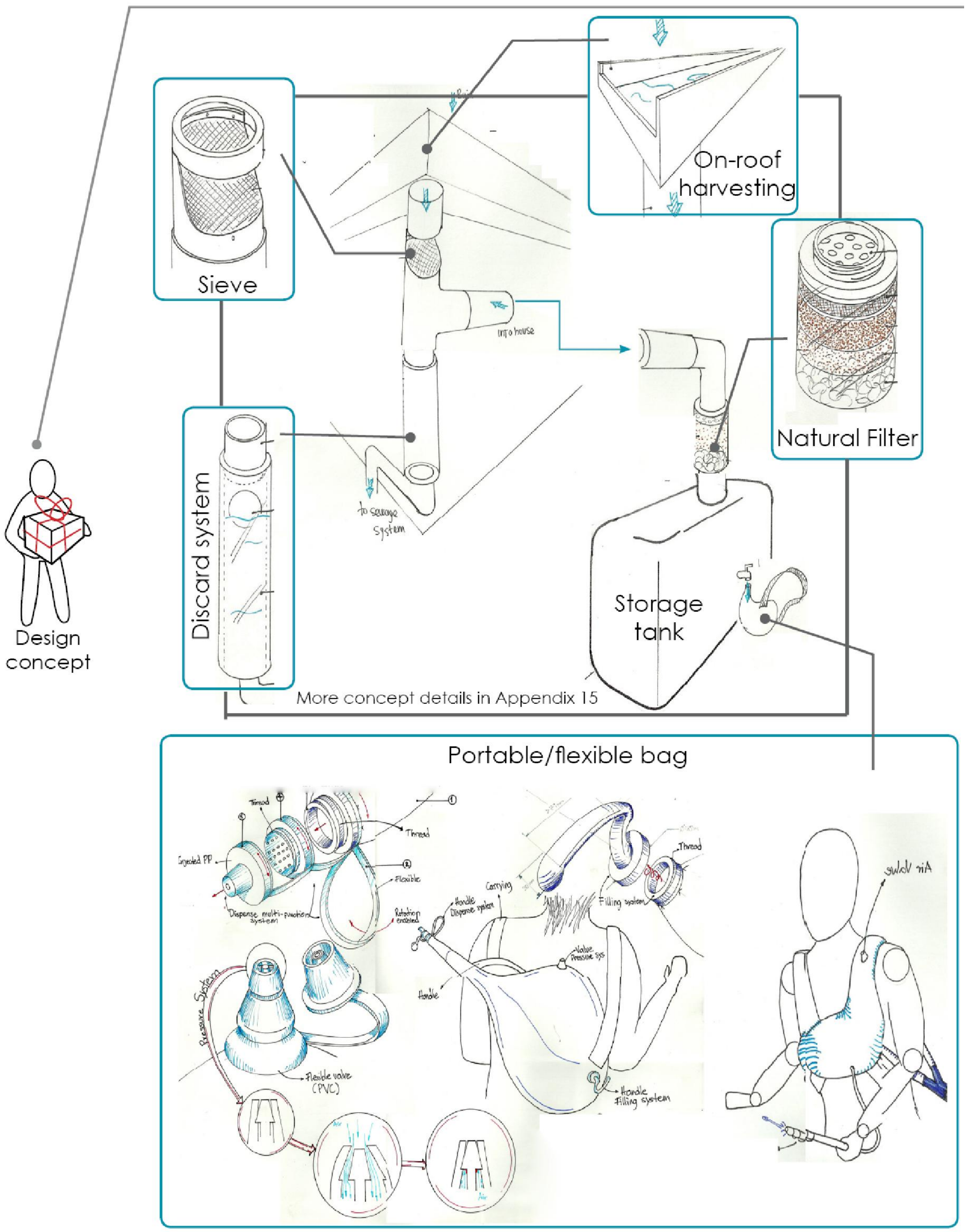
The concept base material will be PVC since is available and easy to obtain locally; in addition, this material is already used by the context and in general is utilized for water transportation.

Water is harvested from a gutter and conduced into the system. It goes through a sieve in order to retain solid waste like leaves and sticks. From there, it enters the discard system which aims to dispose the first five to ten minutes of rainwater in order to avoid acid rain into the system; however, the use of this component depends on whether Medellín's rain is considered acid or not. This will be established on the next step of the design ("Create" - Detail design). The discard system is made by PVC pipes (a main cavity) as well as a floating plastic ball which closes water entrance to the cavity when five to 10 minutes have passed, allowing rainwater to continue its journey into the other components of the RWH system.

When these ten minutes are discarded, water flows through a filter to retain smaller size particles such as pollen, dust and minerals contained in the air and dragged by the rain. Once filtered, water is stored on a tank whose material and characteristics are defined in chapter 5, and dispensed to the user using a manual pump and into a portable bag to be carried to different areas inside the house.

The manual pump and the portable bag are key components; they represent direct contact and interaction with the user. On the coming chapter, these two system parts are studied in order to determine their usability and endure their performance. The pump represents a design challenge because its functioning principle shall be studied in order to begin its design.

Figure 28. Design Concept.

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## 4.2 "CREATE" CONCLUSIONS

- Because the product can be categorized as an *adaptive design,* the main task was to make it suitable and feasible for the selected context (*Comuna 1*); therefore, conclusions found during the "Hear" step concerning how to build for BoP communities were an important basis for the design. They served as guideline for material and manufacturing processes selection as well as for costs limitations.
- During function and sub-function analysis as well as the *Stop and Go* exercise, it became clear that most of the components consisted on rearranging existing pieces or modifying them in order to meet the context needs. The same situation was found when selected morphological paths.
- Design challenges were found on dispensing and filtering water since these two functions represented situations which couldn't be solved by using existing components without incrementing costs.
- When evaluating the 5 concepts, it was important to keep in mind the user while analyzing technical facts (modularity, materials, assembly) and economic considerations (local materials and processes) of each of the possible solutions.
- Idea generation methods served to analyze the problem from different perspective, hence, different solutions were born in order to be studied and designed in detail.
- Four components have to be designed in order to elaborate a proper RWH system: harvest, transform rain quality, store and dispense.
- The most effective way for RWH is on roof collection, especially for the environment designing for; roof collections decreases costs because infrastructure is already available. Therefore, a component shall not be designed in order to fulfill this function which decreases costs and complexity for the system to be implemented by the user.
- In order to supply quality water, its physicochemical characteristics have to be measured and transformed by using a sieve and a filter; these processes will prevent health issues among users and increase their acceptance into implementing the system and giving water a proper use.
- Storing water is necessary in order to ensure the resource availability during dry seasons. The storage system must provide enough water to develop the domiciliary activities equivalent to two peak hour's water consumption. In this case, the system intends to provide 100L of water per day which covers the daily water demand; therefore, average rainfall during dry seasons will be the starting point to analyze storage capacity.
- Dispensing water represents one of the biggest design challenges because the resource has to be taken to different areas inside the house without compromising or

rearranging their current infrastructure. Therefore, a pumping and transporting system must be designed. As for regulating water quantity, it is not considered as a big challenge because it can be easily solved with existing products such as faucets.

- Pumping water is also considered one of the biggest design challenges to overcome because the component must be powered by human energy in order to ensure the resource in case of lack of public services. Moreover, it should fit into the required economic characteristics of the context.
- Portable bags are considered in the concept for transporting and regulating. This component has to be analyzed by comparing it with the existing products being used to transport and regulate water. Because the activities are done on the daily basis, the user has developed confidence over the product he/she is used to utilize; therefore, this new concept shall be analyzed and verified based on this fact.
- User-product interaction takes place when dispensing water. The required components to do so must include ergonomic considerations in order to provide a proper use experience which will result into product's acceptance.
- The use of common construction materials available on the context will increase user's acceptance towards the product and it will reduce costs and simplify manufacture and assembly because of the number of standard pieces.
- Because the product will be mainly delivered to the user by the administration or other institutions related to habitat improvement in the city, simplicity is always to be kept in mind. Available materials, local manufacture process and standard parts are some of the characteristics which shall define the system itself; they represent easier implementation, and reduce costs which will also increase the chances of installing the system and including it in the development plans.

## 5. "CREATE" – DETAIL DESIGN-

The last phase of the design methodology proposed by G. Phal and W. Beitz is the detail design; during this phase the arrangements, forms, dimensions and surface properties of all the individual parts are laid down (Phal & Beitz, 2007) as well as the possible production methods, general costs, and blueprints. Throughout this phase corrections and refining may be done, as well as repeating the preceding steps, in order to achieve a feasible solution meeting the requirements. In addition, this phase includes pertinent tests to be done to the components in order to ensure their well functioning when being implemented.

To develop the detail design, each of the components was studied according to their nature and required technical approach. The analysis was also made based on the concept evaluation. Because of the amount of information required and developed for this phase of the design method, chapter 5 is dedicated strictly to it.

### 5.1 ON-ROOF HARVESTING

As it was said before, and proved by the *Holcim foundation awards* participants, it is necessary to make the best out of the environment we are designing for; this idea will turn into lower prices and higher community acceptance. On roof collecting is the most efficient rainwater harvesting way and it gives the opportunity to include the context into the solution. Several details were evaluated in order to determine the sufficiency of the context roofs.

- **Collecting area**

The amount of rainwater to be harvested depends not only on the annual rainfall of the region but the available collection area, meaning the roof's horizontal projection and the run-off coefficient[22] (OMS, 2001). The run-off ($R_c$) coefficient for SDS's houses is 0,9 since their roof is generally made with corrugated metal sheets or roof . The established water demand (D) for the selected activities according to the consumer habits is 100 liters/day which equals 3000liters/month or $3m^3$/month.

The run-off coefficient and the water demand are established facts; on the other hand, thought Medellín has an annual average rainfall ($RF_a$) of 1687 mm, or 140,58 mm/ month ($RF_m$), this amount changes according to the season (see Appendix 9). Therefore, to calculate the required roof area (A) three scenarios were elaborated in order to illustrate

[22] Run-off coefficient:

the situation with the minimum, medium and maximum average rainfall; Table 4 illustrates low rainfall scenario which will be considered as the base for the analysis since it represents dry season periods. The other two scenarios can be found in Appendix 16. The area is calculated with equation 1.

Equation 1: Required roof area for water harvesting (Practical actions UK, 2010)

$$A = ((D)x(365))/((RF_a)x(R_c))$$

Table 4. Necessary roof area for dry seasons

| **Scenario #1: Low rainfall** | | |
|---|---|---|
| Consumption | 100 | lt/d |
| Monthly rainfall | 65 | mm |
| Annual rainfall | 780 | lt/y |
| Run-off coefficient | 0,9 | |
| Days (year) | 365 | |
| Harvesting area | 51,99 | m^2 |

Authors: María Hock, Manuel Echeverri

According to the scenarios, the necessary rainfall area for the most critic situation is 52 $m^2$ which can be considered as an available roof area in SDS's houses. This low rainfall situation happens only three months per year in a non consequent pattern. Therefore, in case of lower collecting area, it wouldn't compromise system's functioning; nevertheless it is recommended that houses have at least 52$m^2$ roof area in order to ensure water availability throughout the year, even during dry seasons.

In case of inferior collecting area available, the storage system will provide sufficient water for the aimed activities; it's important to highlight that these domiciliary activities do not compromise the user's health and life quality in case there is not enough collected rainwater. In addition, in case of extreme dry periods, the user can chose to use potable water from EPM.

## 5.2 TRANSFORM WATER QUALITY

After harvesting the water, it shall be conducted into the quality system. In order to transform water quality and obtained the required physicochemical characteristics according to the activities to perform, three activities were found on the function's tree: discard initial water, filter and treat. From the previous analysis, the discard system, which aims to dispose the initial five to ten minutes of rainwater, will be used in case of acid rain[23]. On the other hand, water does not require to be treated because of its final use (non human consumption). Therefore, the main design is focused on filtering the water.

### 5.2.1 Discard

According to the IDEAM Medellín's rainwater PH is equivalent to 6 (IDEAM, 2010). When PH levels oscillate between 4,7 and 5,7, rainwater is considered as slightly acid, and between 4,4 and 4,7 is considered as acid. Therefore, Medellín's rainwater is not catalogued as acid rain. With this value, it can be stated that a discard system is not required with current water characteristics in the context. Nevertheless, if the system is implemented in other BoP communities, outside Medellín, further analysis must be made to determine if the discard system is necessary.

### 5.2.2 Filter

Because rainwater is being collected from roof, different solid waste materials may come into the system; the filter is designed to prevent this. Two components were designed in order to obtain the required water quality: a basic sieve and natural filter (sand and stones). The first one aims to retain large solids such as leaves and sticks coming from the gutters. The second one aims to retain smaller solids which include volatile particles, reduce turbidity and improve aesthetic characteristics such as color, odor and taste.

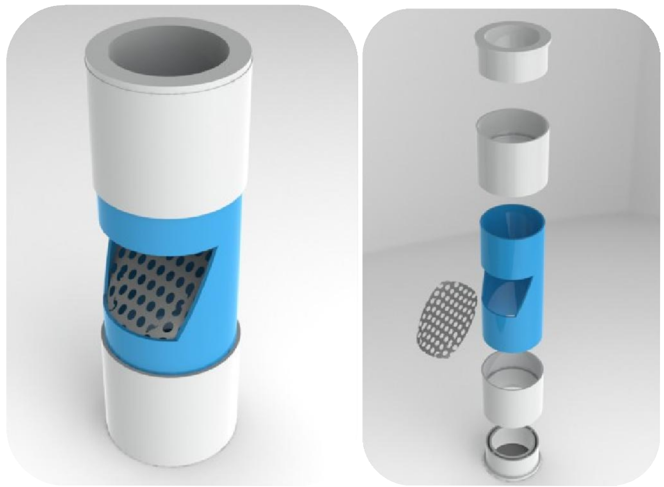
- **Sieve**

Because the products is made for low income families aiming to get the best of their surroundings, commonly used construction materials were used for the system. Generally, three inch PVC pipes are used to transport water; therefore, they are also used in the RWH system to elaborate the components. The result is a homemade system which can be easily elaborated by the user.

The sieve (Figure 30) is composed by the PVC pipe and connectors with a thin aluminum mesh where large solids are retained and can be manually cleaned in case they are not thrown out of the system because of water flow and the mesh's inclination.

[23] Acid rain: according to the IDEAM, rainwater is considered to be acid when its PH level is below 5,6 which is considered normal rainwater acidity. Therefore, when 4,7<PH<5,7 is considered slightly acid. If 4,3<PH<4,7 rainwater is considered acid and if PH<4,3 is considered highly acid.

Figure 29. Sieve.



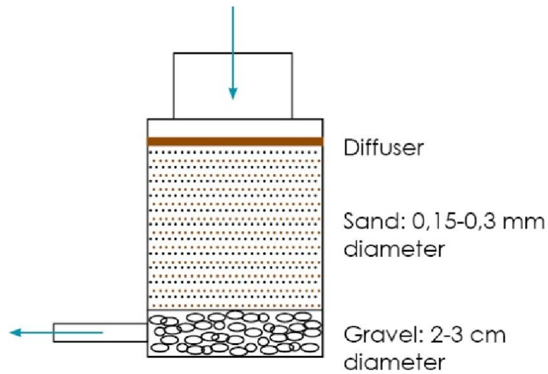
Author: Manuel Echeverri – María Hock

- **Natural filter**

Natural filters are based on the soil property of cleaning water while it runs through the different elements, sand and stones, contained in it. These filters represent a good opportunity to be used in a low resource community because of the availability of the materials and their simplicity.

The health ministry in Guatemala elaborated a homemade water filter for human consume to be used in native communities based on a previous design form Nicaragua's health ministry (Ministerio de salud pública de Guatemala, 2010). The filter, Figure 30, consisted on a concrete recipient (40x40x90 cm) filled with one or several layers of sand and stones (running from the thicker sand layer to the thinnest); in addition, the filter has a diffuser plate to reduce the turbulence of the influence and prevent channels forming through the sand. The maintenance of this filter is simple; the diffuser is washed every 6-8 months and a few centimeters of the upper sand layer must be removed when the filter speed is below average. The filter has a vertical input but a horizontal output; therefore, it requires a layer of gravel at the bottom to support the sand and prevent clogging of the output pipe.

Figure 30. Natural filter used in Guatemala.



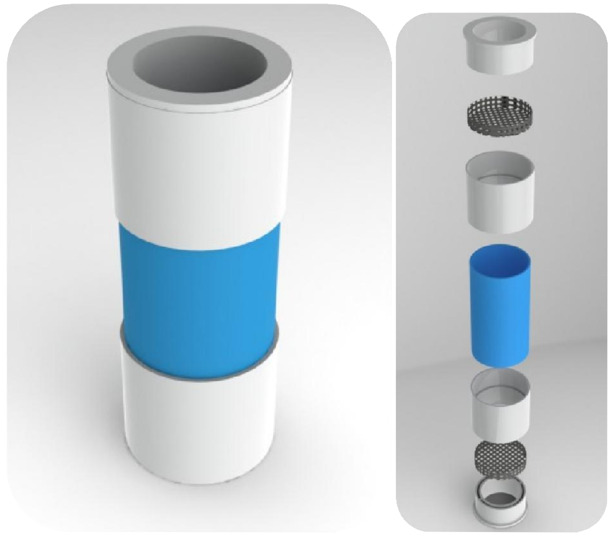

Author: Manuel Echeverri – María Hock, based on (Ministerio de salud pública de Guatemala, 2010)

In addition to sand and stones layers, activated carbon is known to be used in water filters because of its absorbency properties. Activated carbon is also locally available in different chemical product stores. Therefore, this material is also considered for the homemade filter to be designed, and material testing was done in order to select the most proper one to be used.

As it was said, PVC pipes are the basis for the system; therefore, four inch PVC pipes and connectors were used to develop the sieve and filter. A plastic mesh is used as a diffuser and high diameter gravel (24mm) is placed at the higher level in order to prevent conducting channels being formed in the filtering material (sand or activated carbon); channels keep water from spreading evenly through the container diameter (PVC pipe); if channels are formed, water will constantly run through them, this will cause the filter to get blocked sooner than expected.

Because the filter will be placed after the sieve water will vertically run through it. Therefore, a synthetic fiber was added to the filter as the bottom layer material in order to retain those particles of the filtering material being dragged by water flow. The filter basic design (without its filling materials) can be seen in Figure 32.

Figure 31. Filter without filtering materials.



Author: María Hock, Manuel Echeverri

- Filtering material selection

With two types of filter materials (sand and stones and activated carbon) in mind, three tests combining them were made in order to select the most appropriate to be used. The procedure to test the three filters is shown on Figure 33. It consisted on building the basic filter and filling it with the different material layers. Pour rainwater into the filter, let it flow and collect the sample in transparent containers.

Figure 32. Filter materials testing procedure.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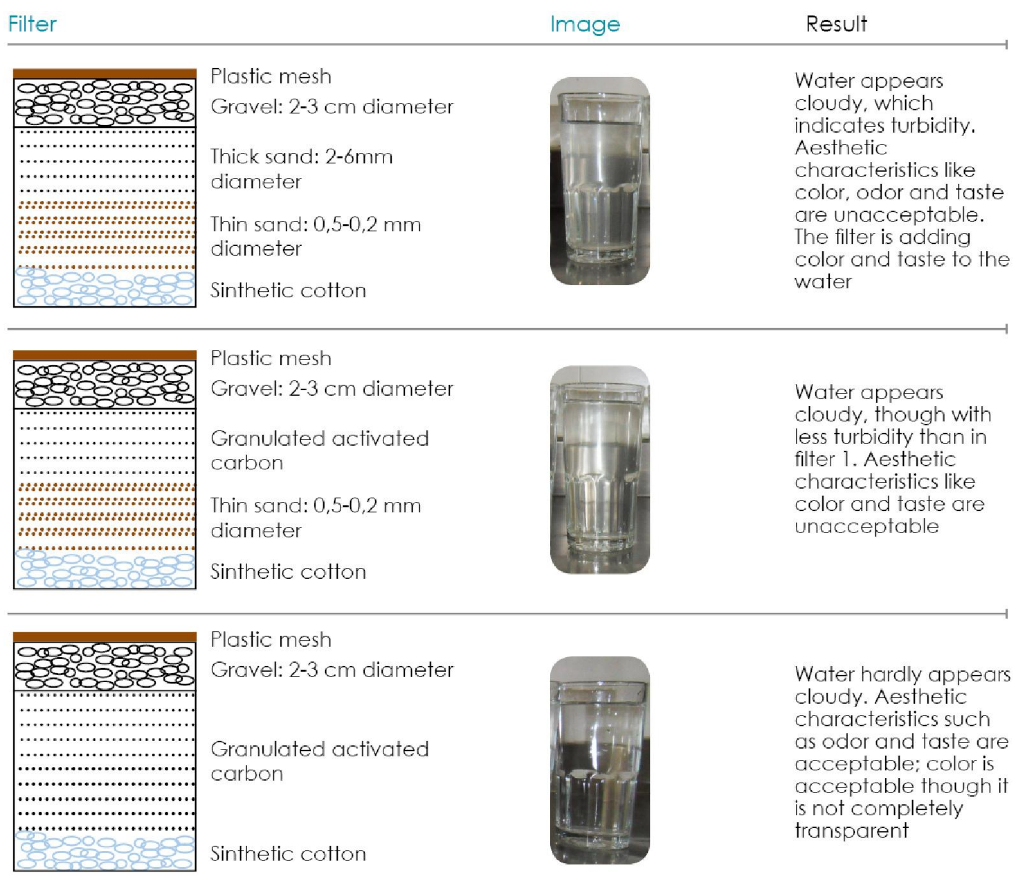
Afterwards, they were put side by side in order to compare them. In addition, water was smelled and tasted to determine if odor and taste were acceptable; this means, that the sample doesn't have earthy taste or unpleasant odors. The selected filter material will be tested by developing physicochemical analysis when technical validation takes place (chapter 6); these tests are done to determine water quality when filtered and compare it with Medellín's rainwater characteristics and acceptable quality values determined by regulations.

From the three tested filters (Figure 34) activated carbon was selected as the main material because it does not pollute the water running through it. In addition it doesn't add odor, color or taste.

Figure 33. Possible filter materials testing.

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### 5.3 STORE

A storage system is necessary in order to ensure water availability for non-rainy days and dry seasons. Storage capacity (liters and dimensions) as well as its material (rigid or flexible) were the two main issues to define.

- **Storage capacity**

According to monthly average rainfall the amount of collected liters of water ($W_c$) month by month was calculated using equation 2. The collecting area for the average rainfall scenario (Scenario 1, A= 52m$^2$) was the one used for the calculation.

Equation 2. Amount of water being collected (Practical actions UK, 2010)

$$W_c = (RF_m)x(R_c)x(A)$$

$RF_m$ = Average monthly rainfall
Rc = Run-off coefficient
A = Roof area

Rainwater collected and water demand were subtracted in order to find out if the system supplies enough water for the activities extra and to be stored ($W_l$). The most critic month (January) shows a lack of water of 192 liters which means the storage system capacity has to be at least this amount of water. Therefore, a 250 liter standard size tank was selected. Table 5 illustrates water availability, water demand and water leftovers as well as the stored water with a 250 liter tank.

Table 5. Rainwater harvesting and storage capacity throughout the year.

| Month | Monthly average rainfall (mm) | Collected Water (L) | Water Leftover (L) | Stored (L) |
|---|---|---|---|---|
| **Jan** | 60 | 2808 | -192,1 | 58 |
| **Feb** | 78,5 | 3673,8 | 673,8 | 250 |
| **Mar** | 120 | 5616 | 2616 | 250 |
| **Apr** | 170 | 7956 | 4956 | 250 |
| **May** | 195 | 9126 | 6126 | 250 |
| **Jun** | 155,5 | 7277,4 | 4277,4 | 250 |
| **Jul** | 113,5 | 5311,8 | 2311,8 | 250 |
| **Aug** | 151 | 7066,8 | 4066,8 | 250 |
| **Sep** | 178 | 8330,4 | 5330,4 | 250 |
| **Oct** | 215 | 10062,1 | 7062,1 | 250 |
| **Nov** | 148,5 | 6949,8 | 3949,8 | 250 |
| **Dec** | 86,5 | 4048,2 | 1048,2 | 250 |

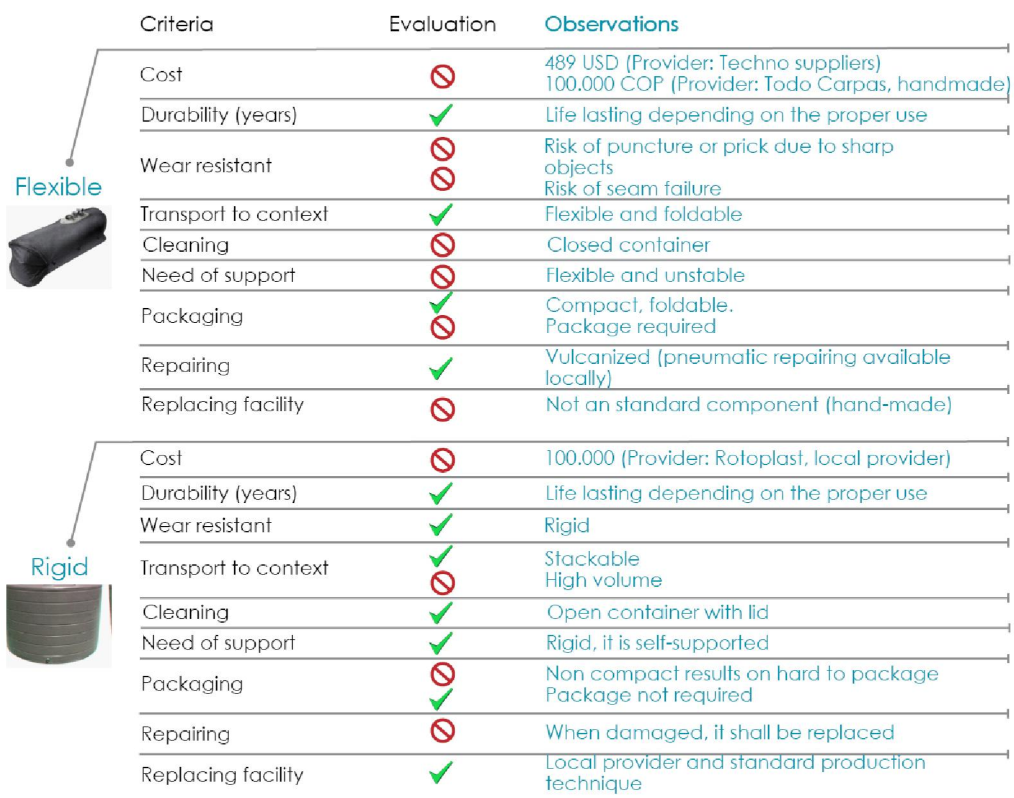
| | | | | |
|---|---|---|---|---|
| **Average (monthly)** | 139,3 | 6518,85 | 3518,85 | 234 |
| **Total (annual)** | 1671,5 | 78226,2 | 42226,2 | 2808 |
| **Collecting area** | **52** | **Monthly demand** | **3000** | |
| **Runoff Coefficient** | **0,9** | **Storage capacity** | **250** | |

Author: María Hock, Manuel Echeverri

- **Storage characteristics**

From the morphological paths two possible tanks could be used: flexible or rigid. The possibilities were evaluated according to the established requirements in the PDS. Figure 35 illustrates this analysis in order to select the most appropriate component for the system based on the user's needs and the environment.

Figure 34. Storage system evaluation chart




Author: Maria Hock, Manuel Echeverri

After analyzing the possible storage systems a rigid tank was selected. The main reasons were its wear resistance and the existence of a local provider with a standard production technique. This means that the tanks can be mass produced which represents economy when a certain number of units is bought. Therefore, is a good opportunity to decrease costs when it comes to implementing several systems in one neighborhood that will be improved by the administration or an NGO. In addition, a support for the tank doesn't need to be designed and built which means fewer components are added to the system; this is reflected on lower production costs, and production time.

The selected tank (Figure 36) with a 250 storage capacity is made of polypropylene by roto-molding and provided by *Rotoplast*. The tank itself comes with an excess water disposal system included. The manufacturing company suggests emptying and cleaning it every 6 months. Since water coming from the roof enters the tank through gravity, once installed, it cannot be placed on the roof because it would require to up the water thorough out the whole treatment system and then into the tank which does not seems as a practical and reliable solution; the tank has to be places somewhere between roof and ground level; therefore, the house floors represents a suitable surface to locate it because it can support 250 kg (equivalent to 250L of stored water) without requiring a structure. In addition, house floor is more Table than roof infrastructure in these houses, since they are built by the inhabitants themselves.

Figure 35. Selected rigid tank.

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## 5.4 DISPENSE

Once the water is stored, it shall be taken from the tank to its final destination where the domiciliary activity will be performed. Three functions were stated on the functions tree: propel, transport and regulate.

- **Propel**

In order to get the water from the tank and take it to the places where it would be used, the propel function was included within the whole analysis and two options were considered to fulfill this requirement: gravity and pumping.

Taking in account the design process developed so far, the gravity does not seem as the best option to solve the dispense challenges because of tank location according to the roof and floor level. However, if the tank is located on the ground and assuming that the tap is located at the bottom of it in order to let get out stored water, it represents ergonomic considerations because the user would have to crouch to get water being exposed to back injuries; in addition, when water level is low, the resource will not come out of the tank by itself. Consequently, a pump appears as a suitable, versatile solution whose complete analysis, from the basic principle to the design, is presented below.

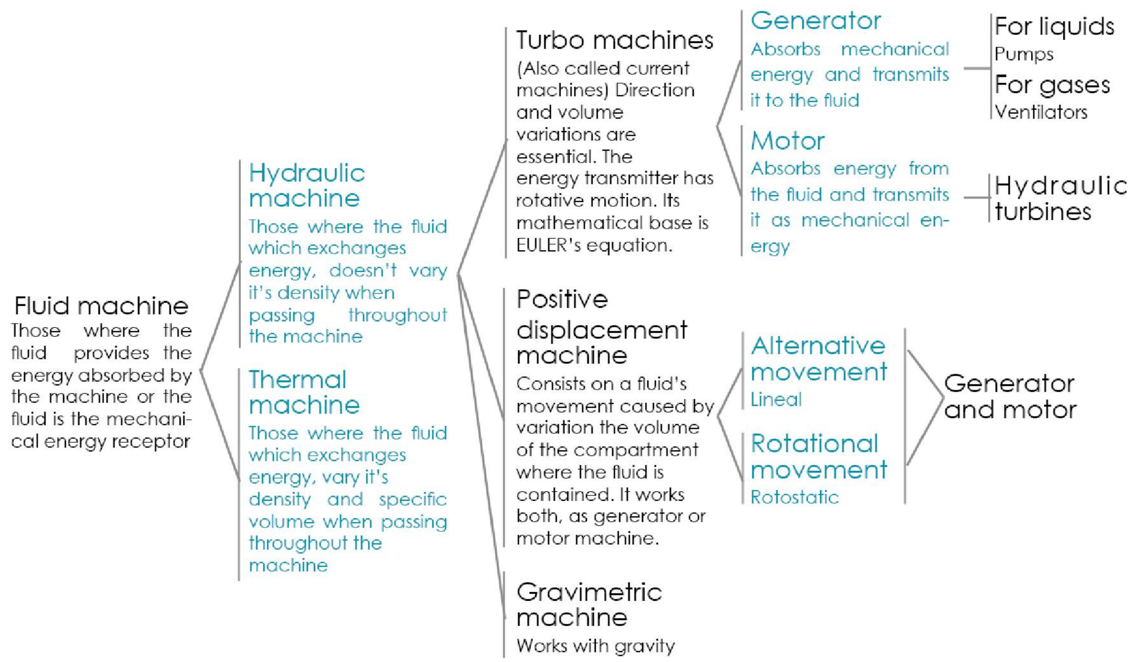
- Pumping principle

In order to select the proper pump; it was necessary to classify pump`s types and understand the way they work; the physical principle was studied analyzing basic principles such as what constitutes a pump and which variables define their function and are used to select the proper type according to the situation it will be used on. Figure 37 illustrates the basic principle for fluid machines and their classification.

Starting with the basics, fluid machines are those where the used fluid provides energy to the machine or the other way around (Mataix, 1982). These machines can be classified in Thermal or hydraulic depending on the fluid's density variation. Because we need water to maintain its density, thermal machines are ruled out of the analysis and selection. Hydraulic machines can be divided in three large groups: turbo-machines, positive displacement machines and gravimetric machines. This last group (gravimetric machines) is also ruled out because they require water to fall thanks to gravity and their performance is based on the high of the fall.

On the other hand, based on Mataix study, turbo-machines are complex machines which require a detail design based on Euler's equation. In addition, their function principle is based on rotation movement, requiring high RPM and consequently they cannot be human powered. The need of an extra energy source and the detailed perfection when designing the machine are the main reasons to rule out turbo-machines because it means they are not suitable for the context which lacks of other energy resources due to low income (such as electrical energy) and they cannot be homemade.

Figure 36. Fluid machines generalities and fluid machine selection.

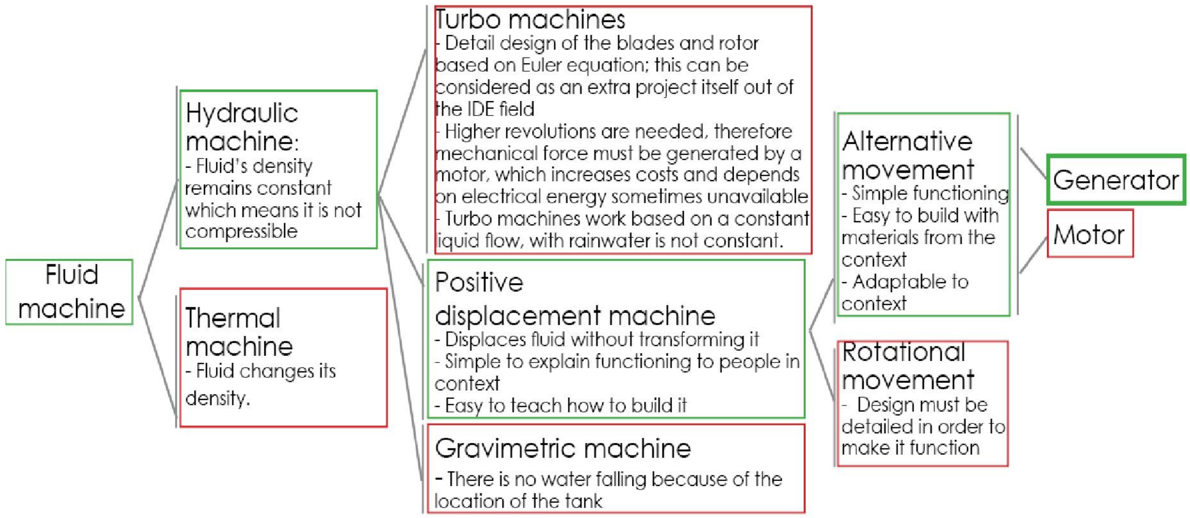



Autor: Manuel Echeverri – María Hock; based on (Mataix, 1982)

Positive displacement machines consist on the variation of the cavity's volume where the fluid is contained; this means, it is a simpler mechanism which doesn't transform the fluid's density. They can be classified according to their basic movement as alternative (lineal) or rotational; as said with the turbo-machines, rotational movement machines required more detailed and complex design which decreases the possibility to be built by the user itself. In addition, it requires extra energy source to produce the rotations. Alternative movement machines can be motor or generator according to the energy receiver and transmitter. Because the component is to transmit the energy to the fluid and not the other way around, a generator machine is selected.

In conclusion, the fluid machine to be used is a positive displacement machine with lineal movement and classified as a generator (positive displacement pump). Figure 38 shows this analysis where the selection was made. The green squares illustrate the selected machines.

Figure 37. Fluid machine selection.

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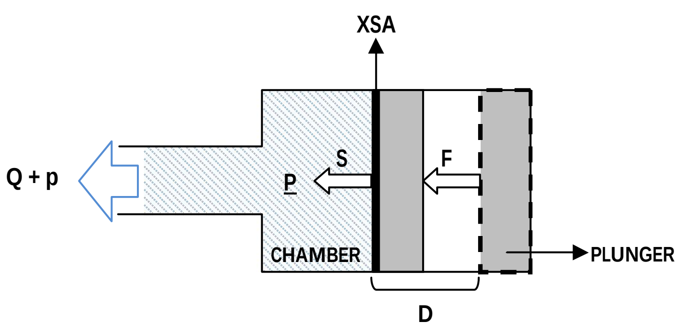
As said before, a positive displacement machine with linear movement consists of a simple physical principle; force is applied to a piston (plunger with rod) in order to displace the fluid contained in a cavity. This principle is shown on Figure 39 where its basic functioning and components are described.

Figure 38. Positive displacement machine functioning.




| | |
|---|---|
| Q | Caudal |
| p | Pressure |
| S | Speed |
| F | Force |
| D | Displacement |
| P | Power transmitted to the flow |
| XSA | Cross-section area |

Author: Manuel Echeverri – María Hock

The caudal of the pump is calculated with equation 3, where "t" represents the amount of time to displace the piston.

Equation 3. Pumping caudal (Mataix, 1982).

$$Q = (XSA)x(D)/(t) = (XSA)x(S)$$

Because the pump being is manually triggered, speed and time are not constant values which can be calculated; instead, they depend on the user itself and how much force it can apply to the piston. Therefore, the pump's caudal depends on who is using it and it cannot be determined. Nevertheless, volume being pumped can be calculated (equation 4) in terms of how much fluid is displaced with a certain amount of pumping cycles.

Equation 4. Volume of water being pumped per cycle (Mataix, 1982).

$$Vd = (XSA)x(D)/(pc)$$

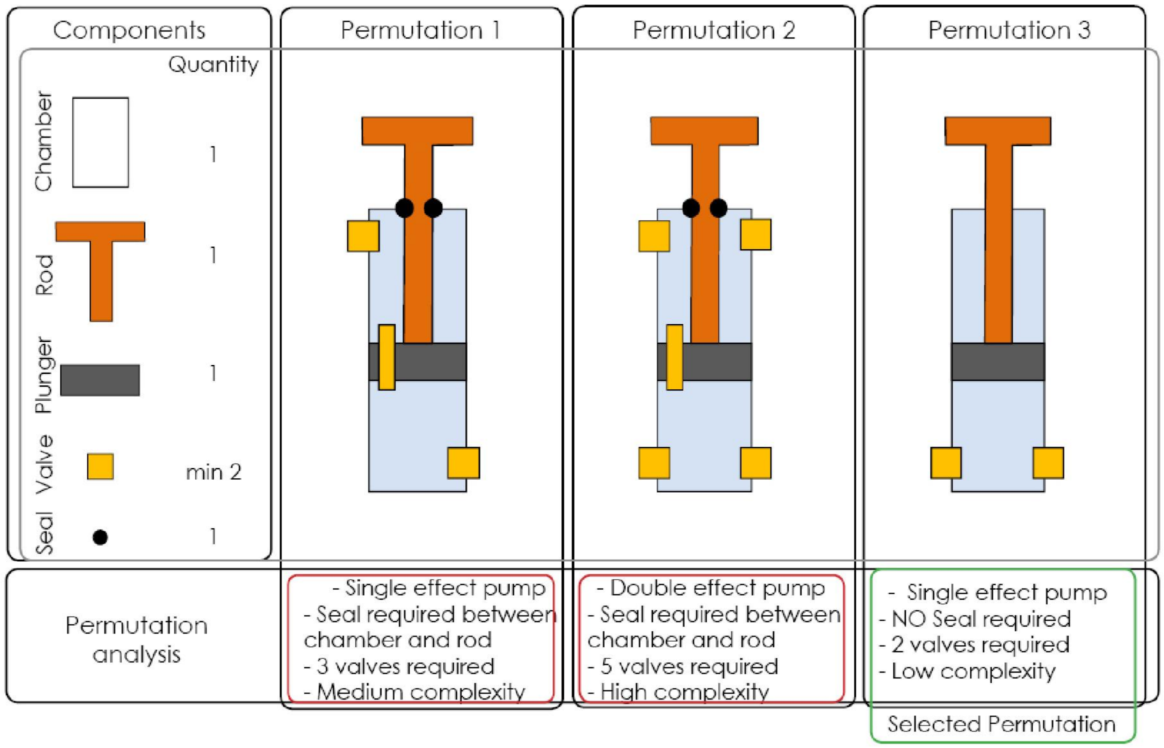
Vd = Volume being pumped
Pc = Amount of pumping cycles

- Positive displacement pump components and possible permutations

Based on Claudio Mataix studies, a positive displacement is composed of a cavity/chamber, a piston (formed by a connecting rod and a plunger) and direction flow valves (known as checks) to prevent water being dragged to the opposite direction where it is propelled to; additional sealing might be required. With these components in mind, three different permutations were proposed and studied in order to select the most proper one to be manufactured and used with the context requirements such as: costs, material availability and low complexity.

Among the permutations one of them was a double effect pump, which mean fluid is pumped with each piston's displacement from either direction. The opposite, a single effect pump, requires two triggering by the user in order to pump the amount of water contained in the chamber. This means, the piston must be displaced from its initial position to its final and back in order to pump the water contained in the cavity. Despite propelling twice the amount of water, double effect pumps require extra valves and seals which represent extra costs and manufacture complexity as well as extra sealing because water flows throughout the plunger which can result in leaking at the entrance of the rod into the cavity. Component permutation as well as the selection is illustrated in Figure 40.

Figure 39. Pump components permutation and selection.




Author: Manuel Echeverri – María Hock

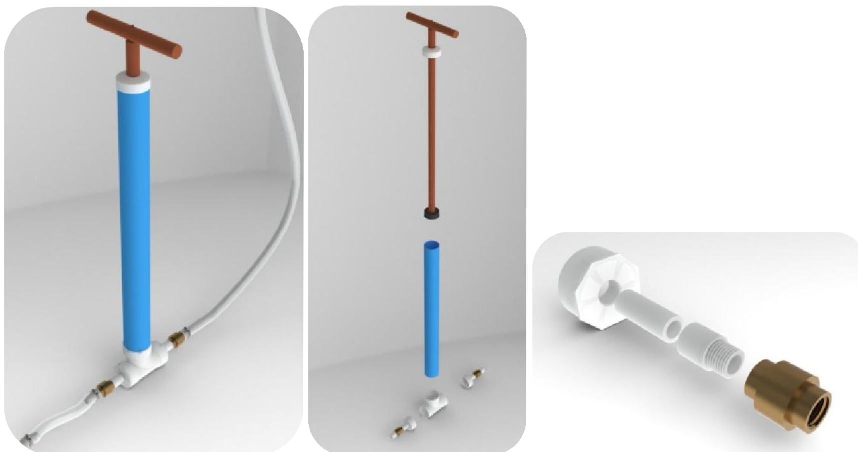
- Pump design

The main characteristic of the pump and the system itself is to be easily built by the user; therefore, available parts were selected from the local market in order to design the lineal pump. It is important to highlight that components are also determined by costs; which usually means that the fewer number of parts, the cheaper and less complex the pump.

The most crucial component is the valves. Their function is to allow water flow in only one direction. This component cannot be made, but must be bought from the local market. Because of its cost, ½ inch horizontal valves are selected since they are the cheapest ones (compared to higher diameter valves). From there, the PVC components are selected to meet this diameter; the cavity shall be reduced to this diameter. Since there is a standard PVC 2-1/2 inch reducer a two inch tube will be used for the cavity; this will give enough volume to contain a moderate amount of water, which will be translated in less action cycles (pumping action by the user) are required. In conclusion only one reducer is required to join the PVC cavity with each valve. A T shaped PVC joint is used to join each of the valves and reducers to the cavity.

The piston is composed by a plunger and a connecting rod assembled together with a screw. The plunger is designed to decrease friction by minimizing the contact area with the cavity; made of elastomeric material in order to have hermetic seal. On the other hand, the rod and grip can be made with a broomstick or ½ inch PVC pipes. Figure 41 illustrates each of the pumps components and its details are contained in the 3D model and technical drawings (see numeral 5,5).

Figure 40. Pump.



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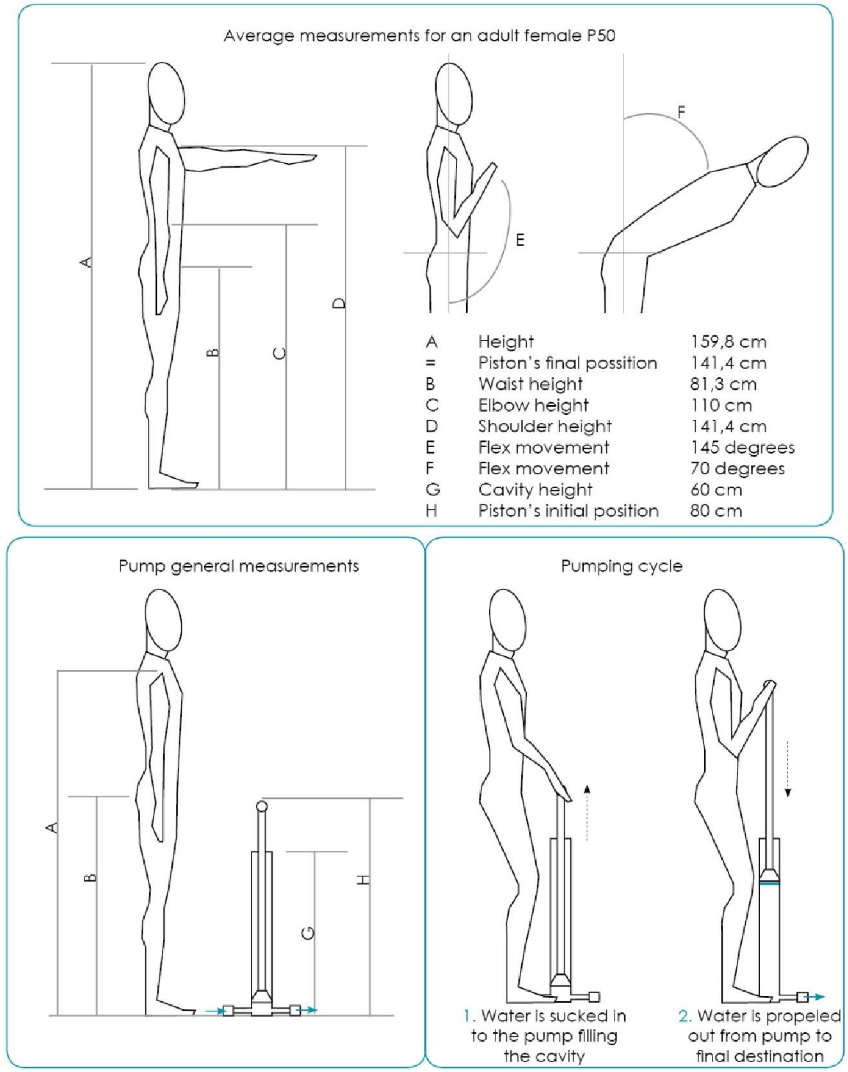
Because the pump represents the system component which interacts directly with the user, ergonomic analysis was the basis of the design. Since the diameter of the cavity is already determined by the other components, its height is determined by the user's average measurements that will be on standing position while performing the pumping action; therefore, waist height represents the initial piston grip location. In addition, the maximum flexion movement done by the forearm is 145 degrees which means shoulder height is the piston's grip final position. Hence, the total piston's displacement "D", which equals to half pumping cycle, is 60,1 cm. This gives the cavity a height of 60 cm. Figure 42 illustrates these ergonomic considerations.

Figure 41. Ergonomic considerations




Author: Manuel Echeverri – Marría Hock; based on Zelnik, 2010

With this height and the previously determined cavity diameter of 50,8 cm (two inch PVC pipe) the volume of the pump can be determined (equation 5). This means that with each cycle the pump will propel 1,2 L of water from the tank.

Equation 5. Pump's volume

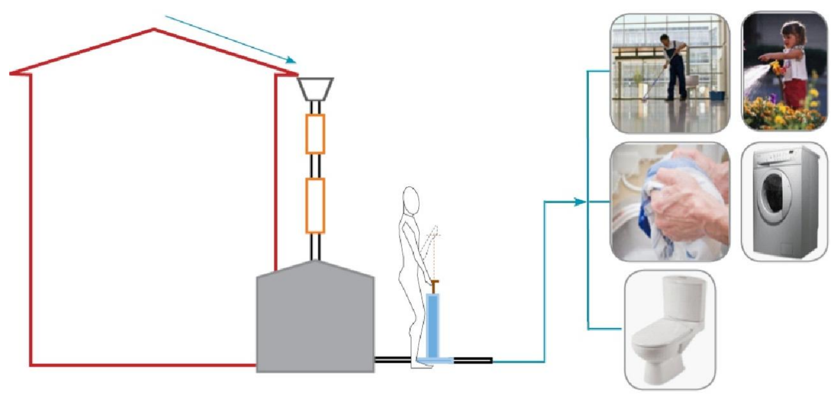
$$\text{Volume} = (XSA)x(D)$$
$$V = \pi r^2 \text{ x } h$$
$$V = \pi\ (2{,}54)^2 x60$$
$$\mathbf{V = 1216\ cm3}$$

- Pump advantages analysis

Besides being homemade, the designed pump arises as a device capable of providing water to different places and for several activities in a house such as the ones found in SDS context: outdoor and indoor cleaning, gardening and clothes washing. The pump represents a mobile, versatile and functional solution for water distribution. Figure 43 shows how the pump can be used for the different activities mentioned above.

It is important to highlight that toilet flushing had been ruled out of the activities because it required being the center of attention (pipe distribution design) and a high amount of water. Nevertheless the pump allows propelling the stored water for toilet flushing if the user desires it.

Figure 42. Pumping water to perform the selected activities.



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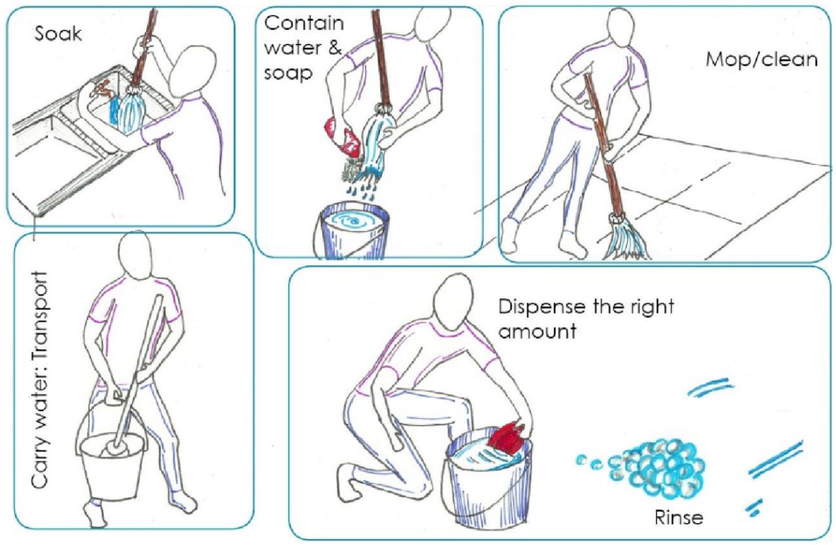
- **Transport**

Water pumped out from the tank must be transported to each of the areas in the house where it will be used. Idea generation resulted on proposing a different way of transporting water inside the house, a portable bag, different from the traditionally used “Bucket”. Because the bucket is a known, commonly used element when performing house chores, an analysis of the bucket itself versus the proposed product was done.

- Bucket analysis

In order to determine the positive and negative issues related with the use of a bucket, a close analysis to the main cleaning activity (moping) was elaborated (Appendix 17); from it, a story board was elaborated (Figure 44)

Figure 43. Story board: cleaning activities generalities




Author: Manuel Echeverri – María Hock

After analyzing the activity itself, four main functions shall be performed by any transport component in order to fully fulfill the user’s requirements: transport, contain, store and dispense; which means, taking water from one area to another inside or outside the house, contain water while performing the activity, storage smaller amounts of water, if required by the user, and dispense the amount of water needed when performing the activity. Figure 45 describes each of the functions and whether if they are needed in each of the aimed activities where the product will supply water.

According to this analysis a bucket serves to transport, contain and dispense water; in addition, if a lid is added to cover it, it can be used to store smaller amounts of water without representing a health risk due to stagnant water. This means, a bucket is useful to develop the required functions to perform the cleaning activities. In addition, the product has a low cost (average cost: 10.000 COP, Provider: ESTRA) and it can also be substituted by other plastic recipients such as paint containers, which means, is locally available and commonly used.

- Portable bag validation

Because a bucket represents a traditional and functional substitute product to be used, a validation of the portable bag was done to determine if represents added value for the user. Five inhabitants of the *Comuna 1* were interviewed about the use of the bucket versus the new element. Figure 46 shows the interview questions and Appendix 18 contains the interview's results.

Figure 44. Transport requirements: bucket analysis.

| Activity | Transport | Contain | Store | Dispense |
|---|---|---|---|---|
| Cleaning - Floor, bathroom, kitchen | ✓ | ✓ | ⊘ | ⊘ |
| Clothes washing by hand | ⊘ | ✓ | ⊘ | ⊘ |
| Outdoors: cleaning and gardening | ✓ | ✓ | ⊘ | ✓ |
| Toilet flushing (alternative use) | ⊘ | ✓ | ✓ | ✓ |
| Description | Carry water for long or short periods from the tank to the required house area | Contain water while performing the activity | Store water in smaller quantities | Supplies enough water to perform the activity |
| Common requirements | Easy to carry<br>Avoid leaks while carrying | Steady<br>Min. capacity of 8 L. | Maintain water quality<br>Hermetic | Water saving |

Author: Manuel Echeverri – María Hock

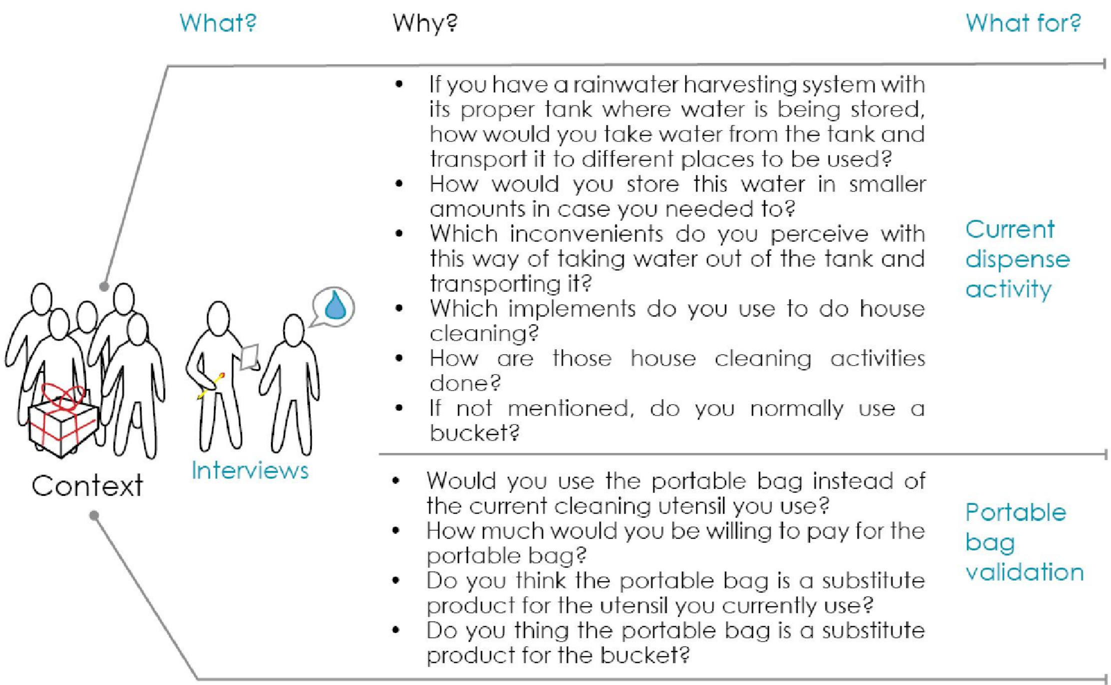
- Bucket analysis result

The user explained the importance of having a bucket when developing house activities; especially when it comes to cleaning, a bucket is always necessary because it serves to contain water when moping. In addition, buckets are cheap and easy to find in the market, other plastic recipients are also used to do so. For dispensing, throwing buckets of water to the place where the resource is needed seems to be the manner. Nevertheless, the bag came superior vs. the bucket when asking them about how to transport water because the buckets can be heavy and may break.

The bucket is at their everyday activities; therefore, it is the top of mind product when it comes to containing and transporting water for domiciliary use.

From the analysis done, the graduation team decided not to continue with the portable bag concept. Therefore, this product is open for further studies in case it can be used in a different context where it could add value to the system instead of representing extra costs.

Figure 45. Portable bag validation interviews.

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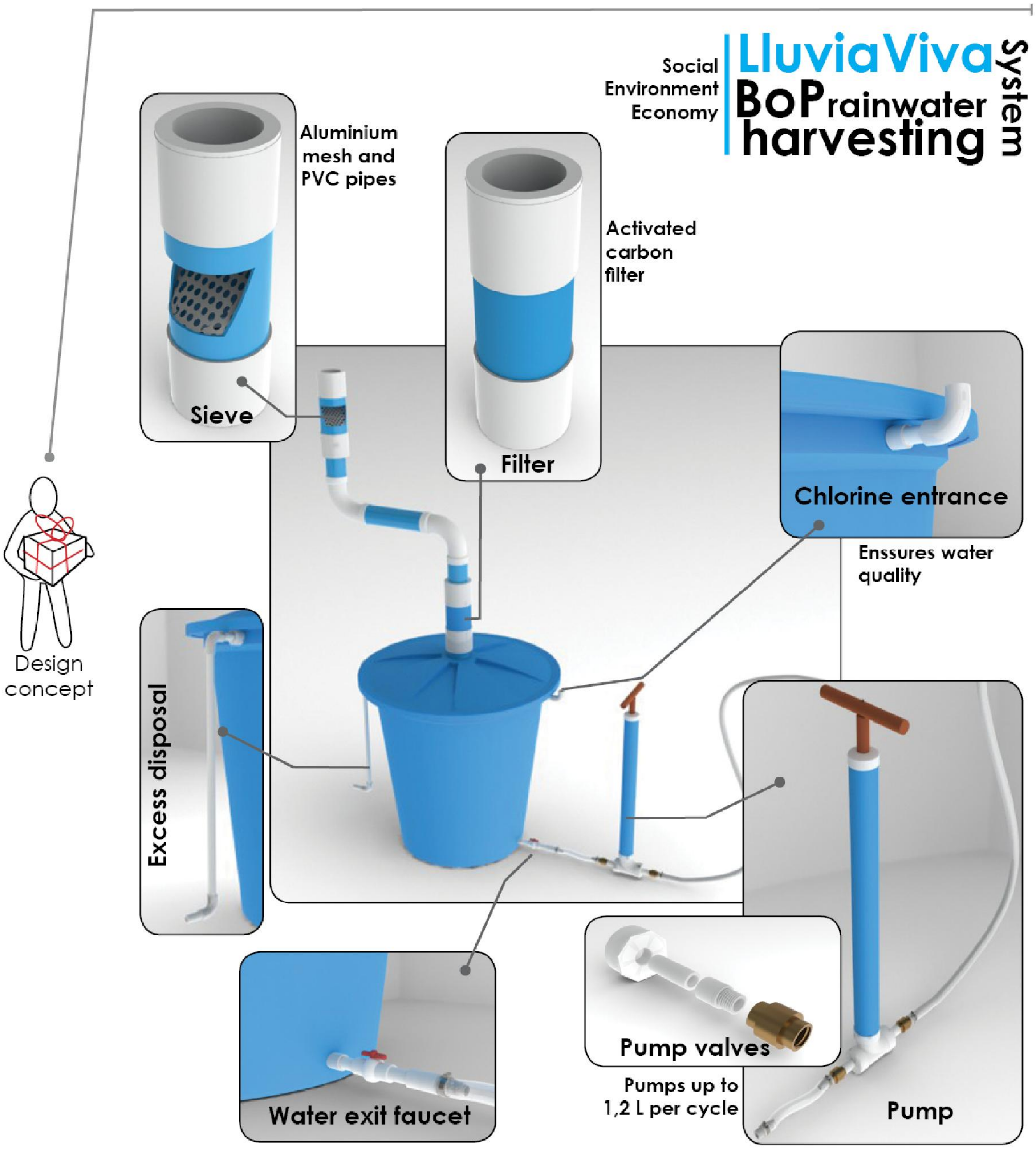
## 5.5 SYSTEM 3D MODEL

Once the components technical aspects and materials were selected; a 3D model using Solid Works[24] was elaborated in order to visualize the system with its dimensions and proportions. In addition, this model serves to develop the required blueprints for the functional model fabrication and for future implementations of the system. Figure 47 illustrates the 3D model of the system and Appendix 19 contains the required technical drawings. The model itself has a total of 51 different parts (excluding filtering materials). 56% of these pieces are standard accessories (PVC, copper, rubber seal) which do not need any production process, an extra 40% of the pieces are made from standard components (PVC pipes, PVC flexible hose, plastic mesh, among others) with simple production techniques like cut and bend; the remaining 4% have to be made manufactured (rubber plunger and aluminum mesh). In conclusion 96% of the parts are standard.

[24] Solid Works: 3D design software, www.solidworks.com

Figure 46. RWH system 3D model.

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## 5.6 MANUFACTURE AND USER MANUAL

Since the system will be delivered to the user through development plans or NGO's, a manufacturing manual was elaborated in order to explain the different pieces and steps for building and implementing the system. The manual serves to qualify these partner institutions to implement the system or give them the tools in order to prepare the community to apply it themselves. The system aims to be modular and homemade, each of the parts can be manufactured and assembled by using basic manufacturing processes such as cut and bend; in addition, the system's components are mostly based on standard pieces.

Because a proper use of the system is required to ensure water quality and the user's health a user manual was also elaborated. The manual states not only which activities can the water be used for but those instructions in order to clean the system and maintain water quality. Appendix 20 contains the user and manufacturing manual. These two manuals were written in Spanish because they are directed to local institutions and the context itself.

The design team named the system "LluviaViva" ("Alive Rainwater") a catchy name in Spanish which gives an idea of what the product is about: collecting rainwater and using it for daily activities giving it life as it goes from a sub-utilized resource to a reliable water source.

## 5.7 COSTS, MATERIALS AND POSSIBLE PROVIDERS

As said before, the RWH system will be delivered to the user by development plans taking place in the city or by NGO's and foundations, which means the user is different from the client (partners). Nevertheless costs are required in order to establish the required budget to put the plans in practice.

The costs are based on both, building one system individually or manufacturing a set of 100 units in case of implementing them on a set of houses being improved among the development plans previously mentioned. These are the two scenarios evaluated when developing the cost analysis (Appendix 21).

The cost of the system's materials per unit is 183.763 pesos (61 euro) and per 100 units is 155.990 pesos (52 euro).

As for manufacturing, 3.25 hours are needed to build the system and 52 minutes to install it by 2 people (see Chapter 6); therefore, manufacturing costs are equivalent to 16.031 pesos per worker (5,3 euro) with the minimum Colombian wage of 513.000 pesos per month (171 euro). On the other hand, if manufacturing 100 units, two employees are required (with an average wage of 513.000 plus 50% of bennefits). On this scenario 38 systems can be built per month which gives a total of 20.250 pesos per worker (6,7 euro).

In conclusion, the total cost of the system is 215.825 pesos per unit (71 euro); if implementing 100 units, the cost of the system is 196.490 pesos per unit (65 euro).

The costs per component can be seen in the Table xx below

Table 6. RWH system costs (in Colombian pesos)

| Part | Cost x1 | Cost x100 |
|---|---|---|
| **Sieve** | $ 17.735 | $ 17.466 |
| **Filter** | $ 21.715 | $ 21.299 |
| **Tank** | $ 100.000 | $ 90.000 |
| **Pump** | $ 31.860 | $ 17.694 |
| **Pipes & accesories** | $ 12.453 | $ 9.532 |
| **Manufacture** | $ 32.062 | $ 40.500 |
| **Total** | $ 215.825 | $ 196.490 |

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## 5.8 CREATE - DETAIL DESIGN - CONCLUSIONS

- With the specific collecting area and storage capacity together with Medellín's average rainfall, the system is able to provide at least $3m^3$ of water per month which represents 23% less potable water being used in domiciliary activities when the system is implemented and properly used by the community
- With a storage capacity of 250 L the system is able to provide rainwater thought the whole year, including dry seasons, to fulfill the selected domiciliary activities
- The system is flexible enough to provide water to different areas of the house; therefore, it can be adapted to the user needs. In addition, it takes in account ergonomic details in order to fit the user's anthropometry.
- Cavity volume is able to store 1,2L of water to be propelled with each cycle. Therefore, it will only take 6 cycles in order to fill a bucket, which is the utensil generally used to fulfill the domiciliary activities.
- A bucket is a complement product for the system itself. The use of a portable bag was considered aiming to improve those functions fulfilled by the bucket. Nevertheless the user seemed habituated to the use of the plastic recipient; therefore, the portable bag was ruled out because it represented an extra component which increased costs making it not feasible for the target context.
- Although a portable bag was ruled out by the user when validating it, thanks to the pump design the system continues being versatile and able to provide water to the selected activities by using a bucket to transport and contain water.
- The system is built by putting together parts which can be found in the local market. It is 96% made of standard components which makes it economic.
- Manufacturing process consists on cutting PVC tubes and assembling them together; in addition other basic processes such as bending and screwing have to be used. This makes the system able to be built at home and with basic training.
- Because simplicity was kept in mind when designing, institutions can train the users into building the system themselves by following the manufacture manual. This shall be accompanied by educational programs which encourages and teaches them to use the system properly.
- The total cost of the system is 215.825 pesos per unit (71 euro); if implementing 100 units, the cost of the system is 196.490 pesos per unit (65 euro)

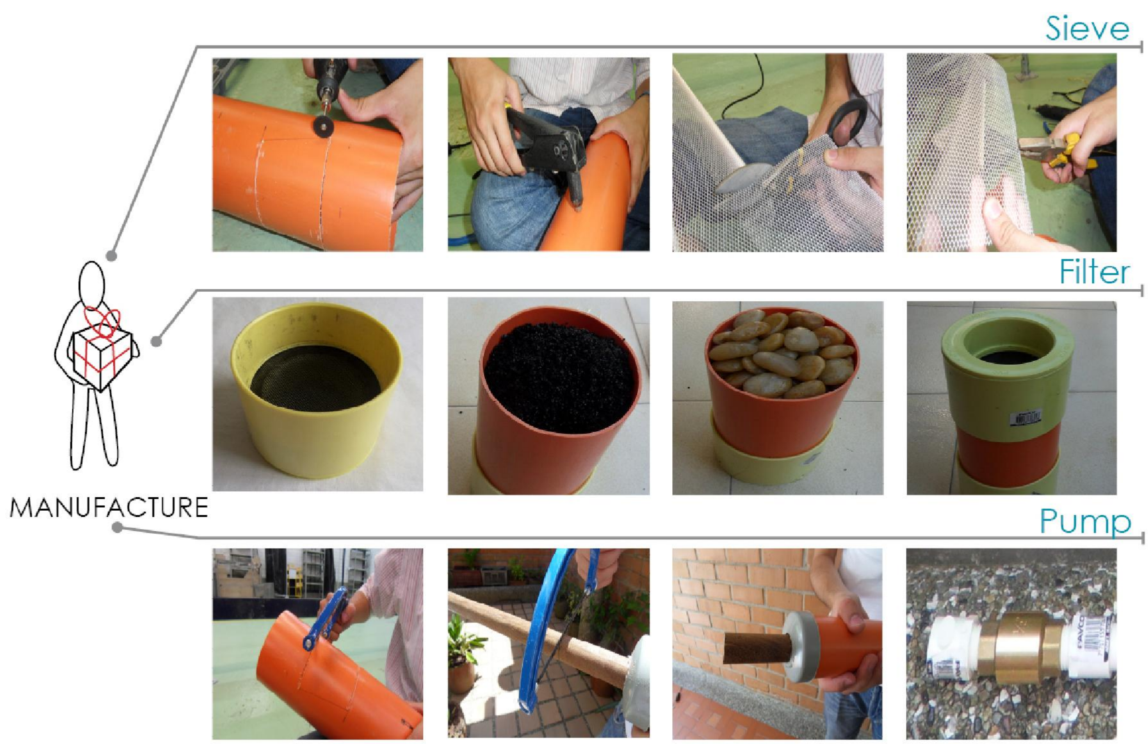
## 6. "CREATE": IMPLEMENTING THE SYSTEM – FUNCTIONAL MODEL MANUFACTURE AND TESTING –

During this step of the project a functional model was elaborated; it allowed to visualize on a real scale the designed product. Moreover, it served to analyze its usability; this means whether the technical specifications determined during the detail design stage were accurate. Usability testing is based on what the system should do, how it should work and if it is doing what we want it to do (Rubin & Chisnell, 2008).

### 6.1 BUILDING THE MODEL

The model was built based on the technical drawings (numeral 5,5) and manufacture steps stated on the manufacture manual (numeral 5,6). Figure 48 gathers images of how the sieve, filter and pump were built. The tank is not considered as a component to be manufactured whereas harvesting is done by using the roof. The manufacturing of the components took 3:25 hours.

Figure 47. Functional model building.

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## 6.2 ASSEMBLING THE MODEL

With the components built, the whole system was put together. Because the system needed to be monitored, for this first test, the model was assembled at one of the team member house; it took the team (2 people) 52 minutes to put the system in place. The main idea of this initial testing was to evaluate water collecting ability as well as the proper functioning of the filter when subject to constant rainfall. Figure 49 illustrates how the system components were assembled and Figure 50 shows the system put together.

Figure 48. System's assembly.


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Figure 49. RWH System.


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## 6.3 VALIDATION TESTING

Validation testing is usually conducted late in the development cycle and it is intended to measures usability of a product against established standards which were originated from previous objectives and stages of the project (Rubin & Chisnell, 2008); in this case, PDS are used as standards and the main objective is to evaluate how all the components of the system work together. In addition, the interaction between the user and the system was also analyzed. Based on Rubin and Chisnell's usability handbook three main stages are to be done when conducting a validation test: standards identification, testing and data collection and analysis.

For the RWHS two validation tests took place; the first one aimed to test the system according to its technical specifications whereas the other intended to involve the user and partners in order to analyze the system's performance in the selected environment/context.

### 6.3.1 Technical testing

With the system assembled in a familiar location where it could be monitored the initial test began. The model was built and assembled September 17th 2010 and was observed until October 8th (three weeks). The average rainfall for Medellín during this period was 3mm/day (IDEAM, 2010). The selected house roof area was 70 $m^2$. Therefore, according to equation 2, the daily rainwater collection for the tested period was 189 L/day. It is important to highlight that September is a rainy month in Colombia (see Appendix 9).

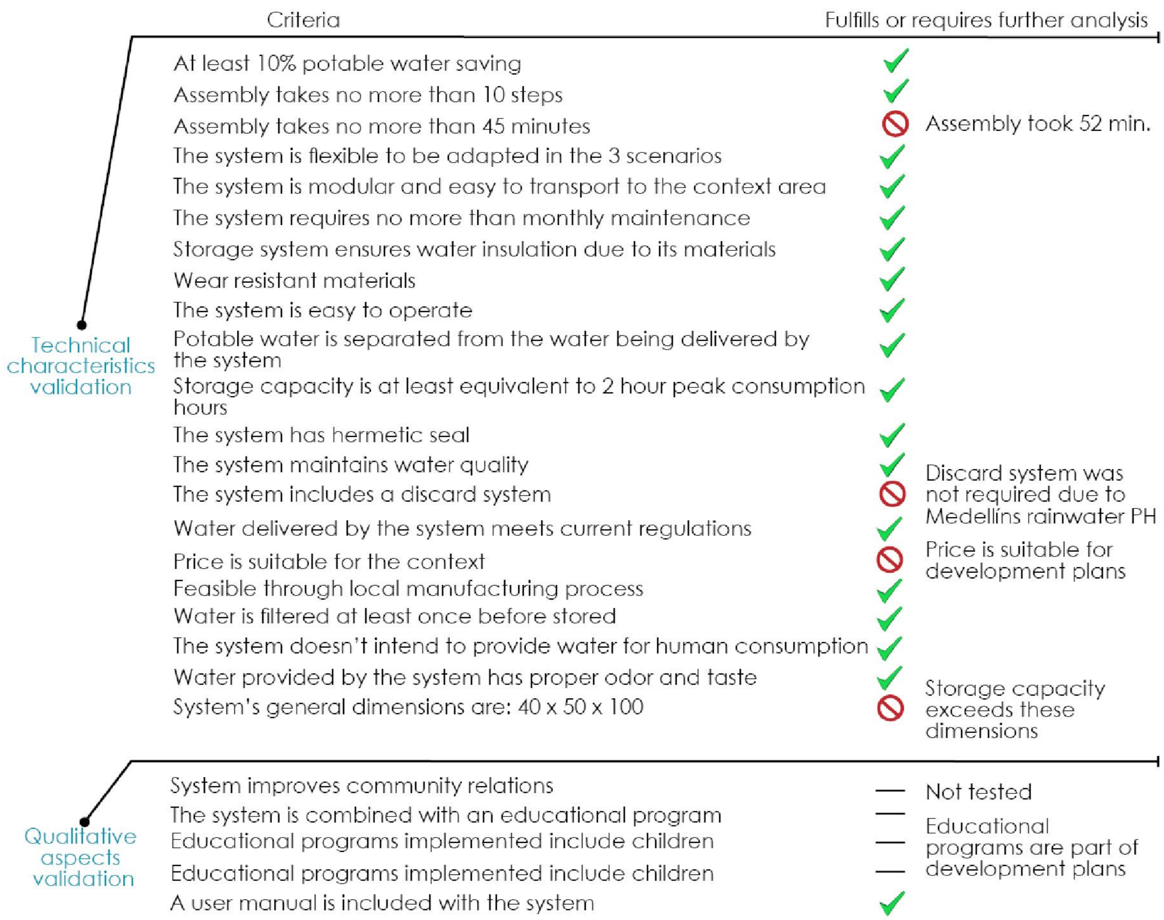
It took the storage system 2 days to get full; from the 19th of September excess water was being disposed directly to the sewer system. This means that with this rainfall the system would be filled in the same amount of days at the *Comuna 1* with 52$m^2$ as the area for the calculation. Filtering speed was ideal since it flowed continually without clogging. The filter was unassembled in order to check its performance. Some solid waste, mainly sand, was found on the stone layer; these were washed with water. Therefore, it is suggested that the filter is unassembled and the stones are washed once per month.

Water was used on September 25th for domiciliary activities such as cleaning and manual clothes washing. Color and taste were optimum.

For this validation test PDS criteria was used as standards to measure. It was found that during this initial testing, qualitative aspects were hard to measure because neither the user nor possible partners were involved. Figure 51 shows the criteria and the results found while the technical validation test.

The system has a positive evaluation based on technical facts which respond to the PDS criteria. Assembly took more than expected and storage system exceeds the dimensions planned when the requirements were determined. In addition, there is no discard system implemented because Medellín's rainwater is not considered as acid. Manufacturing costs are suitable for the product to be implemented among development plans, but it could be considered as not suitable for the user itself to acquire the system.

Figure 50. Validation testing for technical aspects

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### 6.3.2 Water quality testing

Because water quality is a key aspect for the project, it is important to develop a physicochemical water analysis[25] in order to determine the initial quality which will enter the system as well quality for the resource after filtered.

Since the resource will not be used for human consumption, not all the physicochemical analysis tests are required. The specific tests selection was suggested by Luis Eduardo Forero, environmental engineer (see the interview in the Appendix 22) and validated by Professor Dario de Jesús Suarez, MS Environmental engineering. From these two sources at least 8 water analyses were advised to develop (Figure 51).

Figure 51. Rainwater analysis.

Water quality analysis

| What? | What for? | Why? |
|---|---|---|
| PH | Determines rainwater acidity | If Medellín's rainwater has a certain PH value which represents high acidity, a discard system must be implemented |
| Conductivity | Determines the metals carried on rainwater | If Medellín's rainwater has a conductivity value exceeding regulations, water can not be used for clothes washing because it will damage the fabrics |
| Hardness | Determines the metals carried on rainwater ($CaCo_3$) | If Medellín's rainwater has a certain hardness value exceeding regulations, water can not be used for clothes washing because it will damage the fibers |
| Turbidity | Determines water clarity it indicates solids on the water | Water should not contain solids nor particles in order to be accepted by the user and to ensure its cleaning properties |
| Total solids | Indicates solid waste on the water | Water should not contain solids nor particles in order to be accepted by the user and to ensure its cleaning properties |
| Total volatile dissolved solids | Indicates solid particles (minerals, dust, pollen, organic waste) on the water | Water should not contain solids nor particles in order to be accepted by the user and to ensure its cleaning properties |
| Color | Indicates water color | Color, taste and odor are considered important aesthetic characteristics when it comes to water |
| Iron | To determine iron presence on water | If Medellín's rainwater contains big amounts of iron, water can not be used for clothes washing because it will stain the fabrics |

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- **Rainwater quality analysis**

As said, at least two analyses had to be done; the first one was done to Medellín's rainwater collected from a gutter in SDS (Sample 1). The other one was done to water coming out from the system after filtrated and stored (Sample 2).

[25] Physicochemical water analysis: defined by the Colombian resolution 2115 from 2007 as those laboratory procedures carried out to a water sample to evaluate its chemical or physical characteristics or both.

The result of the analysis is to be compared with the Colombian resolution 2115 of 2007, which stipulates the permitted physicochemical water characteristics for human consumption (potable water). It is important to highlight that there is not available Colombian regulations for clothes washing or domestic cleaning; therefore acceptable values for the analysis are also established based on Brazilian regulations (see Appendix 6) and the mentioned resolution. Appendix 18 contains the information and procedures for the analysis.

- **Water analysis results**

Physicochemical analysis has to be done to rainwater collected from roof and from water filtered with the selected activated carbon filter. The results are expressed on Table 7 and compared with Brazilian regulation acceptable values as well as Colombian resolution acceptable values. The complete analysis can be found in Appendix 23.

Table 7. Rainwater analysis result

| Analysis | Unit | Acceptable values | | | Results | | Lab |
|---|---|---|---|---|---|---|---|
| | | NBR 13969, ABNT, 1997 | Colombian resolution 2115, 2007 | Other | Sample 1 (Medellín's rainwater) | Sample 2 (RWH system output) | |
| **PH** | PH | 6<x<9 | 6<x<9 | x>5,6 (IDEAM) | Pending | Pending | UNAL |
| **Conductivity** | microsiemens/cm | - | x<1000 | - | Pending | Pending | UNAL |
| **Turbidity** | UNT | x<5 | x<2 | - | Pending | Pending | UNAL |
| **Total solids** | mg/l | x<200 | - | - | Pending | Pending | UNAL |
| **Hardness (CaCo3)** | mg/l | - | x<300 | - | Pending | Pending | UNAL |
| **Volatile dissolved solids** | mg/l | - | - | - | Pending | Pending | UNAL |
| **Color** | UPC | - | x<15 | - | Pending | Pending | UNAL |
| **Iron** | | - | - | X<3 (Prof. Darío Suarez) | Pending | Pending | |

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Because the test results are pending, they will be analyzed when the project is presented.

### 6.3.2 User and partners testing

After fulfilling technical performance, the system could be tested by potential users as well as validated by possible partners.

- **User testing**

The main idea of user testing is a qualitative analysis of those characteristics that couldn't be studied with the previous validation of technical facts (user's opinion). As mentioned during the "Hear" stage, due to safety, social and geographical conditions, in situ testing is difficult to develop; in addition, the product has been already set up in an easier to monitor location which makes it useful for addition use testing. On the other hand once assembled the system is fixed; therefore, installing it in the context represents posterior monitoring and educational plans have to be executed, which is not included among the graduation project but expected to be implemented when development plans begin to include the system itself. For Installation testing with the user the manufacture manual was shown to the user in order to gather their impressions regarding manufacture and assembly.

The tests required a specific test plan (Rubin & Chisnell, 2008)which is included in Appendix 24. According to the planning and the testing goal six main tasks were to be evaluated:

- Manual understanding: how well the user understand s the manufacture/use manual
- Manufacture: how does the user feel about the manufacture process for the system
- Installation: how easy or difficult does the user find the system's installation based on the already built model and the manual
- Pumping: how easy is the pumping activity performed by the user, what are the impressions he/she gets while pumping, how many pumping cycles are needed to fill up a bucket (8L)
- Cleaning: how easy does the user perceive this action for the different components
- Water quality maintenance: how committed is the user on well using and maintaining the system once installed.

For the usability testing, a group of 3 target group housewives was invited to the location where the system had been installed. The idea was to reunite a group of potential users in order to observe how they would use the product and listen to their impressions and future expectations. Figure 52 gathers photographs from the user testing and Figure 53 illustrates the criteria evaluated during the session.

Figure 52. Usability testing.


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Figure 53. Usability testing criteria and evaluation.

| | Criteria | Evaluation | Observations/opinions |
|---|---|---|---|
| User 1 | Manual understanding | ✓ | Easy to understand |
| | Manufacture | ✓ | Her husband could build it for her |
| | Installation | ✓ | Simple to install. But it can not be used on two stories homes |
| | Pumping | ⊘ | It is hard to pump at the start while learning |
| | System cleaning | ✓ | Easy to wash and clean |
| | Water quality maintenance | ✓ | Simple |
| | Overall opinion | ✓ | Its a good system to implement, save money and water |
| User 2 | Manual understanding | ⊘ | It was understood, but the user felt it was complex for her to follow |
| | Manufacture | ⊘ | The user would rather be part of development plans rather than building it herself |
| | Installation | ✓ | Easy |
| | Pumping | ✓ | Easy to use, pumps enough water |
| | System cleaning | ✓ | Easy to wash and clean |
| | Water quality maintenance | ✓ | Bleach as Chlorine is a simple solution |
| | Overall opinion | ✓ | Good idea but is best if is implemented by an institution |
| User 3 | Manual understanding | ✓ | Appealing |
| | Manufacture | ✓ | Simple |
| | Installation | ✓ | Simple |
| | Pumping | ⊘ | Cavity was too high for her |
| | System cleaning | ⊘ | Is required but it can be complex because it requires disassembly |
| | Water quality maintenance | ✓ | Flexible and unstable |
| | Overall opinion | ✓ | She seemed eager to implemented despite having some issues with some components such as the pump and filter. |

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As it was said before, this testing served to study the user-product interaction. Overall, the test was a positive experience for the users. More important, they seemed eager to implement it at their houses; product acceptance can be inferred from this testing.

In general, the manual was understood by them, as well as the manufacture and installation processes.

The most critical point was the pump. Its measurements were uncomfortable for one of the users. Despite the use manual, for the users pumping was catalogued as a complex task to perform because they felt it was hard at the beginning while getting a rhythm. After pumping a couple of times, the activity became easier to perform increasing its acceptance.

Overall maintenance of the system seemed as a simple process to be performed periodically. When talking about quality, the filter caused the most curiosity among the users. For User 2, this component convinces her to utilize water for clothes washing. On the other hand, User 3 found the filter complex to clean because it involves disassembling part of the system. In addition, using bleach as chlorine to ensure water quality is an accepted solution for the user.

With this testing several suggestions can be made for further developing of the product before its implementation:

- Pump design has to be studied further. It represents a key factor and a user-product relationship builder. Therefore, its design shall not be uncomfortable for the user. More instructions on pumping have to be included on the user manual; pumping speed and piston displacement distance (which depends on the user's height) are important aspects to illustrate on the use manual.
- The user understood the uses of the system and which activities water could be used
- A re-design of the filter can also be studied and implemented in order to eliminate the activity of disassembling it for cleaning.

  - **Partners validation**

Because the system intends to be delivered to the user by possible partners which are involved in development plans; the idea and final system's 3D model and functional model testing was presented to Xiomara Urrea, ISVIMED's technical director, in order to know her opinion about implementing the system in neighborhoods like SDS1.

Two main issues were discussed at a meeting done on October 6, 2010 at the ISVIMED installations in Medellín:

1. Possibility of developing educational plans with the administration through institutions such as the ISVIMED
2. How feasible it is to implement the system to current development plans taking place in the city

According to Urrea, this type of projects hasn't been implemented in the city before; there are current plans of improving housing while using sustainable products which will not only increase life quality but decrease environmental impact. For her, the system benefits the user in three ways: environmental (proper use of the resource), economic (reduces potable water consumption), risk reduction (decreases earth slides).

The best way to implement the system is through those organizations working with the ISVIMED related to MIB plans. These plans embrace basic public services as one of the main issues to attack when improving BoP neighborhoods. On this area, the system could be included.

# 7. PROJECT CONCLUSIONS

## 7.1 ABOUT THE OBJECTIVES

- LluviaViva, provides up to 100 liters of rainwater per day to the context's inhabitants (SDS1 and BoP communities in general); this amount of water is ensured thanks to Medellín's annual rainfall of over 1650mm and a harvesting area of at least $52m^2$. The resource is to be used on domiciliary activities such as clothes washing, indoor/outdoor cleaning, gardening and toilet flushing.
- LluviaViva is designed to be built using common construction materials available in context such as PVC pipes and PVC accessories. In addition, it is manufactured by simple production techniques like cutting with a handsaw, riveted joints and PVC glue mates. The system comes with a manufacture/user manual which allows community member or organizations to implement it among development and educational plans. Hence, LluviaViva provides an extra water source getting the best of the surroundings (materials, production techniques, work force and developing plans) promoting the community to get involved.
- The system responds to the community's needs and expectations which were stated during the "Hear" phase of the project thanks to observation and interaction visits, deep in-context research and user's environment exploration. LluviaViva saves BoP communities up to 23% water consumption per month which is reflected on lower bills. The system was designed based on their consumption habits established during the "Reflect" phase; it includes current houses infrastructure by avoiding dwell's remodeling and considers social structure by analyzing development plans like *Presupuesto participativo (PP), Mejoramiento integral de barrios (MIB)*, among others to be used as mean of implementation.
- LluviaViva stands out as a RWH system with worldwide required characteristics adapted to this specific case (Medellín's BoP communities mainly focused on the *Comuna 1*). This is the result of a developed State-of-the-art which includes similar context cases in countries such as Brazil, its applications and water use systems and technologies used around the world. Together with local rainwater availability in terms of annual average rainfall, it could be concluded that RWH systems are appropriate to implement in Medellín's BoP communities if being adapted to their consumption habits and purchasing power.
- LluviaViva was designed in detail by using 3D modeling with SolidWorks and developing technical drawings documents (Appendix 21). In conclusion, these techniques allowed the authors to visualize each individual part as well as the

design as a whole. On the other hand, these documents were the base for functional model manufacturing and they will be the starting point for further testing and future implementations.

- A functional model was elaborated based on the technical drawings and the 3D model; it was used for technical validation where the model's performance met the expectations established on the PDS and the "Create" phase. In addition, it served to verify user's interaction and acceptance through user testing. LluviaViva fulfilled their expectations with positive feedback; at the same time, remarks to the product were done in order to improve its performance from the community's point of view for further development.
- It is possible to implement the system through development and education plans taking place in the city, as was proposed by the authors; the ISVIMED showed interest on the project and claimed to be taking in account this type of projects (based on sustainability) among their housing programs. This could be concluded after validation interview with ISVIMED's technical director Xiomara Urrea.

## 7.2 ABOUT THE METHODOLOGY

- Using the HCD-IDEO methodology as project's methodology enabled to fulfill every project's objective; nevertheless it was also a good choice to add extra steps, contained during the "Reflect" phase, it in order to state project's key points. The methodology helped to get a proper approach to the community and create a suitable solution for them.

### 7.2.1 Project's methodology

- Great community involving was achieved thanks to the HCD-IDEO methodology which enabled the authors to understand the user form different perspectives. The method it supplies the tools to develop a user-designer empathy which leads to solutions made to meet user's needs.
- From the team's perspective, the IDEO methodology is focused on rural or remote environments; it lacks urban perspective where development plans and institutions such as MIB, Viviendas con corazón, NGO's aids, administration goals, ISVIMED and EDU rolls should be considered since they are directly involved with the communities. Although the methodology suggests expert's interviews where these institutions could be included, for the authors, special attention was paid to partners because they represent a way of getting to the community and a mean to implement the solutions.

- From authors' experience, it can be said that HCD-IDEO methodology is designed to be implemented in short term projects while aiming to build a close user-designer relationship. These characteristics appeared as contradictory; when working with the Comuna 1 since social, political and security aspects demanded to spend time and effort in order to create empathy with the community. Several visits to the context, as well as interaction with community leaders and institutions were necessary in order to establish this close user-designer relationship.

### 7.2.3 Product design methodology

- A step by step design process took place achieving a feasible solution thanks to following Pahl & Beitz methodology which gives a systematic approach going from broad understanding and analysis, into one concrete solution. Nevertheless, it was necessary to look into some design tools in detail by referring to different authors which dig deeper into each of them.
- During the project, the use of Pahl & Beitz methodology seemed inherent for the authors; this is a consequence of the education received to become Product Design Engineers (PDE) since the method has been inculcated throughout the bachelor degree. Therefore, is a method well known by the authors and their colleagues and it is easy to get advice from faculty's professors.
- The selection of Phal & Beitz methodology for the design process was appropriated because it focuses on technical aspects which were a key factor when developing LluviaViva.
- The use of Pahl & Beitz methodology is recommended by the authors for other Product Design Engineers when considering undertaking similar projects. The methodology was simple to understand and follow because it gives the tools to follow a step by step design process.

## 7.3 ABOUT THE PRODUCT

- LluviaViva is a RWH system consisting on four main parts: on roof collecting, sieve, activated carbon filter, storage tank and manual water pump. With these components, LluviaViva supplies up to 100 liters of water per day which saves up to 23% (3m$^3$) potable water consumption per month while ensuring the resource availability and quality to perform clothes washing, indoor/outdoor cleaning, gardening and toilet flushing on Medellín's BoP houses.

- LluviaViva is designed to be attached to the house roof in order to collect and obtain rainwater. With a minimum collecting roof area of $52m^2$, the system is able to provide enough water through the year.
- The sieve has been designed to retain big size solid waste in order to ensure water quality for the selected activities. It is built with a PVC pipe and an aluminum mesh which makes it simple to manufacture and implement in-context.
- An activated carbon filter retains small pollutants (pollen, metal particles, sand, and mud, among others). Required water quality according to regulation standards is achieved. In addition, the filter can be dissembled for its cleaning and maintenance with no need of tools.
- A 250 liter tank is used to store water in order to ensure the resource availability through dry seasons. The capacity is the result of calculations based on Medellín's average rainfall and the user's consumption habits.
- A manual water pump which propels up to 1,2 litters per cycle, has been designed based on physical principles research, translated and adapted to the context. The pump is manufactured with standard components found on the local market (PVC accessories) and simple production techniques (cut, bend, screw, etc).
- A user and manufacture manual were developed because LluviaViva is to be implemented through institutions, development and educational plans. Therefore, the manual represents the mean to instruct involved institutions to develop the system or teach the community to build it themselves.
- The model itself has a total of 51 different parts (excluding filtering materials). 56% of these pieces are standard accessories (PVC, copper, rubber seal) which do not need any production process, an extra 40% of the pieces are made from standard components (PVC pipes, PVC flexible hose, plastic mesh, among others) with simple production techniques like cut and bend; the remaining 4% have to be made manufactured (rubber plunger and aluminum mesh). In conclusion 96% of the parts are standard.
- The total production cost of the product is 215.825 pesos (71 euro). Nevertheless if implementing 100 units the costs of each system is 196.490 pesos (65 euro). This means 26% can be saved if the system is included on developing plans taking place in the city.
- LluviaViva counts with a modular design, flexible enough to be used in different environments with slight changes to its components. Therefore, with further studies, it can also be implemented on other scenarios found in Medellín's BoP

communities: those houses with no public services connection and social housing complexes.

- From an environmental perspective RWH systems implemented in other context such as industrial and commercial would significantly reduce human impact on water sources. Although the system was designed for domiciliary purposes, the achieved the design is flexible for other uses.

## SUGGESTIONS FOR FURTHER GRADUATION PROJECTS

- Designing for BoP projects is a rewarding situation for the designers. Great potential and several design opportunities can be found in those scenarios where the community makes the best of the little they posses. The authors suggest this type of design projects to be highly encouraged among the academic projects taking place in EAFIT University PDE bachelor since they represent social involving, possible applicability with administration accompaniment, entrepreneurships opportunities, low costs for the students while developing the project and for the outcome product and because of the opportunity of making a difference throughout a product.
- It is important to comprehend the difference between the project and the design methodology. The first one allows visualizing the problem as a whole, from different perspectives (social, political, environmental) and the design methodology seeks to develop a solution for the problem itself by following certain steps. This is to say that design methodology is fed by those issues analyzed during the project's development which are contemplated among the project's methodology. For instance, when carrying out LluviaViva project, the limits and differences between project and design methodology were not clarified from the beginning and confusion took place. This situation could only be solved when a clear distinction was done and a specific methodology was established for the design process.
- International advisory represents a good experience for the authors, especially because it brings a different perspective to the project. However, this situation may bring issues such as communication difficulties due to time difference, lack of meeting opportunities to discuss specific situations and planning delay due to slower response time from both parts. A local, committed co-advisor is recommended by the authors.

- It is recommended to select an academic advisor for graduation projects because no matter what the design topic is, it is still an academic project; if specific knowledge from a certain topic is required, a co-advisor, expert on the theme, is the most appropriate solution. In addition, through the whole development of the graduation project experts will always be consulted.

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