RAINWATER HARVESTING

IN ARCHITECTURAL PRACTICES

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN ARCHITECTURE

BY

NAZLI SÖZER

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İZMİR

Approval of the Graduate School of Natural and Applied Sciences

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Architecture.

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ABSTRACT

RAINWATER HARVESTING IN ARCHITECTURAL PRACTICES

SÖZER, Nazlı

Master of Science in Architecture
Graduate School of Natural and Applied Sciences

Supervisor: Asst. Prof. Dr. Athanasios STASINOPOULOS
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This thesis investigates the application of rainwater harvesting in architecture by surveying a selection of historic and contemporary examples in building or neighborhood scale. Since Minoan times (ca. 3200–1100 BC), the method of rainwater harvesting has been applied for water supply in settlements and buildings as primary or alternative freshwater resource. It also offers a convenient solution to alleviate water demand from municipal network and to support transitional shelters, and to offer self-sufficiency to off-grid buildings.

From the large amount of water existing on the planet, only a limited portion is fresh and only a small fraction of that is easily accessible for the multiple types of water use -agricultural, industrial, domestic, etc. Considering the current water stress around the world and the strong probability of future water scarcity, rainwater harvesting - the traditional water supply method of rural, arid, semi-arid or sparsely populated areas - comes forward as an alternative solution to meet global water demand. This study surveys at first various techniques of freshwater harvesting from different sources of water - underground, surface, and atmosphere. As one of such techniques, rainwater harvesting is studied further, focusing on the reasons that make it important as a water supply, its place in the world today and in the past, its practical phases, and its implementation in architectural applications, in order to comprehend the various aspects of the subject.

The study continues on the relation between rainwater harvesting and architectural form as the main concern of this thesis, surveying various design possibilities on ways to emphasize rainwater harvesting through the architectural form. The work sets three objectives in relation to rainwater harvesting:

- to *"combine modern water systems and old rainwater harvesting methods or to modernize the existing rainwater knowledge to benefit human settlements facing water scarcity"* (Akpınar Ferrand and Cecunjanin, 2014),
- to emphasize its prominence among the architectural attributes, and
- to increase the water-awareness through built environment.

For that purpose, a number of possible changes in the visibility of rainwater harvesting, and also how it can become a form-determining factor for architecture were discussed. The main phases of the system (collection, conveyance, storage, treatment and distribution) have been reviewed, and suggestions regarding how the components of these phases can become architectural elements have been developed.

Keywords: rainwater harvesting, rainwater usage, environmental architecture, green design

ÖZET

MİMARİ UYGULAMALARDA YAĞMUR SUYU HASADI

SÖZER, Nazlı

Mimarlık Yüksek Lisans Programı
Fen Bilimleri Enstitüsü

Tez Yürütücüsü: Yrd. Doç. Dr. Athanasios STASINOPOULOS
Temmuz 2018, 80 sayfa

Bu tez yağmur suyu hasadının mimarlıktaki uygulamalarını bina ya da mahalle ölçeğindeki bir tarihi ve güncel örnekler seçkisi üzerinden incelemektedir. Yağmur suyu hasadı yöntemi, Girit Uygarlığı döneminden beri (MÖ 3200-1100) temel ya da alternatif bir temiz su kaynağı olarak yerleşkelere ve yapılara su tedarik etmek için kullanılmıştır. Ayrıca bu yöntem merkezi su şebelekelerindeki su talebini azaltmaya ve geçici barınakları desteklemeye elverişli çözümler sunmakta ve şebeke dışı binalara kendi kendine yeterlilik sağlamaktadır.

Yeryüzünde büyük miktarda su bulunsa da, bunun sadece küçük bir kısmı temiz sudur ve bunun daha da küçük bir kısmı tarım, sanayi, evsel vb. su ihtiyaçları için doğrudan ulaşılabilirdir. Şu anki küresel su stresi ve yüksek olasıklıkla yaklaşan su kıtlığını göz önünde bulundurduğumuzda, yağmur suyu hasadı - kırsal, kurak, yarı-kurak ya da dağınık nüfuslu alanların geleneksel su tedarik yöntemi- dünyanın su ihtiyacını karşılamada alternatif bir çözüm olarak öne çıkmaktadır. Bu çalışma ise öncelikle farklı su kaynaklarından -yeraltı, yer ve atmosfer- çeşitli su hasadı yöntemlerini araştırmıştır. Bu yöntemlerden biri olarak yağmur suyu hasadı ise daha ayrıntılı incelenmiş; konunun çeşitli yönlerini kavrayabilmek için bunun su tedariği için önemine, tarihteki ve günümüzdeki konumuna, aşamalarına, ve mimari uygulamalardaki tatbikine odaklanılmıştır.

Çalışma, odak noktası olan yağmur suyu hasadı ve mimari for arasındaki ilişkiyle devam etmiş ve yağmur suyu hasadını mimari form ile vurgulamak için çeşitli tasarım olasılıkları araştırılmıştır. Çalışma, yağmur suyu hasadı ile ilgili olarak üç hedef ortaya koymuştur:

- *"su kıtlığı çeken yerleşimlerin faydalanması için varolan yağmur suyu hasadı bilgisini modernleştirmek veya modern sistemleri eski yağmur suyu hasadı metotlarıyla birleştirmek"* (Akpınar Ferrand and Cecunjanin, 2014),
- yağmur suyu hasadının görünürlüğünü mimari niteliklerle vurgulamak, ve
- yapılı çevre ile su farkındalığı yaratmak.

Bu amaçlarla, yağmur suyu hasadının görünürlüğündeki bir kaç olası değişim ve bunun nasıl mimarlık için bir şekillendirici etken olabileceği tartışılmıştır. Yöntemin ana aşamaları (toplama, iletme, depolama, temizleme ve dağıtım) yeniden gözden geçirilmiş ve bu aşamaları oluşturan parçalarının nasıl birer mimari öğe haline gelebileceğine dair öneriler geliştirilmiştir.

Anahtar Kelimeler: yağmur suyu hasadı, yağmur suyu kullanımı, ekolojik mimarlık, yeşil tasarım

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Above everything, I want to thank my mother Ayşe and father Mutlu for being best parents any child can wish. They always make me feel their limitless, unconditional love and support; put my education before everything else and gave me every opportunity to fulfill my goals.

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"What is needed for any person to be happy and delightful as they live is working not for self, but for those who will come after."

Mustafa Kemal ATATÜRK

For the noble people of the world,

who are working for a better future

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1. INTRODUCTION

1.1. Problem Statement

The availability of clean water and convenient water supply is crucial in every aspect of human life. It is used for vital necessities such as drinking, cooking, cleaning; also, in agricultural, industrial, domestic and recreational sectors. Therefore, water crisis means crisis in health, welfare, environment, economy, making water scarcity as one of the most important issues that humanity has been facing since antiquity and even more so in our era.

"Today, more than a billion people lack safe drinking water and almost two and a half billion live without access to sanitation systems. An estimated 14 to 30 people, mostly young and elderly, die every day from avoidable water related diseases. If current trends persist, by 2025 two-thirds of the population will be living with serious water shortages or almost no water at all." (Scanlon et al., 2006)

Such critical situations that we have already began to face, have increased the awareness of water as human right that allows an adequate standard of living with dignity. According to United Nations Committee on Economic, Social and Cultural Rights, CESCR (2003); "*The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses.*" “The Human Right to Water and Sanitation” was declared officially in 2010 by the United Nations. The notion of right to water stands for the preservation of equality against upcoming alterations due to climate change, especially considering the existing injustice in water access, distribution and consumption.

Even when water is naturally available to meet consumption demands in a location, access to water may be limited due to institutional and financial conditions. As shown in Figure 1, countries with little or no water scarcity have less than 25% of water from freshwater resources withdrawn for human purposes. ‘Physical’ water scarcity occurs when freshwater resources are approaching or have exceeded sustainable limits. But, dry areas do not necessarily have water scarcity technically, unless more than 75% of freshwater resources are withdrawn for agriculture, industry, and domestic purposes. If this rate is between 60-75%, then a region is approaching physical water scarcity. On the other hand, 'economic' water scarcity is about institutional and financial limitations when less than 25% of water from freshwater resources withdrawn for human purposes and accessing to water is insufficient due to mentioned issues (UNESCO, 2012:125).

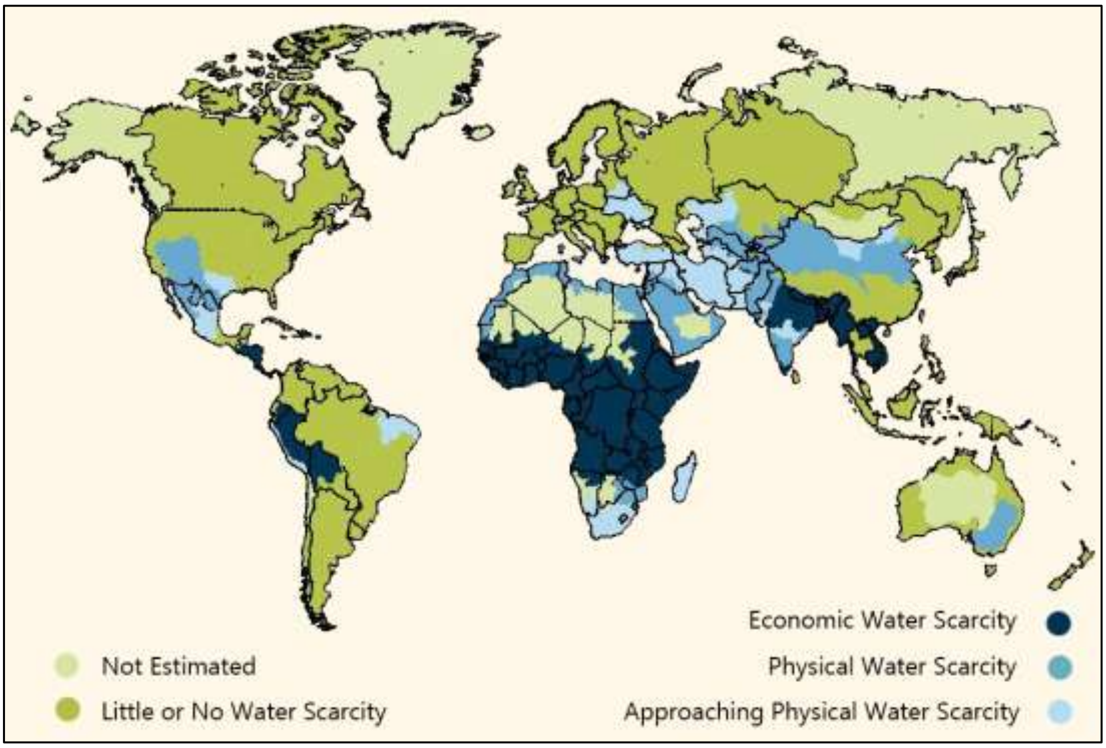

Figure 1 - Physical and Economical Water Scarcity *(UNESCO, 2012:125)*
While northern and southern areas of the planet are not facing water scarcity, the areas closer to the equator are facing or going to face physical water scarcity. South Asia, middle Africa and western South America are facing economic scarcity because of the economic rather than physical conditions.

For instance, cities in developed countries are only subject to temporary cuts due to maintenance or temporary additional water demand. But the problem is not only meeting water needs but also for how many hours or days freshwater is available. The situation can be endemic in under-developed countries like in some parts of South Africa where 60% of households must endure two-day water cuts. (Slaymaker and Bain, 2017).

In addition to social and geographical conditions, human-induced misuse of freshwater resources constitutes a great problem. Some of the water in motion cannot complete its natural hydrologic cycle due to issues like environmental pollution, climate change, or deforestation, along with rapid urbanization and overall population growth. In the last 60 years, the world's population tripled from 2.5 billion people in 1957 to 7.5 billion people in 2017, while urban population increased from 30% to 54% and by 2050, two-thirds of the global population will be living in cities (United Nations Population Division, 2018; UNESCO, 2015: 42)

If a country's annual water supplies drop below 1,700 m3 per person, the area is classified as "water stressed"; below 1,000 m3 per person is regarded "water scarcity"; and below 500 m3 means "absolute scarcity" (UNESCO, 2012: 124). As it is mentioned in the Sustainable Development Knowledge Platform (2017): *"More than 2 billion people globally are living in countries with excess water stress. Northern Africa and Western Asia experience water stress levels above 60 per cent, which indicates the strong probability of future water scarcity"*. Freshwater availability in 2007 is shown in Fig. 2 and a prediction about the status at 2040 is shown in Fig. 3.

In the light of such information concerning issues of water scarcity, the proper response must be in the agenda of every profession as much as other common humanistic subjects. In terms of architecture, the sustainable use of water in buildings is essential for mitigating water crisis effectively. This is the topic of this study, in which the author surveys such possibilities.

1.2. Importance of the Study

Despite the negative predictions, it is still possible to meet global water demand and that is where the importance of the present study lies. At this point, rainwater harvesting comes forward as an alternative water source and has a great importance where the central distribution networks are insufficient, or as a main water source where freshwater is not available in other forms. Therefore, the reasons that make rainwater harvesting important as a water supply vary, with some listed below with examples around the world.

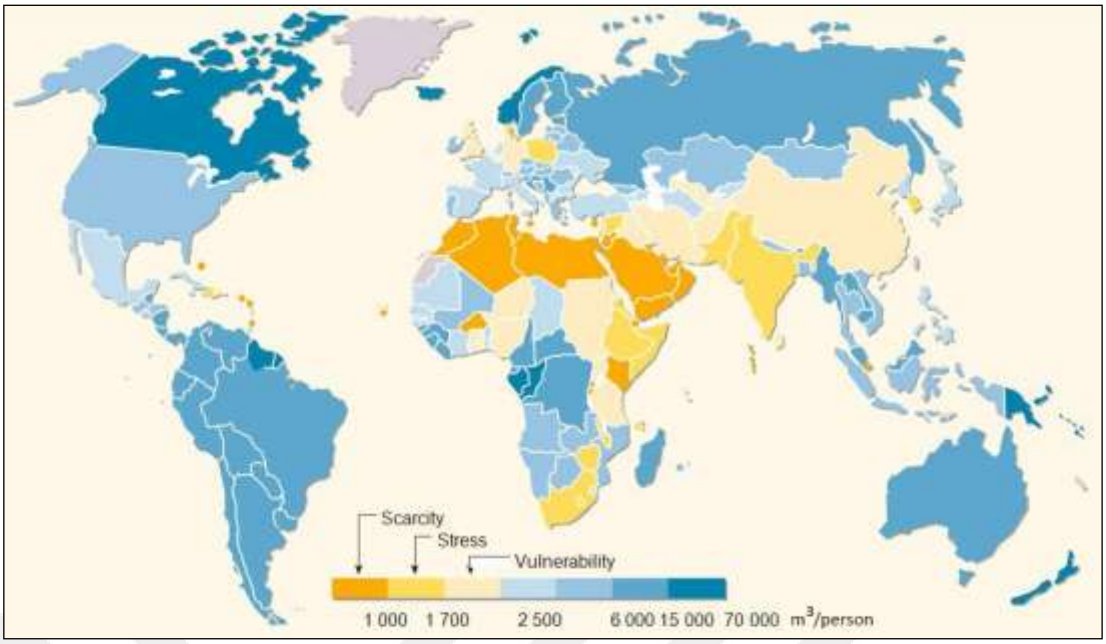

Figure 2 - Freshwater Availability in 2007 *(UNESCO, 2012: 124)*
As of 2007, North Africa experiencing water scarcity; while India, Pakistan, Poland, Somalia, Ethiopia and South Africa are facing certain levels of water stress. Southwest and middle Asia, northwest Europe and Middle Africa are in vulnerability.

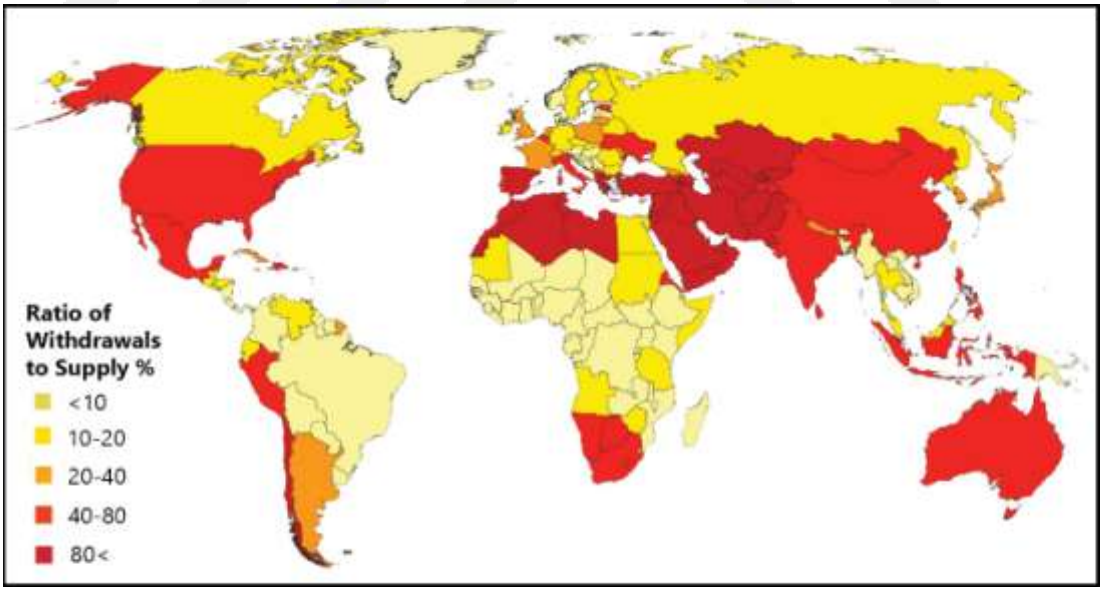

Figure 3 - Water Stress by Country: 2040 *(Maddocks et al., 2015)*
33 of 167 countries, now regarded as "water-tightening" with 40-80% supply withdrawals, will be "water poor" by 2040 with more than 80% ratio.14 of those 33 countries are in the western parts of the Asia and northwest Africa. (Maddocks et al., 2015).

The cases mentioned below, coming from different parts of the world with different objectives and conditions, show how effective rainwater harvesting can be and how it can respond to a wide range of water related problems. Therefore, it is important to explore the water harvesting systems and their potential as a solution to world's freshwater supply.

1.2.1. Rainwater as a Primarily Source

In the town Volcano of Hawaii, the pockets of groundwater do not exist or are extremely deep due to volcanic bedrocks' porous structure. Therefore, rainwater is primary water source as in most settlements of the island. [Figure 4] (Seigel, 2015) With an average of 288 rainy days and 2736 mm rainfall per year, rainwater harvesting is a convenient water supply method for the town (Weatherbase, 2018).

Figure 4 - Town Volcano of Hawaii *(sincedutch.wordpress.com, 2014)*
The active lava of Pu'u crater, flowed through Pahoa Marketplace in 2014.

1.2.2. Rainwater for Transitional Settlements

Rainwater harvesting decreases the amount of time spend to reach a water source in areas where there is not any distribution network at all. The significance of rainwater harvesting increases with poverty and in crisis times like natural disasters, epidemic diseases or war. [Figure 5] Although there are more advanced options, the concept of rainwater harvesting is based on simple technologies and materials that are inexpensive and easy to find and maintain which makes rainwater harvesting socially and economically adaptable.

For instance, given that immigration crisis is one of the biggest issues humanity is facing today, transitional settlements for displaced populations such as tent camps or container cities, needs convenient clean, freshwater supply to ensure public health. Due to the fast-moving process of emergency sheltering and the ephemerality of structures, container cities are built without any sanitary infrastructures. Rainwater harvesting is a substantially advantageous solution since any structure can be transformed into a water collecting system by adding undemanding accessories such as collecting surfaces, pipes and water tanks.

Figure 5 - Syrian Refugees at Zaatari Refugee Camp, Jordan *(Saleh, 2017)*
Although Jordan itself is in among the world's top five water poor countries; Zaatari refugee camp is consuming over one million liters per day by housing about 15% of registered Syrian refugees, (Bertelsmann Stiftung's Transformation Index, 2016).

1.2.3. Rainwater for Self-Supply

From the welfare of a country to the individual's homesteading movements, whichever scale you take to analyze in terms of self-sufficiency and sustainability, what is expected from a building is similar to all systems with continuity. In relation to water, this means having a total control over water supply. A building that is no longer depended on central distribution network means a building that no longer has to be located close to urban areas, but still able to provide the comfort its occupants are looking for.

For instance, scattered settlements and uneven population distribution are seen in Canada where to be included in a central distribution network is frequently not feasible. [Figure 6] Although there is no existing or expected water scarcity as shown in Figure 2 and 3, rainwater harvesting can be an alternative for Canada as a replacement for central distribution networks.

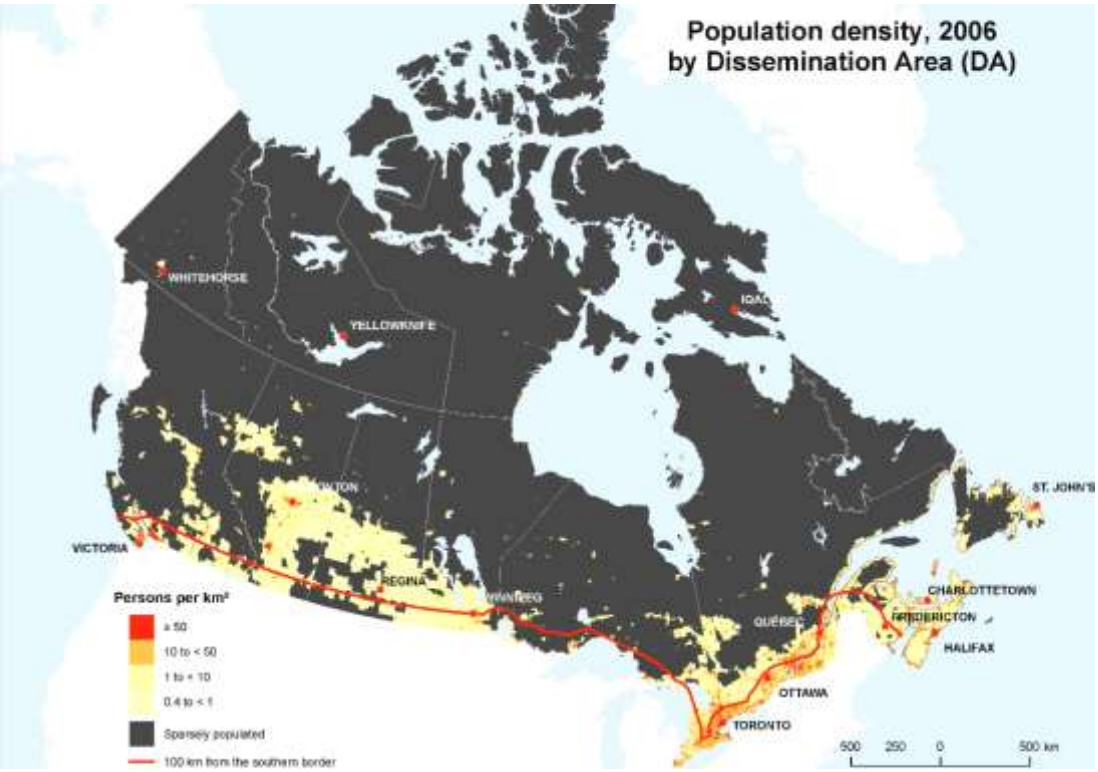

Figure 6 - Population Density of Canada as of 2006 *(The Huffington Post, 2016)*
Places in red have more than 50 people per km^2; in yellow areas they have 10 to 50 people per km^2. Although the southwest of the country and the regions south of the red line are dense, all light color areas have 0.4 to 1 person per km^2 while gray areas are sparsely populated.

The reasons of uneven population distribution can be varied as unfavorable climate, concentrated business capacity, historical urbanization or lifestyle choices. Through rainwater harvesting people can enjoy nature, stay in their favorable hamlet or settle anywhere they wish, and yet meet their basic needs without living in deprivation. What this system offers is reducing a building's use of municipal water, without reducing water use.

1.2.4. Rainwater as an Alternative Source

In addition to the above, rainwater harvesting is ideal for places that receive fair amounts of precipitation, but also have a high evaporation rate, a condition that necessitates the prevention of temperature-related water loss by storing water in closed tanks. For example, Antalya, Turkey receives on average 1062 mm rainfall annually [Figure 7] with 74 rainy days, having an evaporation rate between 1000-1100 mm per year [Figure 8] (Turkish State Meteorological Service [1]; Turkish State Meteorological Service [2]). Consequently, it is crucial to preserve the collected quantity of rainwater before it evaporates in order to achieve water-related goals.

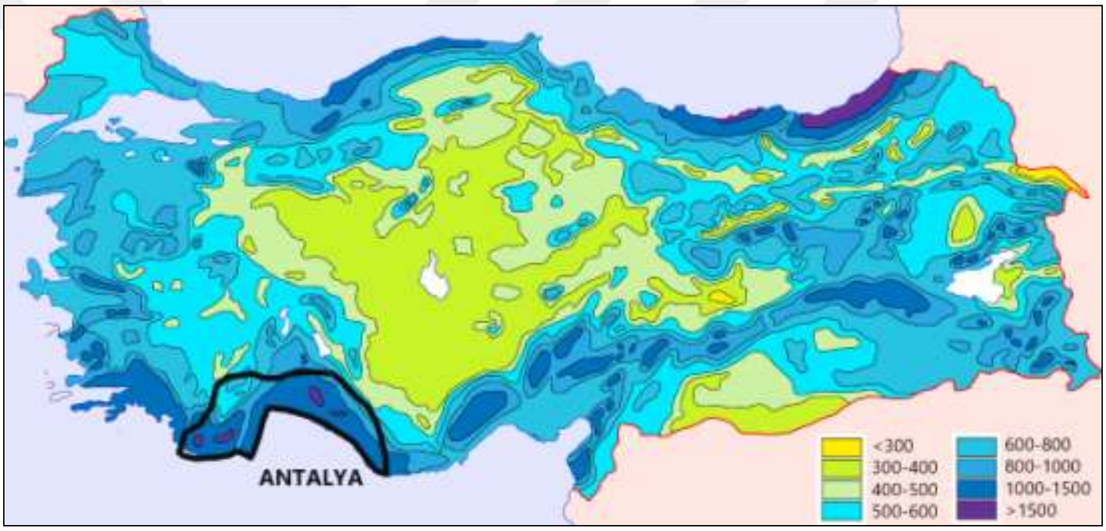

Figure 7 - Rainfall Map of Turkey (mm) *(cografyaharita.com, 2018)*
Antalya located in the southwest of the country receives 1000-1500 mm rain annually as a regional average.

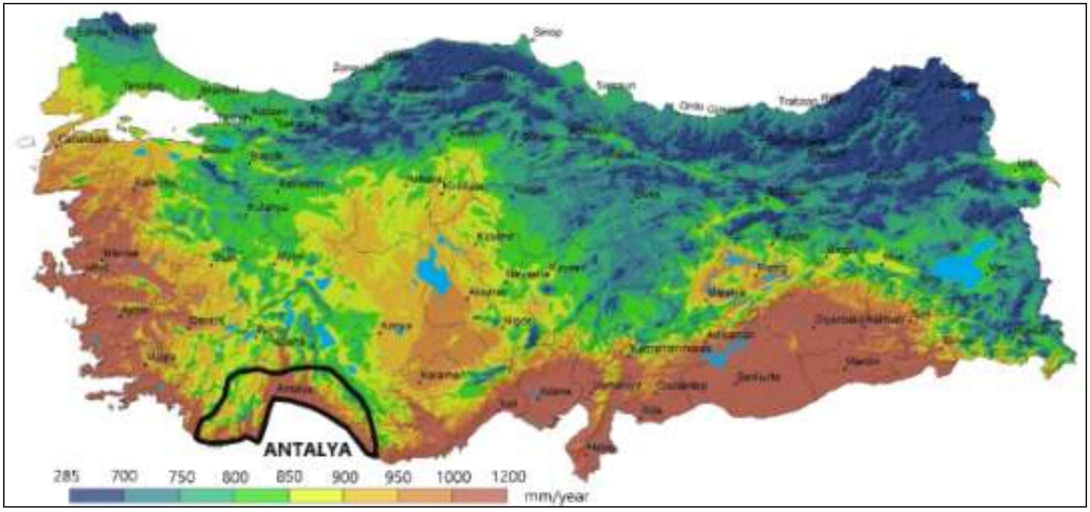

Figure 8 - Evaporation Map of Turkey *(Turkish State Meteorological Service [2])*
Contrast to receiving high rainfall, southwest of Turkey has high evaporation rates.

1.3. Research Questions of the Study

In order to comprehend different aspects of rainwater harvesting, its relation to architecture and how it can address the problems that were mentioned above in ‘Problem Statement’, the following research questions have been asked:

1) What is the place and importance of rainwater harvesting worldwide?
2) Why, where, when, how to perform rainwater harvesting?
3) How various societies solved fresh water problems by harvesting rain, according to their geographic and climatic conditions?
4) How rainwater harvesting methods affected layouts of settlements and design of the buildings?
5) How we can improve rainwater harvesting through architectural design, how we can improve architectural design through rainwater harvesting?

1.4. Methodology and Outline of the Study

This study started with actual observation and author's own experience. It continued as a general survey on the topic on the internet, which has been the main source of information here along with city archives, printed sources in university library and other bookshops.

Parts of the study have been based on available literature on freshwater topics including rainwater harvesting in order to comprehend the aspects of the particular concept. Although the both research and the structure of the thesis has the general-to-specific approach, the parallel findings during the thesis period which are presented separately in Discussion and Conclusion parts affected the designated structure.

In addition to keyword-based research, "image search" technique -when images substituted words for searching- used often to find similar examples especially for Contemporary Selection and Discussion parts. Besides the various types of information from other sources, the author visualized certain ideas by her own sketches for Discussion part.

The work is divided in chapters covering various aspects of the topic:

- *"Water"* chapter focuses on the various forms of water, its change of state and movement on earth in the Hydrologic Cycle, alongside with diverse water resources, their usage and importance. A classification and basic concepts of different freshwater harvesting methods for freshwater resources of underground, surface and atmosphere are also introduced.
- *"Phases of Rainwater Harvesting"* describes the components and requirements for each phase of the whole process: collection, conveyance, treatment, storage and distribution. The criteria for the optimal performance of each phase, how they related to each other and the issues that must be considered to ensure the proper functioning are also studied.
- In *"Rainwater Harvesting in the Past"*, several examples of traditional rainwater harvesting methods are studied, in order to understand how societies solved fresh water problem by harvesting rain.
- *"Selected Contemporary Cases of Rainwater Harvesting"* presents a number of notable present-day examples of rainwater harvesting.
- In *"Discussion",* rainwater harvesting's architectural visibility and its effects on architectural form or the absence of these are investigated. Based on the phases that introduced previously, the various ways in which each phase and the related architectural elements can be developed for creating a specific identity for rainwater harvesting is contemplated.

2. WATER

As a prime natural resource, freshwater has been a matter of scarcity. Water is a renewable resource, constant in quantity and continuously being transformed in the hydrologic cycle. It is a tasteless, odorless, transparent liquid which covers 75% of the Earth's surface and is fundamental for all forms of life to appear, grow, thrive and reproduce in the Biosphere (Graham et al., 2010).

It hosts many ecosystems and is necessary for the survival and health of all living beings, and a fundamental substance for their bodies. For instance, the body of an adult human consists of approximately 70% water, which function as solvent for the transportation of nutrients, a medium for excretion, a lubricant for joints; it controls body heat, preserves nervous system, gives the body form and tension in cells (Watson et al., 1980: 27; Botes et al., 2007: 47-48).

It is used for many varied purposes such as; drinking, cooking, food processing [Table 1], industrial applications, agriculture [Figure 9], domestic uses such as washing or bathing [Figure 10], transportation, medicine, chemistry, heating and cooling, recreation and fire extinction among many others. Eventually, everything we eat, use or produce consumes water [Table 1]. The use of water varies widely between countries, depending mainly on their level of development [Figure 9]. In developed countries the largest portion of domestic water consumption goes for toilet flush [Figure 10], a luxury not easily afforded in the developing world.

Table 1 - How Much Water is Needed to Produce ...?
(Based on the data by Food and Agriculture Organization, 2009; Leahy, 2014)

Food (per piece)	Water (liter)		Drink (per Cup or Glass)	Water (liter)
Potato	25		Tea	35
Bread	40		Beer	75
Apple	70		Wine	120
Egg	135		Coffee	140
Hamburger	2400		Milk	200

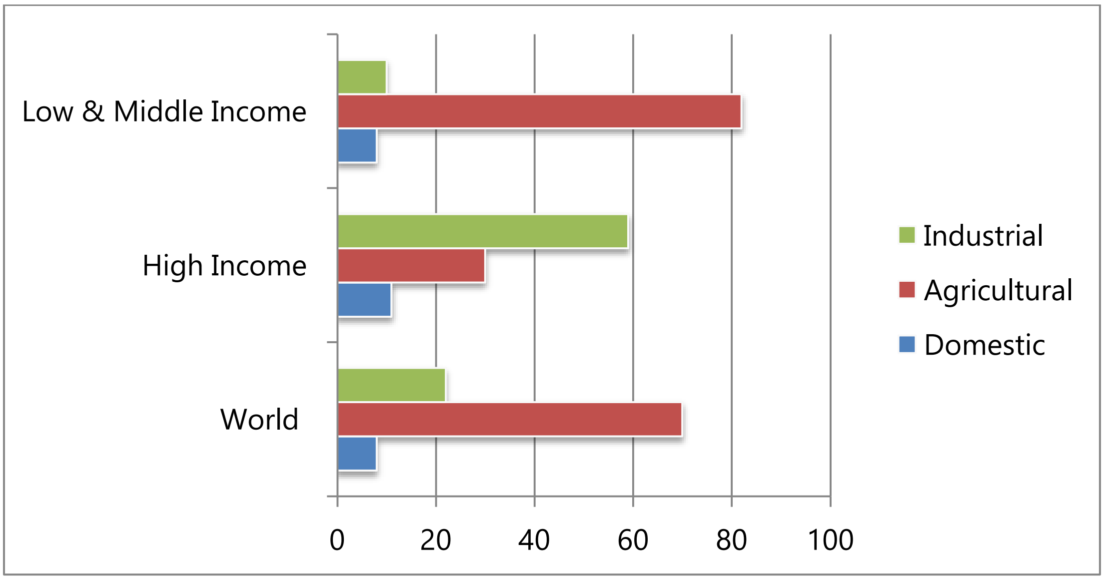

Figure 9 - Water Usage Type Percentages by Income Levels of Countries
(based on the data by Scheele and Malz, 2007:99)
While agricultural usage of water consists most of the total usage in low and middle-income levels, and worldwide; industrial usage passes this rate in high income level.

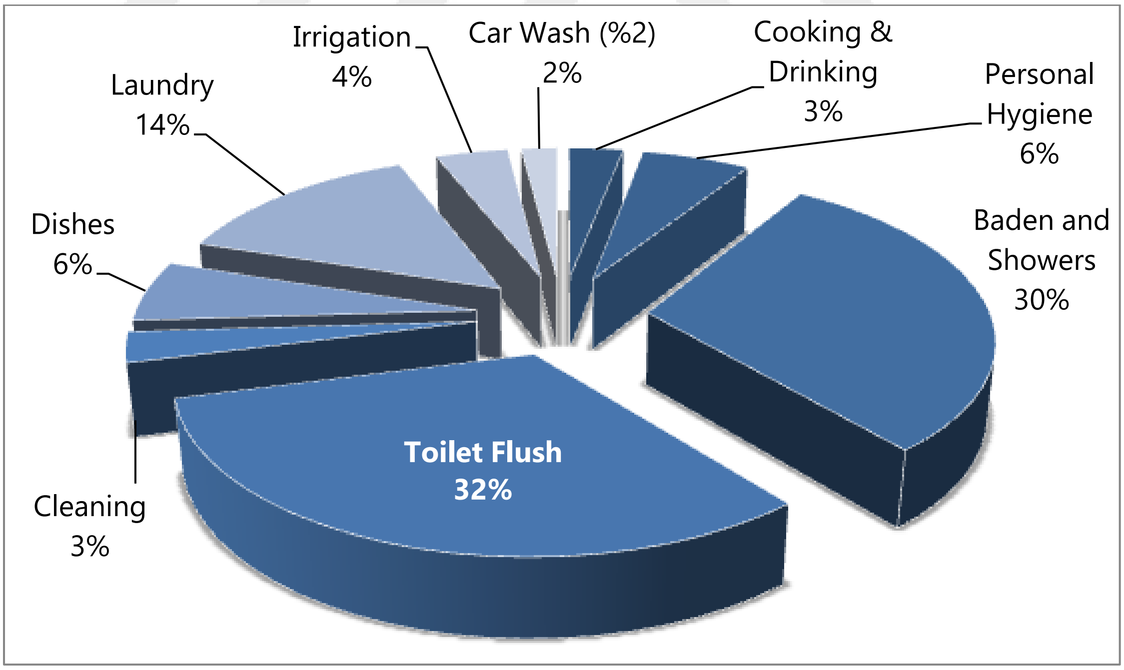

Figure 10 - Usage Percentages of the Domestic Consumption in Germany
(based on the data by Scheele and Malz, 2007: 98)
In Germany, toilet flush consists biggest consumption share by 32% and followed closely by bathing and showers with 30% share.

2.1. Forms of Water

The term ‘water’ refers usually to the liquid state of a substance that exists in three different forms on Earth's surface. It is present in *solid* state as snow, glaciers, hale or icebergs; *liquid* state as rain, dew or aquifers in underground; and *gas* state such as vapor and atmospheric humidity. Oceans and seas constitute 96.5% of the Earth's total water. 1.7% of water is stored in glaciers, ice caps, permanent snow and 0.001% is exist as vapor, clouds or precipitation (Gleick, 1993; 13). Figure 11 illustrates the amount of water on the planet in proportion to its volume.

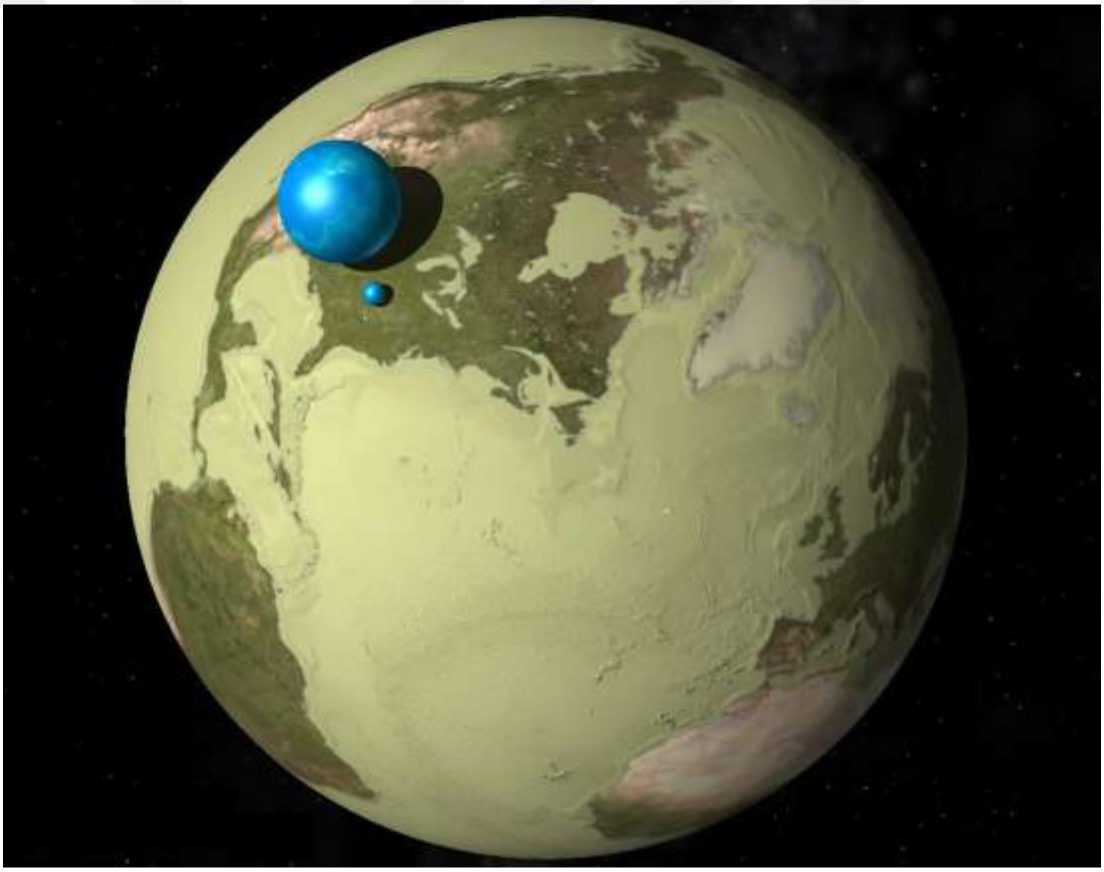

Figure 11 - Global Water Volume *(USGS)*
Various blue spheres represent amounts of Earth's water in comparison to the size of the Earth. The biggest sphere represents all of Earth's water including the oceans, ice caps, lakes, and rivers, as well as groundwater, atmospheric water, and even the water in living beings. The medium sphere represents liquid fresh water including groundwater, lakes, swamp water, and rivers.

The water continuously transforms from one form to another by the physical processes of Hydrologic Cycle in the hydrosphere of Earth; where the atmospheric humidity, sea water, soil water, and groundwater are in motion as an endless system as shown in Figure 12. The solar energy triggers the water cycle, heating up water on the surface -like water on oceans, seas, lakes, rivers, streams or ponds- converting it into water vapor by evaporation. That vapor condenses into droplets in parts of atmosphere with lower temperatures and their concentration forms visible clouds.

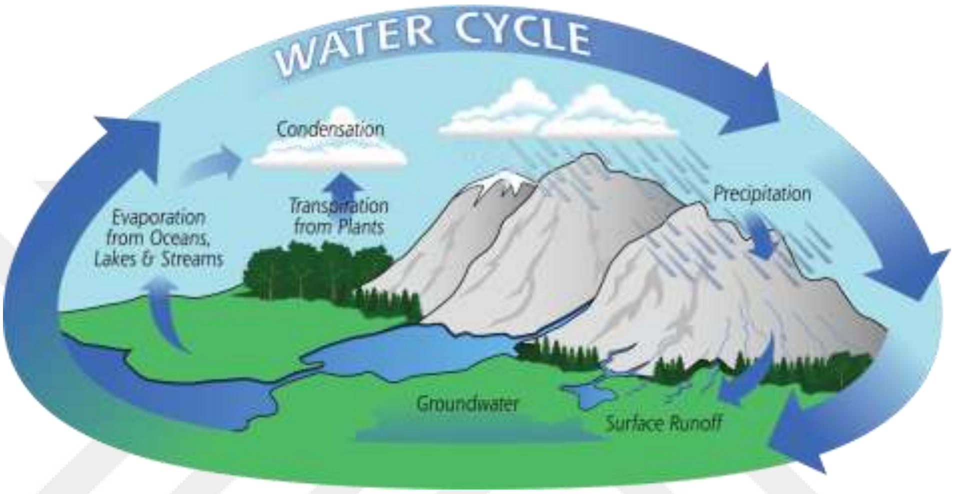

Figure 12 - The Hydrologic Cycle *(NASA [1])*

The precipitation occurs when condensed water vapor returns to surface in forms of rain, snow, fog, dew or hail. The part of water that falls on land instead of the oceans flows to the rivers and lakes as surface runoff; while some of the rainwater, as well as melted snow, infiltrate into the soil and groundwater before meeting greater water bodies such as seas and oceans. Subsequently, the cycle returns to evaporation stage and continue to repeat itself in order to maintain the water balance of Earth.

Water vapor is a powerful greenhouse gas, driving weather and climate by encircling the globe and transporting latent heat with it. *"Latent heat is heat obtained by water molecules as their transition from liquid or solid to vapor; the heat is released when the molecules condense from vapor back to liquid or solid form, creating cloud droplets and various forms of precipitation."* (Graham et al., 2010) This evaporative cooling or warming reduces or increases the surface temperature as a result of energy exchange.

2.2. Water Resources

‘Water resources’ are the amounts of water that are utilizable to fulfill human activities. Although some types of water use such as transportation and energy generation can be done with saline water too, other purposes like drinking, cooking and cleaning that constitute a great part of daily human consumption require freshwater. Despite consisting only the 2.5% of Earth’s total water, freshwater resources meet the demands of 7.5 billion people (NASA [1]; United Nations Population Division, 2018).

Water resources can be divided into three categories according to their positioning to the Earth: ground, surface and atmospheric water. "Groundwater" is the freshwater located in the subsurface, soil and rocks, flowing within aquifers below the water table. The seepage from surface water is the natural input to groundwater, while springs and seepage to greater water bodies are the natural outputs. It constitutes 30.1% of total freshwater.

"Surface water" is naturally lost through evaporation, evapotranspiration, ocean discharge and groundwater recharge, being replenished by precipitation. It constitutes 1.3% of total freshwater and 0.22% of it is "atmospheric water" which is in form of water vapor as cloud or fog (NASA [2]). In addition to the above, glaciers and ice caps are regarded as utilizable freshwater resource in theory. Figure 13 depicts the various types of water on the planet.

The methods and technologies related to providing freshwater from its various origins are a topic that affects the life of billions, therefore is of great importance and requires more comprehensive examination of the processes involved in "freshwater harvesting."

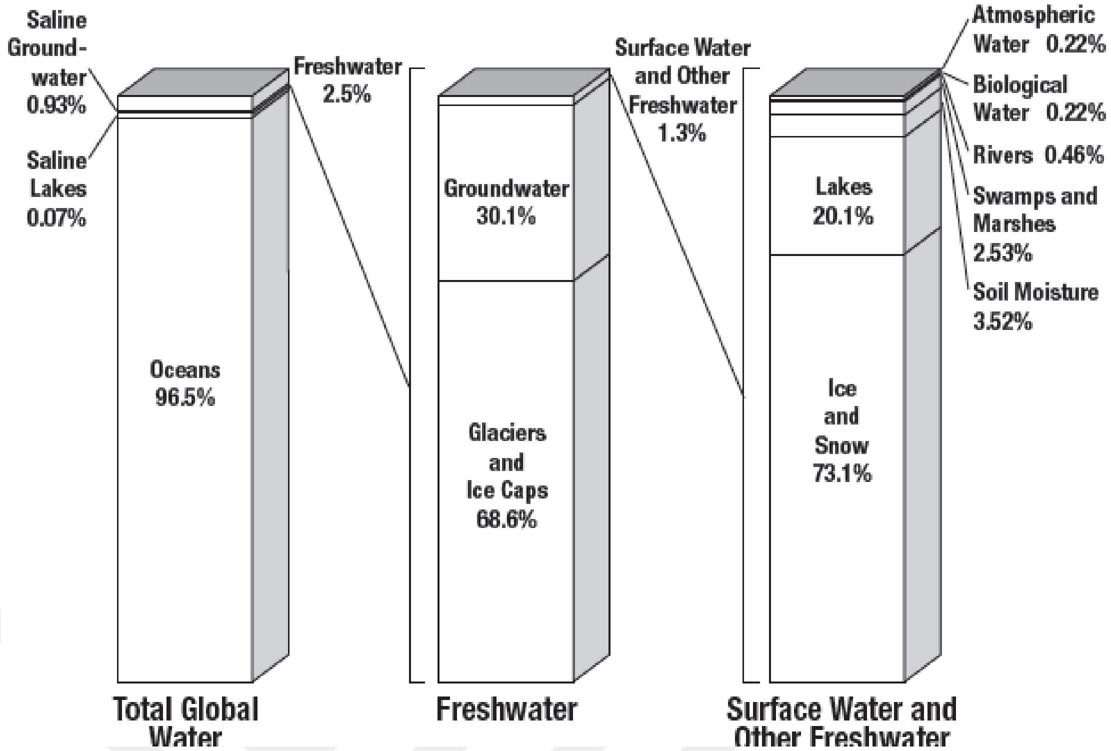

Figure 13 - Distribution of Earth's Water *(NASA [2])*

2.3. Freshwater Harvesting Methods

The term "water harvesting" stands for the combination of several phases of water collection and storage in order to increase the availability of the precious liquid for beneficial use. The techniques to harvest water are called "water harvesting methods", and the source of the freshwater determines the type of those methods: groundwater, surface water and atmospheric water harvesting.

These methods have always been vital for human settlements since early history. It is presumed that primitive water harvesting methods evolved in Bronze Age or earlier in Mediterranean region and Western Asia (Beckers et al., 2013; 145). Most settlements used more than one water harvesting method considering their needs, climatic and geographic conditions. For example; water wells or rooftop harvesting for drinking, and floodwater or rainwater harvesting for irrigation. Therefore, studying water harvesting methods help to understand better the relation of architectural practices with the environment and its inhabitants.

2.3.1. Groundwater Harvesting

A water well is the most elementary and conventional structure to provide freshwater. It is a vertical hole in the ground that gives access to groundwater aquifers. The process to create a well typically consists of (1) detecting the exact location of the resource, (2) digging the soil to reach the water level, (3) constructing supporting walls and (4) drawing the water with the help of devices on the top of the well. It is a technique used extensively in many regions and times, applied in different ways depending to topographic conditions, intended purposes and available technology. For instance, the depth of a borehole can be up to 200 m. below surface to yield 1-10 liters per second with a 25-year lifetime, while a dug well can be last more than 50 years and yield 5 m^3 water per day with nearly 50m. depth [Figure 14] (Brikké and Bredero, 2003; 29-34).

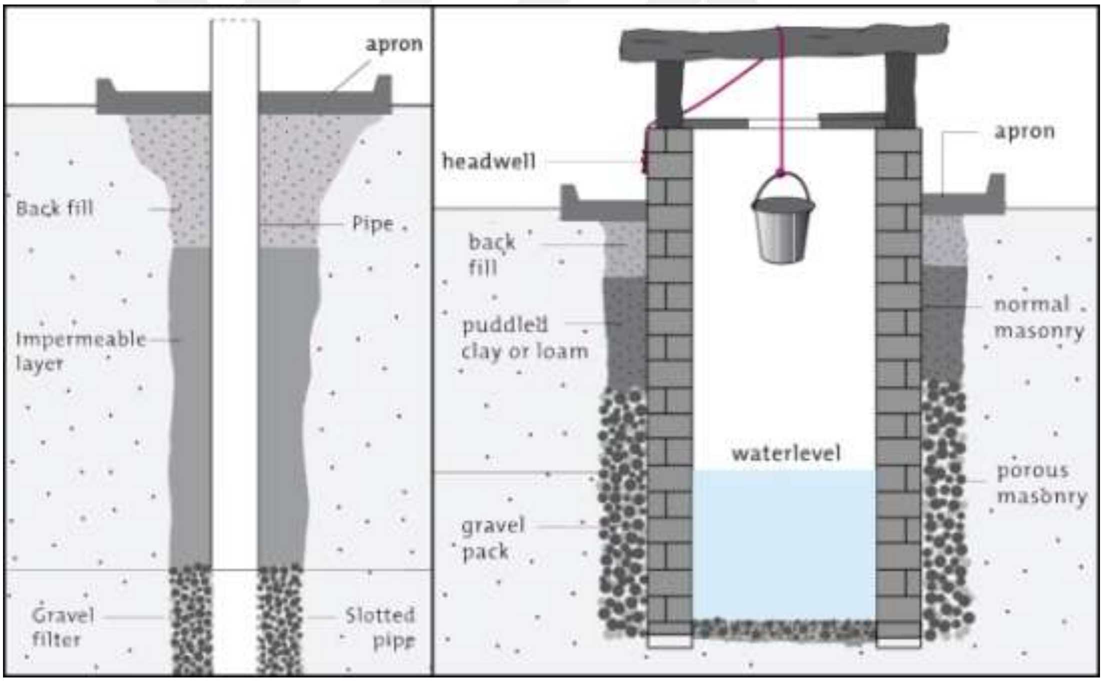

Figure 14 - Sketches of Different Well Types (Brikké and Bredero, 2003)
A drilled well on left and a dug well on the right.

Apart from wells, a more complex tunnel-well system called "Qanat", is often found at the outlet of mountainous catchments and groundwater aquifers. A dense series of vertical shafts that connect the tunnel with the surface, provides the regulating air pressure to the system. The tunnel channels the groundwater to the reservoir and the water is distributed from there as shown in Figure 15. By constructing a tunnel that connects the aquifer with the outlet, the groundwater is conveyed to a reservoir for the distribution of the water to fields or settlements. Qanats can be found in Iran, Syria, Morocco, Spain and Oman with different names but same working principles (Beckers et al., 2013; 149).

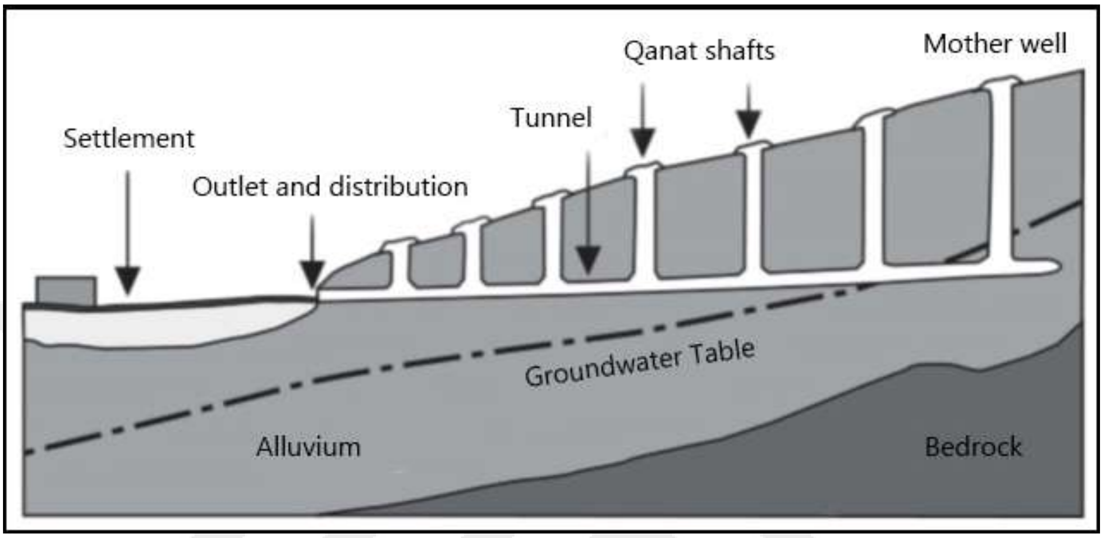

Figure 15 - Sketch of a Qanat (Beckers et al., 2013)

2.3.2. Surface Water Harvesting

The transportation of freshwater from lakes and rivers has always been one of the primary concerns of human settlements. Even if a settlement is located near a surface freshwater source, distribution of that water can be still require developing additional techniques. Therefore, several surface water harvesting methods have emerged through history, such as the *"river-bottom intake"* which is ideal for rivers with little sediment and bed load, or the *"sump intake"* method which functions better on the banks of rivers and lakes [Figure 16] (Brikké and Bredero, 2003; 38-41).

Moreover, a method called *"floodwater harvesting"* (or *"spate irrigation"*) is used for collecting and storing water from temporary streams during flood events, and has several sub-methods. Firstly, in "*terraced wadi system*" [Figure 17], which is used primarily for agricultural purposes, a series of small dams lower the flow rate of the floods and its carrying capacity. As a result, the accumulated sediments of flood transported into a terrace or reservoir system.

Secondly, *"groundwater dams"* [Figure 17] can be used for collection and storage of flood water. This time, the stored water in the sediment bodies is withdrawn by water wells built into the dam. While groundwater dam's storage capacity is lower than terraced wadi system, it reduces the evaporation losses or the risk of contamination. Thirdly, *"Floodwater diversion systems"* [Figure 17] can also be used for irrigation or direct human consumption, built to channel flood water to a specific area. This is either accomplished by blocking some parts or the entire channel by a retaining structure called diversion dams.

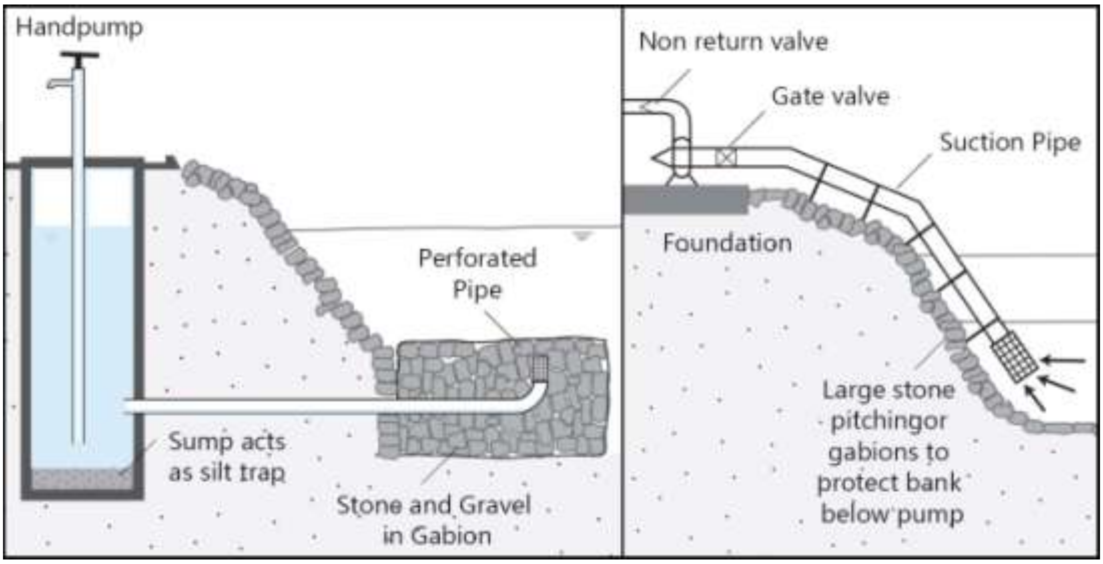

Figure 16 - Sump Intake (left) and River-bottom Intake (right)
(Brikké and Bredero, 2003)

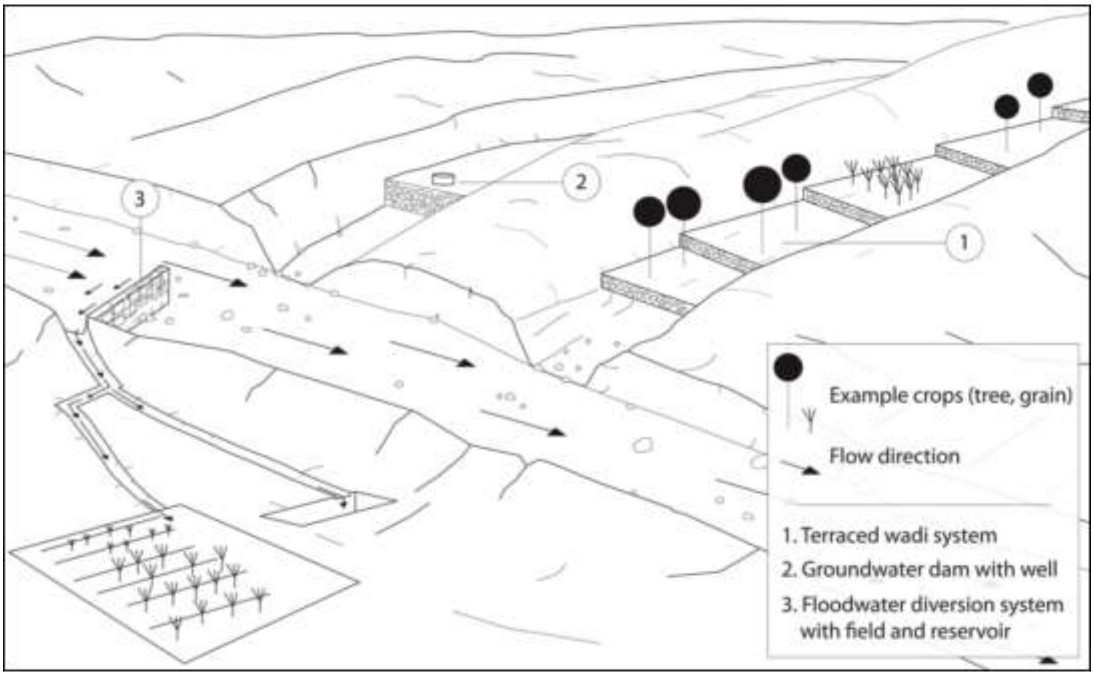

Figure 17 - Floodwater Harvesting Methods *(Beckers et al., 2013)*

In addition to these conventional methods involving geoengineering, the process of "desalination" is used to convert saline water to freshwater by extracting the mineral components. It is used on seagoing ships and submarines because it is one of the few rainfall-independent water sources, along with recycled wastewater. In desalination, first seawater is filtered and chemically treated to leave saltwater pure. Subsequently, salt is removed via reverse osmosis, a procedure of saline water being pumped against a semi-permeable membrane, which freshwater can pass through but dissolved salts cannot. The method is convenient for regions near sea or ocean but have no freshwater resource. For instance, according to data by Fischetti (2007), 1700 desalination plants in the Middle East convert over 20 billion liters of seawater a day.

Desalination can be applied in small scale through evaporation by "water cones" [Figure 18]. In this method, saline water is poured into a pan and a transparent cone is placed on top; the black pan heats up by absorbing sunlight and evaporation starts. The evaporated water condenses, flows down through the inside surface of the cone as droplets and is collected in a gutter at the bottom as salt-free, clean water [Figure 19].

Figure 18 - Desalination with a Water Cone *(Watercone, 2018)*
This is a water condensation process that can yield 1.0 to 1.7 liters of condensed freshwater per day.

Figure 19 – Sketch of a Water Cone *(Watercone, 2018)*

2.3.3. Atmospheric Water Harvesting

When atmospheric water vapor condenses on cold surfaces, it cools by radiating its heat to the sky and turns into droplets of water: dew. That can be easily observed on thin or flat objects like plant leaves. Similar to this, fog -which is also consisted of condensed or frozen-crystallized water vapor- can be collected with large pieces of vertical canvas to make the fog-droplets flow down towards a trough below the canvas, known as a fog fence.

The 2016 United Nations "Momentum for Change" award-winning project collects water from fog clouds for about 140 days per year. The pilot fog collection project, shown in Figure 20, launched in 2015 in Morocco, provides clean drinking water for 500 people in five eight-kilometer away villages by collecting 6000 liters water a day (Prisco, 2016) [Figure 20]

Moreover, newly developed water-catchment systems such as a design by Arturo Vittori named "Warka Tower" also produces freshwater by harvesting rain, fog and dew from the atmosphere as an alternative freshwater resource as shown in Figure 21 and 22. This system, which operates similar to fog fences, provides an average of 100 L of drinking water every day for rural populations with limited freshwater access.

Figure 20 - Fog Catchers in Morocco *(Prisco, 2016)*

Figure 21 - A Built Warka Tower *(architectureandvision.com)*

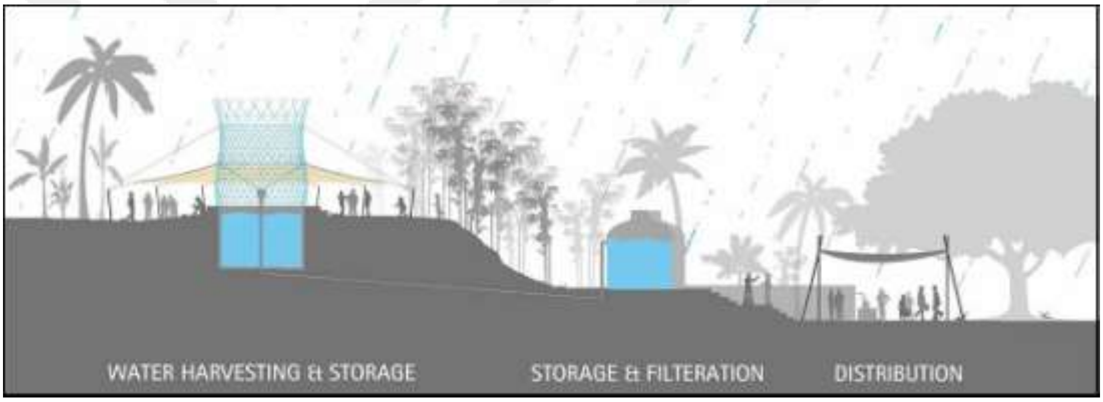

Figure 22 - Water Harvesting Process of Warka Tower *(warkawater.org)*
The tower can be easily built with traditional techniques and simple tools without the need of electricity, and 100% recyclable, local materials such as bamboo.

After water wells, rainwater harvesting has been the second most common technique, practiced for ages in rural, coastal, arid and semi-arid areas, islands and scattered settlements to provide water supply for the inhabitants using various methods. Its applications are used especially where underground and over ground water resources are limited but there is a certain amount of rainfall. Large catchments such as hillsides with long slopes are ideal for agricultural purposes of "hillside conduit system" [Figure 23]. By building conduits, it is possible to keep freshwater near the upper parts of the hill before it reaches the lower areas.

The "hafir" [Figure 23], i.e. a large open reservoir made of soil with a concave shape, is another rainwater harvesting method alongside "agricultural terraces" [Figure 23] that absorb freshwater from the hill by efficient use of natural slope (Beckers et al., 2013). Like the collection of rainwater by ground surfaces, in *"rooftop harvesting"*, surfaces of built environment can be used for rainwater collection. [Figure 23] The impermeable surfaces of roofs, paved courtyards and squares can be relatively easier to be cleaned of sediments rather than other methods. The harvested rainwater is stored in cisterns or reservoirs and commonly used for domestic purposes, irrigation of gardens and administrative and religious buildings.

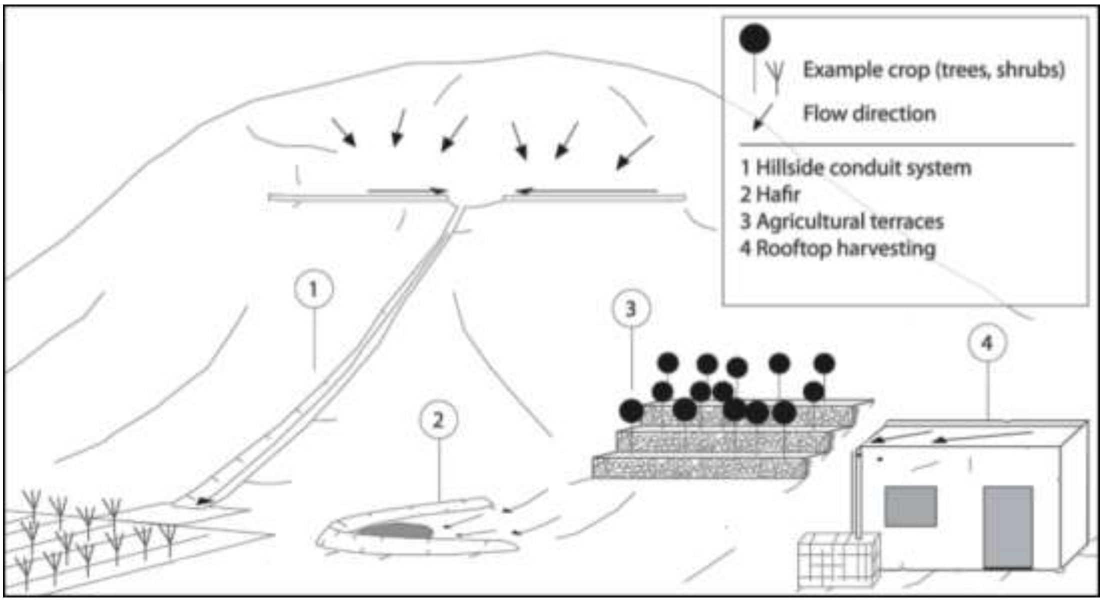

Figure 23 - Rainwater Harvesting Methods *(Beckers et al., 2013)*
A hillside conduit system, a rooftop harvesting, a hafir and an agricultural terrace are illustrated together as different methods of rainwater harvesting.

Traditional rainwater applications are effective climate adaptation strategies for dry-wet, semi-arid and arid regions. Considering the current and upcoming water-related issues such as water stress and water scarcity, harvesting rainwater as a primary or an alternative freshwater source is still a significant option. "*In the past several decades, there has been a call from scientific and non-governmental organization communities to combine modern water systems and old rainwater harvesting methods or to modernize the existing rainwater knowledge to benefit human settlements facing water scarcity.*" (Akpınar Ferrand and Cecunjanin, 2014: 395).

3. PHASES OF RAINWATER HARVESTING

From all the freshwater harvesting methods and their varied types of implementation, this thesis focuses on rainwater harvesting in architectural practices. It is one of the oldest methods of water supply to cover human needs and activities. Although the method has been commonly used for agricultural purposes for ages, this study focuses the stages of rainwater harvesting and how they could be modified or adapted to respond to domestic and recreational purposes of the occupants in an architectural structure. Additionally, from a legal point of view, rainwater is considered a surface water and thus is subjected to technical and regulatory restrictions like other surface water sources. Most of these regulations aim to enforce certain standards to structures for maintaining public health and they are applied differently from region to region. In order to harvest rainwater in the most beneficial way, the following parameters must be taken under consideration before the design:

- *Rainfall:* The design of the rainwater harvesting system or the whole structure must be according to conditions such as rainfall patterns and average annual precipitation rate in the building's geographic region of. Before anything else, at least 24 in (600 mm) average annual rainfall is required for rainwater to be the primary water source. (Siegel, 2015)

- *Water Losses:* In order to accurately estimate the amount of water that can be harvested, it is necessary to determine the amount that is lost by evaporation and leaks in the whole system.

- *Water Demand*: The widely accepted water demand per day and per person is 190 liters, however the actual demand depends on life style and other choices and it can vary between 95 to 190 liters per day per person. (Siegel, 2015) Therefore, it is crucial to identify occupants’ habits of water usage. For instance; the frequency and duration of showers, the type of toilet flushing, washing dishes/laundry by hand or machine, the use of water-saving machines and the existence of water-conserving fixtures or not like motion-sensitive water taps.

- *Catchment Area:* The effective size of a roof or any surface that receives rain directly is not its overall surface area but its horizontal projection, independent of any slopes. That size is vital for maximizing water collection, especially in areas with low rainfall.

3.1. Operation and Components of Rainwater Harvesting

Various outdoor surfaces exposed to rain such as roofs, terraces and paved or unpaved areas on the ground, receive rainwater. After a basic filtration of undesired objects such as leaves and insects, the collected rainwater is conveyed to a storage tank where it will be treated and brought to a certain level of clearness according to the usage purposes. The treated water is then distributed to designated points, where people can get freshwater for their needs. The main components of rainwater harvesting are listed below in Table 2. Detailed information about how each phase operates is explained in the following parts of this chapter.

Table 2 - Components of Rainwater Harvesting *(table by author)*

Phase	**Component**
Collection	Roof Surface
	Terraces & Balconies
	Paved ground areas
Conveyance	Gutters
	Downspouts
	Conveyance Pipes
Storage	Pre-Storage Filters
	Water Tanks, Cisterns, Reservoirs
	Overflow Drainage Pipes
Treatment	Sand filters
Distribution	Pump
	Distribution Pipes

3.2. Collection

The surfaces exposed to the sky are the key element of rainwater catchment system. Among all, roofs are the first architectural element to meet the falling raindrops. Since the horizontal projection of the roof surface is the key parameter, a flat roof would be the most beneficial as it has the largest possible footprint and the minimum overall surface that is exposed to heat transfer. A drawback is the fact that it is rather not convenient for fast draining or roof washing. This is also true for flat ground surfaces as terraces or courtyards of buildings.

The type of catchment material and the geometry of the roof determines the collection efficiency which mainly depends on the amount of rainwater that can be collected, which is affected by possible losses during the collection stage. They can be continuous losses such from wind and leaks in the collection surfaces, or standardized by an initial loss factor (in mm of rainfall) due to the absorbency of the material. (CHMC, 2012) So, in order to maximize the volume of rainwater collected by the system, it is advantageous to select a catchment material with minimal collection losses, such as steel [Table 3].

The uppermost material of the roof can be dissolved under the effect of runoff water and release chemicals, or be eroded into small particles that mix with the rainwater due to external conditions like wind. Therefore, it will be beneficial to have a *"roof wash"* or *"first flush"* system to purge pollutants such as roof material, dust, leaves, bird droppings, etc. before the collected water flows into the storage unit. In addition, a "*pre-storage filtration*" will be useful and healthy in order to prevent entrance of large particles to the storing unit such as dead animals or detached building elements, in case of inadequate roof wash system.

Although the concept of green roofs is highly fashionable in contemporary sustainable architecture, it would be right to say that water collection from their surface is not recommended due to the biodiversity that the soil might contain, especially in terms of micro-organisms. Also, the amount of harvested water will be decreased as a consequence of plants' own water need.

Table 3 - Loss factors of the roof catchment materials
(based on data by Canada Mortgage and Housing Corporation, 2012)

Roof Catchment Material	Initial rainfall loss	Continuous rainfall loss ratio
Steel Roof	0.25 mm	20%
Asphalt Shingle Roof	0.50 mm	20%
Fiberglass Roof	0.50 mm	20%
Asphalt Built-Up Flat Roof	1.50 mm	20%
Hypalon (rubber) Flat roof	1.50 mm	20%

3.3. Conveyance

A conveyance system of pipes, gutters, conduits and downspouts is necessary to concentrate and channel collected water to storing unit [Figure 24]. Sizing and placement of the conveyance network elements according to the building layout and the placement of storage unit are main parameters to consider in design. For large amounts of catchments or for long conveyance distance, additional devices can be installed.

The size of the gutters should be determined according to the amount of flow and be supported considering the water load, to ensure that the system can handle rapid run-off. The size and slope may be specified by the building code of the building area; if not, standard sized pipes can be selected according to water collection calculations.

When determining the size, slope and placement of conveyance network, a parameter that must be considered is the portion of the catchment surface that is conveyed by a particular part of the conveyance system. To make conveyance reasonably practicable, the catchment surface needs to be divided into at least two sections of collection and conveyance. For instance, most pitched roofs have at least two distinct drainage areas for drainage pipes to transfer collected rainwater.

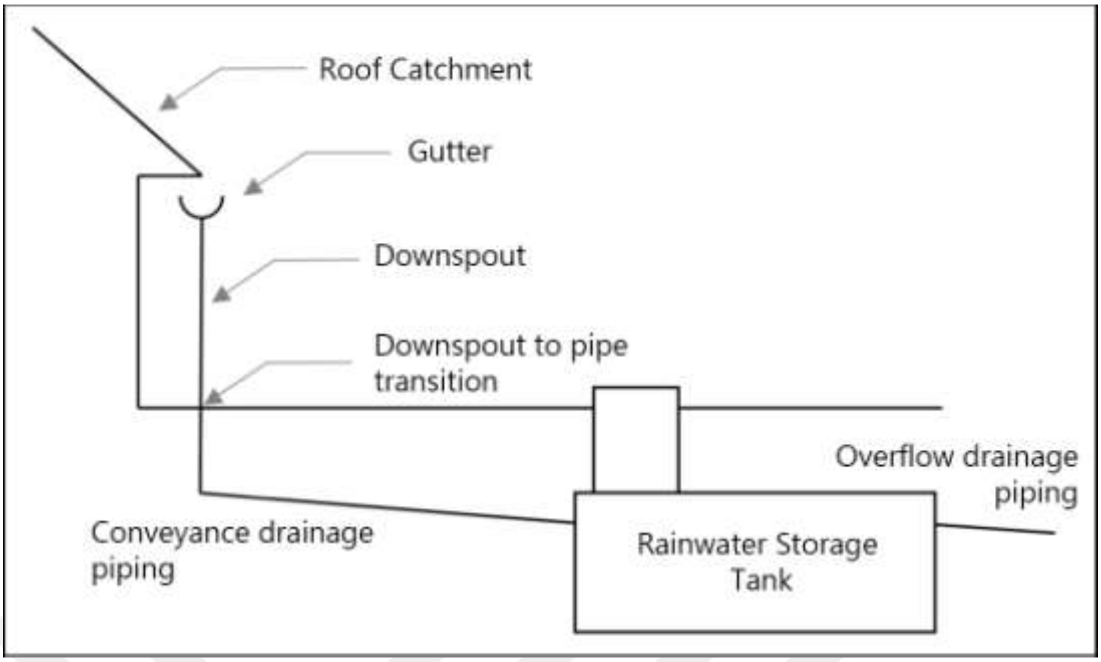

Figure 24 - A Conveyance System for an Underground Rainwater Storage Tank *(CHMC, 2012)*

Positioning gutters' slope towards the location of the rainwater storage tank will be obviously practical. A greater slope ensures that water will flow fast, avoiding problems of congestion. On the other hand, downspouts must be located near the rainwater storage tank, but outside of the structure to avoid problems due to leakages or overflow to the interior. In case of complex roof shapes, long distance to storing tank or uneven site layout may cause difficulties to connect catchment surface to the conveyance system.

For material selection, a fundamental part of the conveyance network design process, the adherence to local regulations and other special conditions is essential. In general, *"the pipe selected must be rated as suitable for ultraviolet (UV) light exposure and burial (where applicable), and, if rainwater quality is a concern, it must be rated for handling potable water. Gutters and downspouts are generally manufactured out of aluminum or galvanized steel, both of which are considered suitable for RWH systems."* However; copper, wood, vinyl and plastic for downspout and gutter materials are not recommended. (CHMC, 2012)

To avoid further complications, it would be preventive to locate the buried service lines such as gas, water, phone etc. Further, another subject that need to be careful is preventing the entry of animals or insects into the system. There must be no holes or other points of entry, particularly in intersection points, but the designated flow passages.

3.4. Storage

In order to store the collected rainwater, a storage tank or a cistern must be constructed [Figure 25]. That can be underground or over ground, inside or outside the building's footprint, each option having pros and cons [Table 4]. The storage can also be considered as the center of the whole rainwater harvesting process, since other phases are connected to it.

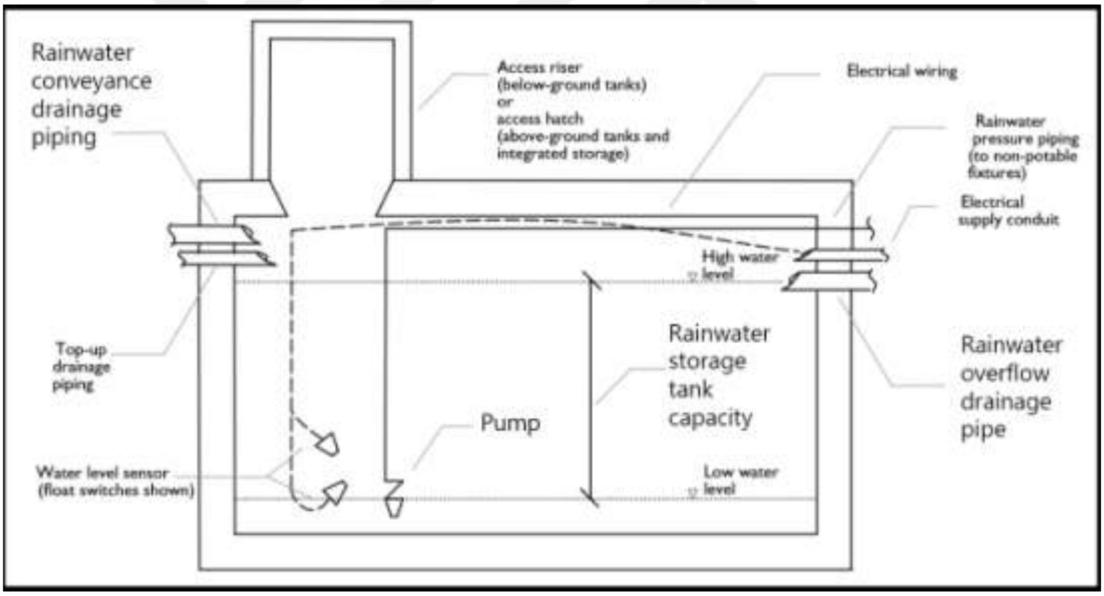

Figure 25 - A Sketch of a Storage Tank *(CHMC, 2012)*
Tanks shall be provided with an access opening for maintenance. There must be an overflow pipe to prevent damage of the storing unit due to exceeding the capacity. The inside surface should be non-toxic.

Selecting material for a rainwater storage tank will largely depend on site accessibility, local availability, cost, tank placement, storage requirements and cost. Galvanized steel, concrete, ferro-cement, fiberglass, polyethylene and durable wood can be used for storage tanks. (Siegel, 2015)

Table 4 - Comparison between placement of storage tanks
(based on the information by Canada Mortgage and Housing Corporation, 2012)

Tank Placement	Advantages	Disadvantages	Possible Material
Above-Ground	- No site excavation cost	- Extra temperature control	- Plastic
Below-Ground	- Not occupy yard space	- Requires excavation	- In situ concrete - Precast concrete - Plastic
Integrated	- Customizable capacity	- Danger of leakage to living space	- Cast-in place concrete

The storage capacity that is required to meet the water demands during dry periods depends on the number of users, the water usage purpose and precipitation levels. If the size is smaller than it should be then the collected rainwater will be overflowing during rainfall events. The optimum size of a rainwater tank is the one providing the best balance between collection efficiency and cost. An average storing capacity can be determined by the calculation of daily use (liters/day) times number of continuous drought days. Site-specific details such as material, location, rainwater availability, water demands or catchment area are decisive to determine ideal tank size. A storage calculation based on number of drought days is shown below.

$$\textit{Storage Size} = \textit{Number of water users} \times \textit{Number of dry days} \times \textit{Per capita demand}$$

3.5. Treatment

The most important parameter in rainwater harvesting is the water quality. Therefore, an optimal objective is capturing the water before hitting the ground, while it is free from the pollutants of the soil. Then, it is relatively cleaner, hence safer than surface water, an essential property for public health. Some treatment of the stored water may be required to bring it to a certain level of cleanness, depending on intended use.

To determine the required treatment, it is necessary to identify the contaminants that are potentially present in harvested rainwater. For instance, in urban areas or industrial districts exposed to air pollution, such contaminants can be lead, cadmium, zinc and arsenic, or even acidic rain. (Siegel, 2015) Moreover, due to fecal contamination coming from many sorts of animals, the water may contain pathogenic microorganisms which can cause infectious diseases even after a single exposure, therefore being more dangerous than chemical contaminants. Waterborne illnesses constitute a great danger to public health, especially people with weak immune systems such as elderly, children, people under medical treatment, or people with insufficient nutrition due to low income. For instance, according to the World Health Organization's 2009 statistics, each year, diarrhea still kill 3.8 million children under five. Diarrhea comes forward as a common symptom of waterborne diseases which's pathogen can be bacterial such as Cholera and E.coli or viral as Hepatitis A. (Dziuban et al., 2006)

The treatment may take place in the storage tank, at the point-of-use, or combination of both. Additional filtering of pollutants with relatively big particles can be take place at every transition point. For instance, chemical disinfection, such as chlorination, is the most widely used method of treatment along with boiling which would kill most pathogens. In addition, pathogens also can be killed by exposing the filtered rainwater to sun for five hours, centered around midday. Ultraviolet radiation, although it does not bring the water to boiling temperature, it has similar effects to microorganisms as boiling. A traditional method is sand filtration, a combination of biological, physical and chemical processes, which is also an effective way to remove suspended solids. While fine particles in the water are filtered in sand, microorganisms on top of the sand filter that feed on bacteria, viruses and organic matters destroy disease-causing organisms in water (Brikké and Bredero, 2003) [Figure 26].

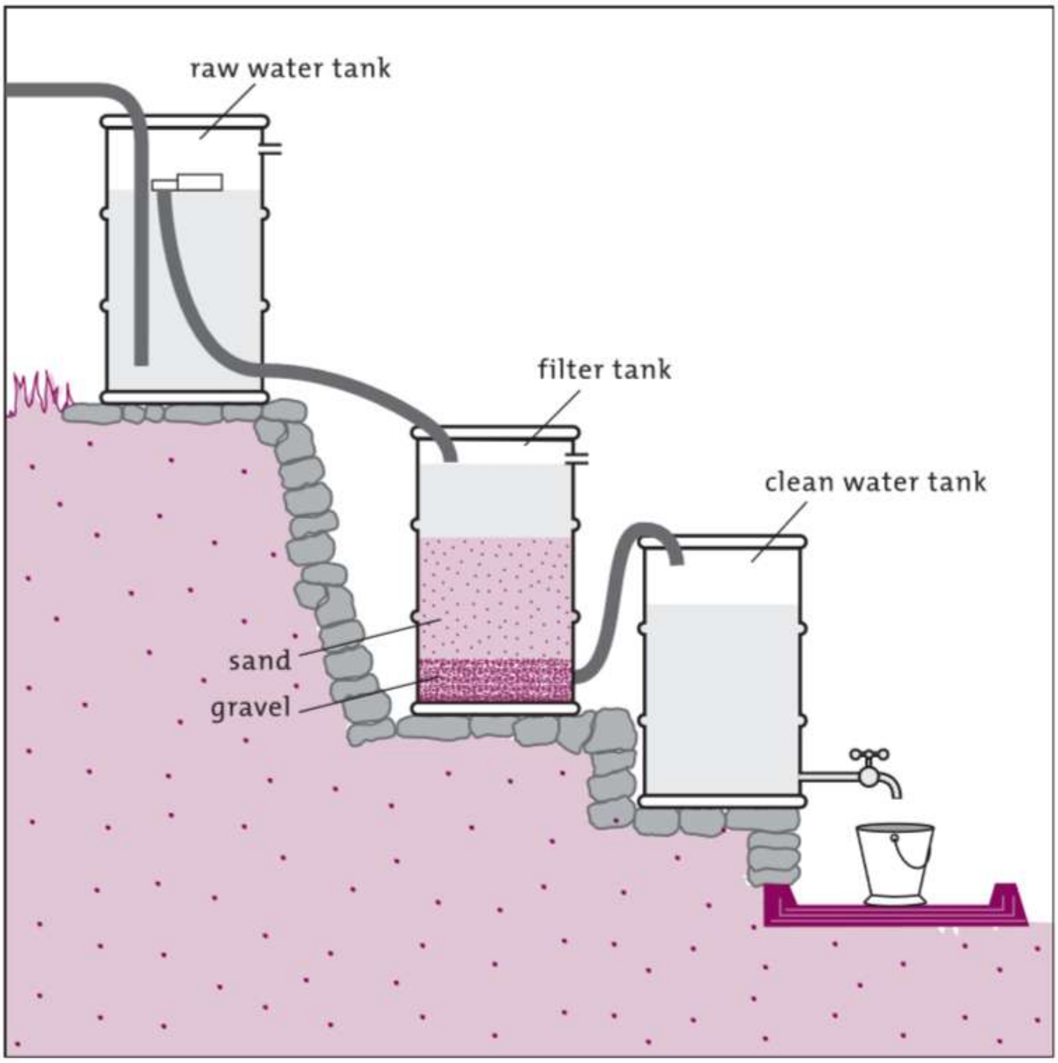

Figure 26 - Sketch of a Sand Filter *(Brikké and Bredero, 2003)*
"The raw water tank maintains a constant flow of water to the top of the filter tank, where it is purified by passing downwards through a 45–60-cm bed of washed sand and a 5-cm layer of fine gravel. The water flows through the sand at about 0.1 m/hour (1 m3 m-2 h-1). Water drains from the bottom layer of the filter tank via a perforated tube and is led to a clean water-storage tank." (Brikké and Bredero, 2003)

3.6. Distribution

The final phase of rainwater harvesting is distribution, in which the treated rainwater is transported usually by pumping from the storage units to taps at the point of use, such as sinks, showers, washing machines or dishwashers. That phase usually takes place inside the building and requires similar installation with a not-rainwater harvesting building. Pipes and pumps are the main components of the phase [Figure 27, Figure 28].

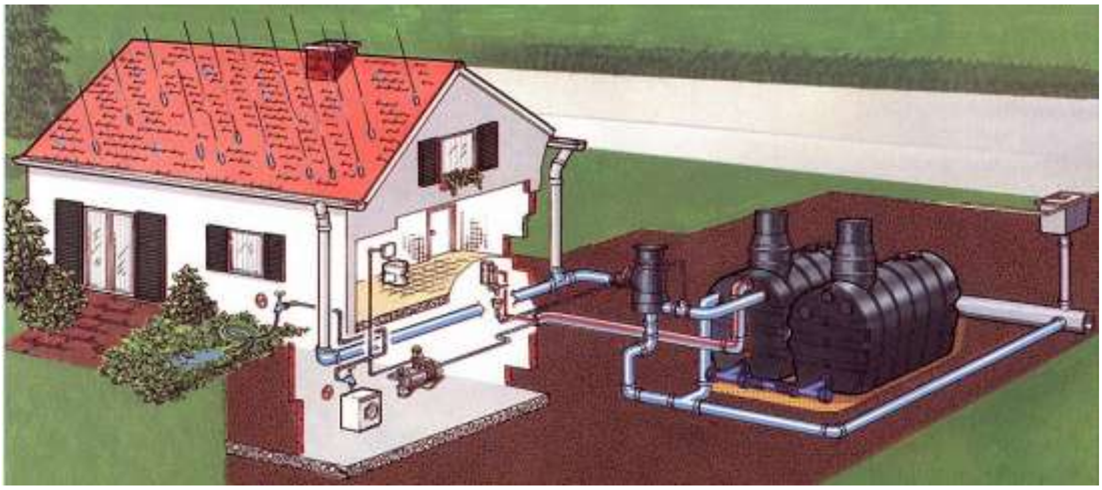

Figure 27 - Rainwater Harvesting House *(moderndream.com)*

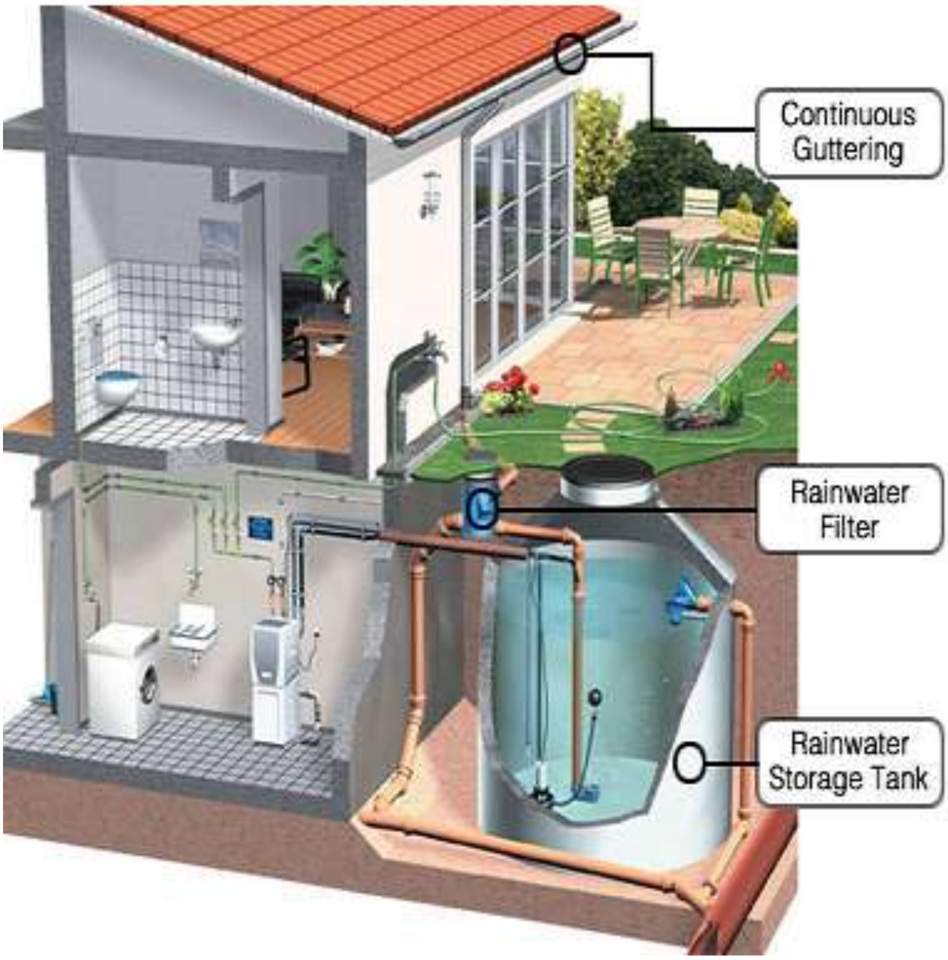

Figure 28 - Section of a Rainwater Harvesting House (prtheating.com)

The collected rainwater is pumped after treatment and distributed to taps where usage of rainwater is intended.

4. RAINWATER HARVESTING IN THE PAST

Water as an essential and therefore highly valuable liquid, has a strong effect on architecture and engineering, in buildings as well as in other construction types such as aqueducts, fountains, cisterns, dams, weirs and baths. Considering water's importance in public life, these examples of the traditional water structures show how diverse the implementation of water's effects can be.

Efficient management of freshwater resources has been of great importance through history. Availability of water resources affected layouts of cities and villages alike. Many city-state civilizations were located near water resources like rivers or sea, that facilitated the coexistence of large numbers of people and domestic animals in the same area. This chapter is about how societies solved fresh water problem by harvesting rain, according to their geographic and climatic conditions.

4.1. Mediterranean Islands

Most of the Aegean islands are characterized by poor water resources. Santorini in particular is a volcanic island without any underground water resources. The inhabitants have been harvesting rainwater and developing collection and storage systems since ancient times. The use of rainwater harvesting can be seen not only on individual households but also in public buildings like temples, or theatres. The water collected from various built surfaces like flat or vaulted roofs, terraces or verandas, was channeled into cisterns with various sizes [Figure 29 and Figure 30].

In fact, rainwater harvesting dates back to Minoan times (ca. 3200–1100 BC) and is still practiced today in, say, rural areas of the Crete island. (Antoniou et al., 2014: 681) For example in the Palace of Phaistos, clean surfaces as roofs and yards of the buildings were used for collecting rainwater and surface runoffs in cisterns to serve the daily tasks. To maintain purity, special care was given to cleanliness of the surfaces and sandy filters used to treat water before it flew into the cisterns in order to maintain the purity of water. (Sklivaniotis and Angelakis, 2006: 661). [Figure 31]

Figure 29 - Ruins of an ancient cistern in Santorini *(greece.com)*

Figure 30 – Cisterns of Santorini *(giannisargyros.blogspot.com, 2016)*

Figure 31 - Rainwater Harvesting in Palace of Phaistos *(Mays, 2012)*
An open yard to collect the runoff water is shown on the left, and a special cistern with a sandy filter is shown on the right.

4.2. Roman House

An 'impluvium' was an interior element of the typical Roman house or *'domus'*, which was a rectangular pool connected to a cistern, used for collecting rainwater [Figure 32]. The system worked together with an exterior element, 'compluvium', the inwards-sloped roof surfaces which were transferring rainwater towards the impluvium pool. This layout had first appeared in Italy during the second century BC and became a regular feature of Roman houses of that period. (Papaioannou, 2007)

Figure 32 - A Roman House *(Coulbois)*
Impluvium (a pool type), was the final collection point of rainwater, which works with another traditional Roman domus element, 'compluvium' (roof type).

4.3. Venice

Since Venice is an island city surround by sea, rainwater is the only freshwater resource. For that reason, the locals developed a public cistern system, shown in Figure 33, which collects rainwater from streets, conveys it through manholes, use sand filter as treatment, and store it in underground cisterns. Thus, water supply can be maintained across the neighborhoods of the populous, dense city [Figure 34].

Figure 33 - Rainwater Cisterns of Venice *(hometimes.com, 2016)*

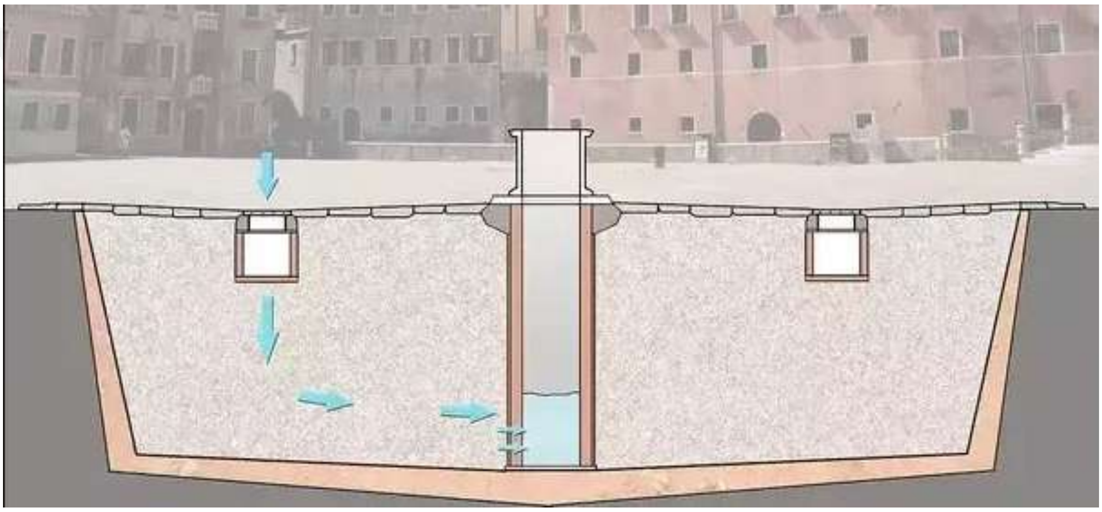

Figure 34 - Sketch of a Rainwater Cistern in Venice *(Davide, 2017)*

The water run-off is collected from manholes that can be periodically cleaned. It undergoes a filtration process through sand contained in cisterns made of non-permeable clay. Water is collected for consumption from a lid-covered well in the middle. Such cisterns are typically located in public areas as well as in the yards of private mansions, covering the needs of several thousand people.

4.4. Appraisal of Past Applications

Discovered ruins of rainwater cisterns date back to 3000 BC, proving that ancient societies settled far from surface water resources used rainwater harvesting to meet water demand. Whether the process is limited to only one domestic unit like in Roman Domus or collective as in Mediterranean Islands and Venice, rainwater in architectural practices had always an effect on the layout of settlements and the design of buildings.

5. SELECTED CONTEMPORARY CASES OF RAINWATER HARVESTING

After the previous examples of rainwater harvesting applications in the past, this chapter displays contemporary cases where rainwater has been used as an element in architectural design.

5.1. 2017 Serpentine Pavilion, London, UK

The Serpentine Gallery Pavilion is a temporary structure of 300 m^2 in Kensington Gardens that has to be a place of gathering, learning, debating and entertainment. It has been a prestigious annual commission for selected architects since 2000. In 2017, Francis Kéré was the 17th architect to design the pavilion that was displayed from June to November 2017.

Kéré's concept was to utilize a tree as a focal point creating a sense of community while connecting people with nature (Kéré Architecture) [Figure 35]. the architect's idea originated from a tree that serves as a central meeting point in the architect's home village, Gando in Burkina Faso. In a Westernized version, the Pavilion has an open-air courtyard at the center, where rainwater is funneled from the roof to create a waterfall effect, before being conveyed to the storage for further irrigation use. Moreover, the cover of the pavilion has shading function at daytime, becoming an illumination resource after dark [Figure 36]. The composition of the curved walls is split into four fragments that allow four unique access points to the [Figure 37].

"We wanted you to still be connected to nature as you enter the pavilion. you will still see the trees when you go inside and with the void, the courtyard, you will have the connection to the sky. In time it will rain – soon, I hope – and you will feel safe and protected by the structure, but you see a waterfall effect in the middle of the pavilion. My team and I wanted to save the water – it is a precious blue that we can celebrate here symbolically, but will be collected and used in the park." (Kéré Architecture)

Figure 35- Top View of Serpentine Pavilion of Kéré (Kéré Architecture)
At the center of the Pavilion, there is a large opening in the canopy, creating an immediate connection to the sky.

Figure 36 - Night View of Serpentine Pavilion of Kéré (Kéré Architecture)
In the evening, the canopy becomes a source of illumination; because it indicates glimpses of a movement, storytelling and therefore gathering.

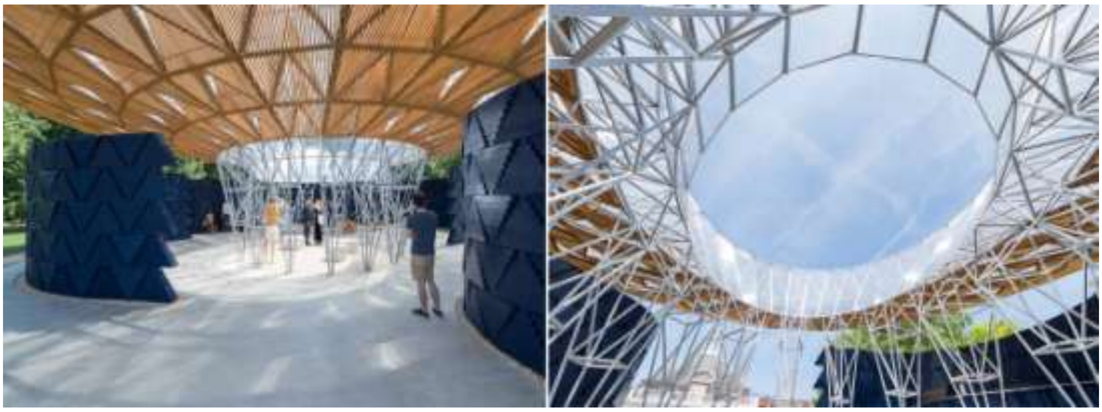

Figure 37 - Inside of Serpentine Pavilion of Kéré *(Kéré Architecture)*
Direct connection to sky, a waterfall effect and feeling protected by the shelter are the impressions that architect aimed to make users feel.

5.2. Olympic Golf Course, Rio de Janeiro, Brazil

Brazilian Rua Arquitetos designed this golf venue for the Rio 2016 Olympic Games, located in Barra da Tijuca, which also collects rainwater for irrigation by a tree-like canopy. As a result of Pedro Évora and Pedro Rivera's winning a 2012 competition, they extended their design philosophy about preventing excessive water consumption in humid climates (Rua Arquitetos: Évora + Rivera). To achieve this, they integrated a rainwater collection system by using canopy surfaces for water collection, while providing sun shading for both indoor and outdoor spaces. The collected rainwater is stored in underground tanks to use for the irrigation of the golf course as well as for visual and thermal comfort [Figure 38]

Figure 38 - Olympic Golf Course *(Rua Arquitetos: Évora + Rivera)*
Harvested water is used for irrigation of the golf course.

5.3. St. Elizabeths East Getaway Pavilion, Washington DC, USA

Designed by Davis Brody Bond Architects, Saint Elizabeths East Gateway Pavilion is a multi-purpose structure providing a venue for casual dining, a farmers' market and other community, cultural and arts events throughout the year. Sustainable systems such as rainwater harvesting decrease the dependency on the central water supply networks, and roof plantings fight the heat island effect (Davis Brody Bond Architects) [Figure 39].

Functional and flexible space that allows for easy circulation across the site is one of the main concerns of the design. The ground floor is filled with modular booths and temporary structures which allow for quick and efficient change of functions and activities; while the elevated open-air structure of the green roof offers new perspective and gorgeous views of the surroundings. The specially-shaped roof helps collecting rainwater for the surrounding greenery.

Figure 39 - St. Elizabeths East Gateway Pavilion
(Taylor, 2013; Davis Brody Bond Architects)

5.4. Sustainable Market Square, Casablanca, Morocco

The rainwater harvesting leaf pavilion was designed for the 2012 International Ideas Competition by Tom David Architecten and won the 1st prize. The program for the project included a market space for meat, fish and sea food, fruit and vegetables, flowers and spices, and social areas such as cafes and newspaper kiosk on 790㎡ in Casablanca (Tom David Architecten) [Figure 40].

The cover structure provides shading from the intense sunshine of the area and a shelter from other atmospheric conditions like rain. In addition to protection, the petal-shaped structure provides also a large water collection surface and channels it into underground tanks for future use such as cleaning and toilet flushing. In addition, the overlapping of the canopy-leaves allows air circulation and ensures the cascading drain of the rainwater [Figure 41].

"The curved concrete forms of the design are both a tribute to modern Casablanca architecture from the 50s as an endorsement of the beauty of the female form, as a nod to the dominant male culture on the street." (Tom David Architecten).

Figure 40 - Market Square Pavilion Design *(Tom David Architecten)*
"The shape of the canopy refers to nature, providing shade and shelter like a tree" (Tom David Architecten).

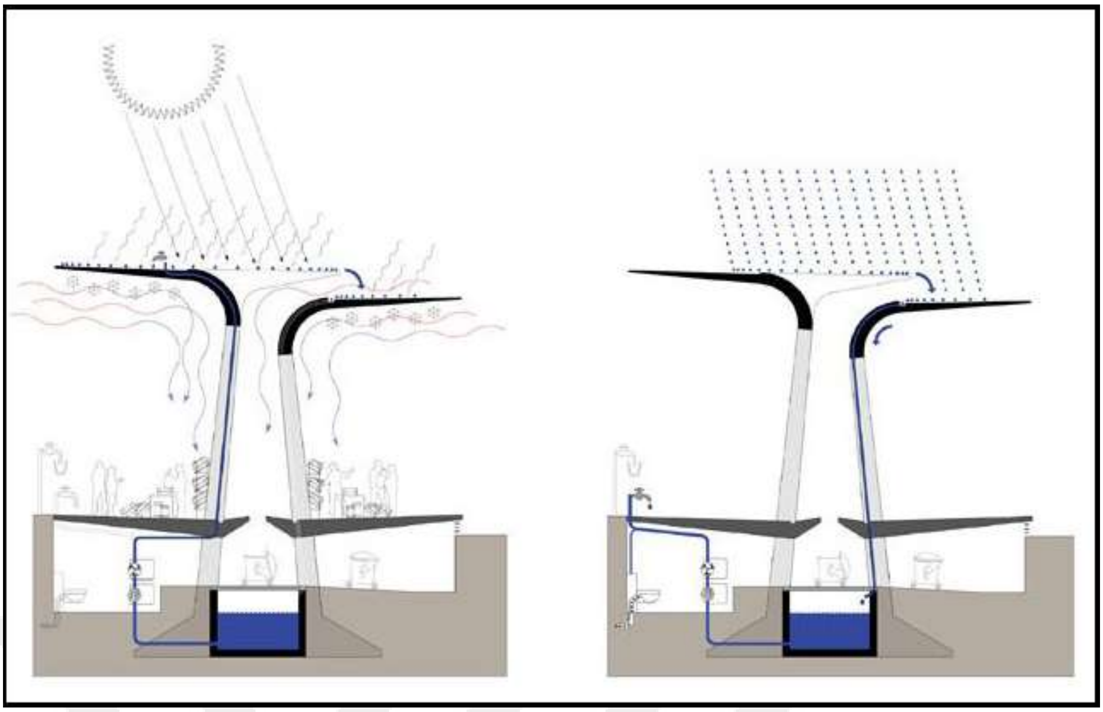

Figure 41- Sketches of Rainwater Harvesting System Operation
(Tom David Architecten)
The collected rainwater is channelled into underground storage tanks to be used for cleaning and toilet flushing.

5.5. Primary Healthcare Center, Dharmapuri, India

The Primary Healthcare Center was completed in 2011, in Dharmapuri of Southern India, a region with an extreme hot semi-arid climate (Lafarge Holcim Foundation, 2012). Responding to climate, the designers developed a V-shape envelope in order to prevent overheating of the inner roof by shadowing of the envelope structure. Also, panels on the envelope can be opened or closed according to the required climatic protection. Moreover, the envelope creates a semi-open gathering space where the patience can wait in line in thermal comfort [Figure 42].

This shading envelope roof, which has a prominent central gutter on the roof valley line, also collects rainwater and that water is stored in a rainwater pond. In addition, an irrigation pipe is used to wet the panels in order to lower the temperature by evaporative cooling of humidified air's transition to indoors as shown in Figure 43.

Figure 42 - Entrance of Dharmapuri Primary Healthcare Center
(Lafarge Holcim Foundation, 2012)
The double skin building concept provides climatic control over the clinic. Shadowing of the outer roof prevents overheating of the inner roof and the panels on the envelope can be opened or closed depending on the degree of climatic protection required for interior.

Figure 43 - Rainwater Pond of Dharmapuri Primary Healthcare Center
(Lafarge Holcim Foundation, 2012)
The outer roof with prominent central gutter on roof valley line, where rainwater collected and conveyed through collection pond gives a visual significance of rainwater harvesting in architectural form.

5.6. Dai-Ichi Yochiren Preschool, Kumomato, Japan

The Dai-Ichi Yochiren Preschool in Kumomato City, Japan was designed by Hibino Sekkei, with *"Open to outside for the adjustability"* as its motto, completed in 2015 (hibinosekkei.com). This is not exactly an example of rainwater harvesting but of utilizing rainwater as a practical architecture feature. The kids are not allowed to play outside when it rains until the ground is dry, but they can play in the puddles specifically designed to appear when it rains, as shown in Figure 44 and Figure 45.

Figure 44 - Front Facade of Dai Ichi Yochien Preschool *(hibinosekkei.com)*
The building was designed with plenty of glass walls and natural light for giving flexible and unconstrained qualities to the built space.

Figure 45 - Courtyard of Dai Ichi Yochien Preschool *(hibinosekkei.com)*
The central opening admits rain to the ground floor where the water is retained by the floor shape for children to enjoy playing with mud-free water.

Taku Hibino, a member architect of the firm, states that *"It is designed to accumulate rain water so that after a heavy downpour there is a gigantic, pool-like puddle just waiting for the kids to come out and play."* (hibinosekkei.com). On dry days, the empty puddle can function as a badminton or softball court and can even be converted to an ice-skating rink in winter, so kids will always be able to go outside. The design encourages children to play and connected with nature by its rainwater harvesting courtyard.

5.7. Siemens Gebze Factory, Turkey

Siemens, the European technology holding company, opened its office, production and technical buildings of 35.000 m^2 gross floor area in Gebze Industrial Zone of Kocaeli, in 2009 (Yaman, 2009) [Figure 46]. Environmental considerations are central in the design philosophy of the facility that designed by Seyaş Sey Architects as the winner of the design competition held in 2007 (arkiv.com, 2009). It was designed for receiving LEED Gold Certificate and achieved its purpose. Accessibility by public transport and the resulting low carbon dioxide emission and reduced fossil-fuel use are results of proper site selection. Furthermore, the wide use of greenery reduces heat island effect and enriches the use of green space. Both in the building and in green areas, a 50% water saving is achieved by rainwater harvesting and the selection of water-efficient equipment. Thermal comfort, air quality, 30% energy-saving, 35% recycled and 40% local material use are other features of the facility. (Yaman, 2009)

In addition to the building rooftops, the ground level of the site is used for rainwater collection to increase collection surface and therefore rainwater harvesting efficiency. The rainwater collection system is divided into two sections, as roof collection and hardscape collection. In order to retain and improve the water quality, rainwater on hardscape is channeled to soil instead of rain channels and filtered there as shown in Figure 47. Water from rooftop rainwater harvesting and soil filtration was used for landscape irrigation, resulting to 50% savings in water (Yaman, 2009).

Figure 46 - Siemens Gebze Factory, Kocaeli *(siemens.com; Altın Oran Maket)*
The photos show a scale model of the site (top), and the entrance of the work space below.

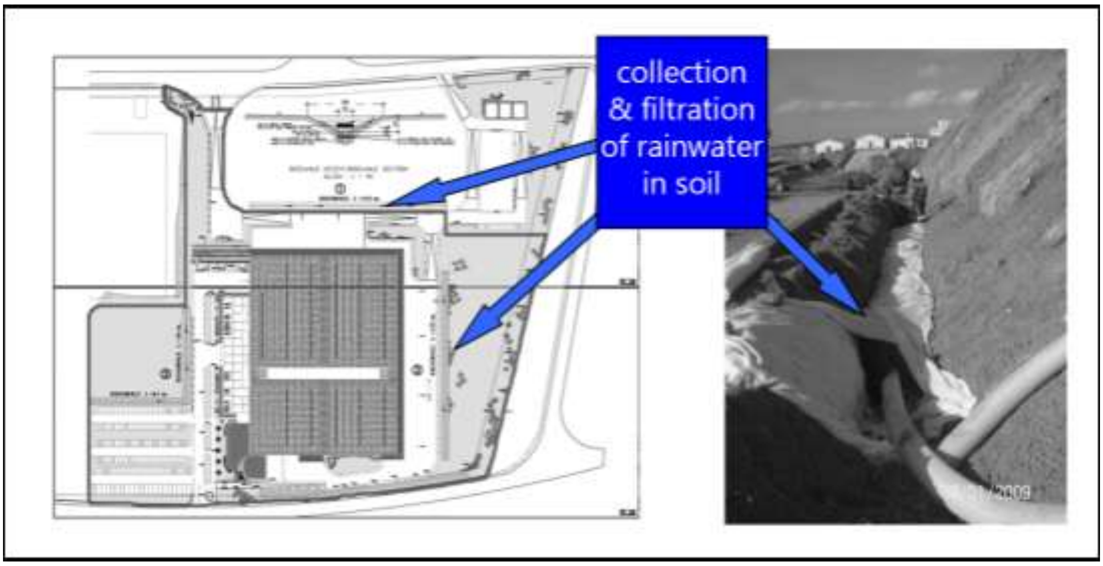

Figure 47 - Rain Channels on Site Plan and Filtration in Place *(Yaman, 2009)*
The water collected from the paved ground surface is channeled over soil.

5.8. Appraisal of the Cases

The 7 cases presented earlier are from different countries and purposes; 3 of them are pavilions: 2017 Serpentine Pavilion in London, St. Elizabeths East Getaway Pavilion in Washington DC, and Sustainable Market Square in Casablanca.

In Serpentine Pavilion, rainwater is given a great importance but it is not used for any purposes other than spatial sensations. It is collected in a manner similar to Dai Ichi Yochien Preschool, where rainwater is accumulated effortlessly in a shallow pond just to provide a play opportunity for children and celebrate the nature. Both cases have strong emphasis on rainwater collection to achieve a functional objective, something that is a highly desired feature for the author in the quest of architectural design related to rainwater harvesting.

In St. Elizabeths East Getaway Pavilion, it is accurate to say rainwater is used for meeting auxiliary functions such as watering plants. In Sustainable Market Square, the roof structure was designed mainly for shading and collecting rainwater, with the usage and distribution of it organized independently. Considering that London and Washington DC receive more rainfall than Casablanca, the level of water stress in Morocco may promote rainwater usage more than in the other examples. According to the author, water self-sufficiency for pavilions and other public installations in the urban context is important in terms of environmental and economical sustainability; therefore any attempt regarding rainwater collection would be beneficial for the life span of the projects.

In Rio Olympic Golf Course, it is observed that the storage and distribution phases of the rainwater harvesting system are rather more developed than in the previous examples due to broadness of the golf fields and the high water demand for irrigation. More than just for irrigation, rainwater in Siemens Gebze Factory is intensively used as an alternative water resource also for human consumption and industrial purposes, which can be a good indication of the method's effectiveness.

Lastly in Dharmapuri Primary Healthcare Center, it is possible to see two atmospheric water harvesting methods combined in a distinctive visual manner. The design performs as a practically, aesthetically, and environmentally adequate rainwater harvesting system, which could be an example of what the author describes in the following chapters.

6. DISCUSSION

Considering the importance of water in architecture as a form-determining element and the continuation of rainwater harvesting methods through history as described in Chapter 4 - Rainwater Harvesting in the Past, this research started with the assumption that rainwater harvesting has a particular effect on form, and it even can change the initial morphology of a structure if rainwater harvesting is implemented after its construction. However, the research revealed not too many examples of such a strong effect.

For instance, in Santorini, an island where rainwater harvesting had been the primary water source for centuries, the characteristic symmetric vaulted roof of ordinary houses is occasionally transformed into an asymmetrical one in order to avoid water loss from its 'blind' side as shown in Figure 48 and Figure 49. Such modification of form is logical in order to maximize rainwater collection due to the permanent water stress. If water collection was not so important, then the water loss from the blind-side runoff could be disregarded and any form alteration would be for reasons other than water. In this example, the broken uniformity of Santorini vaults indicates water's priority over formal integrity.

Figure 48 - Comparison of Normal and Altered Roof Vaults in Santorini
(Dempsey, 2012; Photo courtesy of Thanos Stasinopoulos, 2003)
A typical symmetric vaulted roof as a rainwater collection surface is in the left and an altered roof as a rainwater collection surface is in right.

Figure 49 - Back View of the Altered Roof from Santorini
(Photo courtesy of Thanos Stasinopoulos, 2003)
The asymmetry of roofs can be seen from different points of view.

Considering the existing and upcoming water-related issues that affects the lives of billions, as well as today's environment-friendly, sustainable design tendencies, this research had started assuming that rainwater harvesting has become a widely used application in contemporary architecture. Through the research process, the author came to realize that the environment-conscious considerations mostly focus on energy-related topics and how a reduced consumption of resources can be provided through architectural design. The development of material technologies has also helped to bring principles of recycle and reuse in construction. But unlike other resources, the author has found that most water-related innovations in architecture are only about reducing the demand from the water networks rather than seeking other alternatives embedded in building and urban design.

At this point, the use of rainwater along with gray water re-use come forward as alternative answers to water stress. On the other hand, it is observed that rainwater harvesting is not preferred as primary water resource if there is another way of water supply. Investigating the reasons behind this, one can say that most of the buildings are connected to a central distribution network which is probably fed from a ground or surface water source, relieving occupants from having to collect water on their own as in the past. Furthermore, the rareness of rainwater harvesting in dense urban areas is understandable; when a building rises, the collection area and the amount of water that can possibly be harvested remains the same but demand increases with each floor added. Therefore, buildings still need to be connected to a remote water reservoir and the origin of water has no importance for their design. However, there are still cases where rainwater harvesting can decrease the water requirements from external sources and lessen the growing water stress.

Another issue that the author wants to draw attention to is rainwater harvesting's *visibility*. Water self-sufficiency is not a leading idea in common design and it is a feature that cannot easily be reflected on the appearance of buildings. It is possible to understand if a building uses solar energy from its solar panels; if it is sensitive about oxygen level of dense cities or if it is biophilic from its vertical gardens and green roofs. But it is hard to determine a building's water-related qualities by its visual attributes.

According to the author, architecture is the art of representing abstract concepts in a material space. A building is the ideas we physically live in. Every decision an architect makes in the design process, intentionally or unintentionally, stands for a position. Considering architecture's permanence and scale, it has been a leading and guiding characteristic of society. Whether it be a style as deconstructivism or a movement like minimalism, the way architects arrange people's daily life or the identity they give to their built environment has always the potential to grow into something greater than just physical necessities.

Therefore, if we want to design a building that directly aims to collect water or addresses water-sensitivity, some conceptions of architectural elements must be altered. Below, the author investigates the possible changes in rainwater harvesting's visibility and how it can become a form-determining factor for architecture based on the case studies in Chapter 5, Selected Contemporary Cases of Rainwater Harvesting, and other personal observations.

In order to appraise systematically the form-related influences of rainwater harvesting or the lack of them, the research was focused on the potential effects of each phase - collection, conveyance, storage, treatment and distribution as introduced in Chapter 3.

6.1. Collection

Among the recent examples of rainwater harvesting, the concave roof of BM Design Studios' inbuilt primary school design [Figure 50] is found to exemplify what is meant by saying *"changes in conceptions of architectural elements"* previously. The school's location (Jiroft, Iran) has an arid climate, where precipitation is "less than one-third of that of the world average, and evaporation is more than three times higher than the world average" (BMDESIGN Studio, 2017).

Figure 50 - Primary School Design with Concave Roofs *(BMDESIGN Studio, 2017)* *BMDESIGN's 2017 proposal is come into prominence with its unusual roof design and the importance given to the rainwater harvesting.*

If the aim is efficiency, then a simple solution can be sufficient. In rain-collecting elements, the decisive factor on the amount of collection is not their total 3D surface but their horizontal projection. Therefore, the unusual roof cover of this example cannot collect more water than the flat roof underneath, unless it extends beyond the building’s footprint. Still, as the water scarcity may even result to the evacuation of the particular area in future, the large bowls above the roofs expressly stand for the water's importance to the daily life and the livability of the settlement.

That observation made the author to question the common understanding of "roof". Thinking the traditional pitched roofs, their convex shape is meant to quickly remove rain and snow load. This is also may be practical for structural reasons, enabling the use of triangular trusses or curved arches, with their peak at the middle of the span.

On the other hand, the author assumes that once you decide to collect rain water and specify your design's starting point as this, the notion of collecting may lead you to a concave shape. [Figure 51] Even with our primitive instincts, we put together out hands in the shape of a bowl when we want to contain something fluid. As said, the concave shape indicates the notion of "collection" and that's why the concave roofs are quite suitable for rainwater harvesting. A few examples on converting existing roofs of that form into rainwater collectors are presented next.

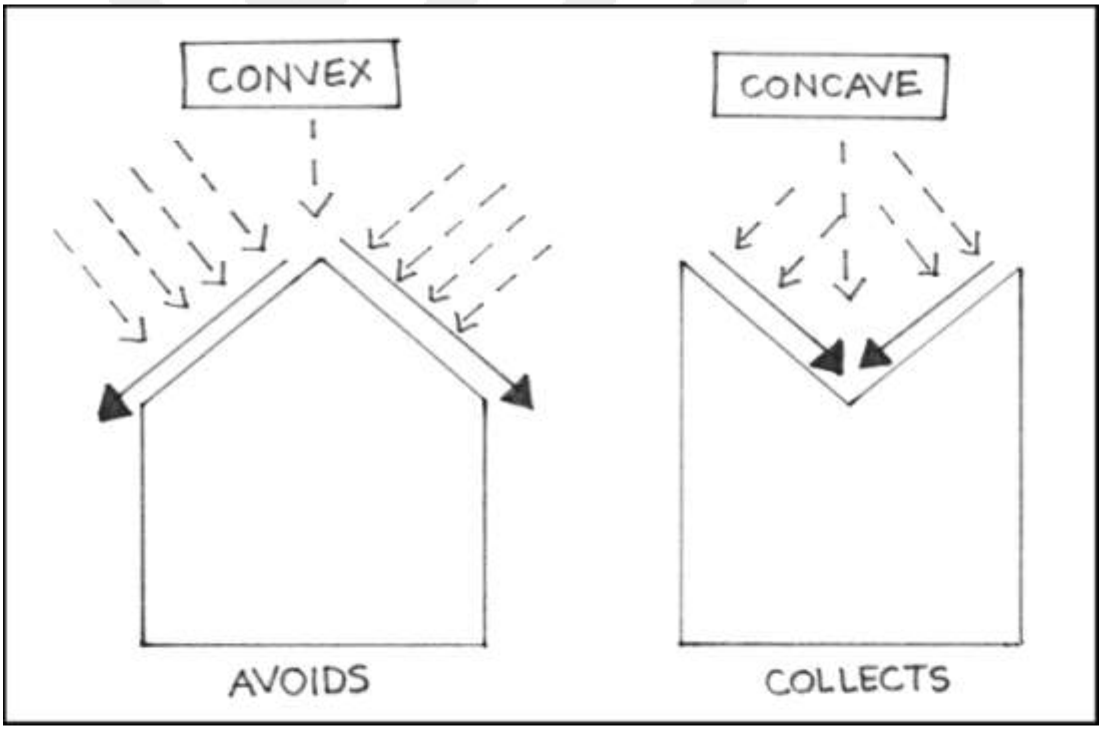

Figure 51 - Comparison of Convex and Concave Roofs *(sketch by author)*
According to author, the convex roof on the left is about avoiding the rainwater, while the concave roof is associated with collecting it.

The concave roof idea refers to the type called "butterfly", which may become a trademark of rainwater harvesting structures. An early example of such roof can be seen in an unbuilt vacation house, Maison Errázuriz, designed by Le Corbusier for the arts patron Eugenia Errázuriz in 1930, Chile [Figure 52].

Figure 52 – 1/50 Scale Model of Maison Errázuriz by Le Corbusier *(doizymaquettiste.com, 2013)*

Later, in 1957, William Krisel built similar houses in South California, USA as shown in Figure 53 (Epstein-Mervis, 2018). Briefly, semi-open spaces are created under both sides of the roof valley line, one for an entrance and the other for parking. The conveyance of the collected rainwater can be embedded in the vertical volume under the roof valley line; a storage tank can be blended in that volume or simply under the outdoor areas. Originating from such examples, the author suggests that any existing or future building with a butterfly roof can be easily converted into a rainwater harvester without any significant visual transformation or addition.

Another example comes from 1968, when Chinese-American architect I. M. Pei added a sculptural concave roof in the shape of a wing that allows additional light into the exiting gallery of the Des Moines Art Center in Iowa (desmoinesartcenter.org). The design distinguishes the exhibition space from other compartments by its inward-inclined shelter as shown in Figure 54. According to this author, besides the additional light, the particular shape also draws attention to the center of the plan, which could be a desirable area for exhibited objects. Furthermore, as in the Southern California houses above, the roof valley line of the two wings would be a physically advantageous gutter where the rainwater meets conveyance pipes if harvesting rainwater was intended.

Figure 53 - Butterfly Roofs Throughout Southern California *(Daniels, 2015)*
The reason that these roofs are referred to as 'butterfly' is the inward-inclined roof evoking an image of butterfly wings.

Figure 54 - A Gallery in the Des Moines Art Center *(Campbell, 2016)*
I.M. Pei's 1968 design is come into prominence with its inward-inclined roof.

As another example is Gabion House, designed by the Mumbai-based architectural firm Spasm Design Architects and completed in 2017, in Lonavala, India. The house draws attention with its Y-shaped roof as shown in Figure 55. Although the shape was intentionally designed to collect rainwater, the collected rainwater is not stored or used for any purposes but just guided far from the main verandah. *"The innovation of the musket spouts and the full-length Y-rain collector makes sure that the water shed by the roof is tamed and shot out away from the verandah. This is a high precipitation area"* (SPASM DESIGN) [Figure 56].

Figure 55 - Side View of the Y-Shaped Roof *(spasmindia.com)*

Figure 56- A Sketch of Gabion House *(spasmindia.com)*
A Gabion wall on the upper side of the slope is the protective back of the building.

In addition to horizontal surfaces for rainwater collection, there might be a way of using also vertical surfaces for the collection. For instance, in the Justice Palace in Brasilia, architect Oscar Niemeyer -who also planned the new Brazilian capital and designed several of its civic buildings in the late 1950s- used half-cylinder protrusions on the facade for creating local waterfalls. [Figure 57] Although they have not been designed to collect rainwater, those protrusions on the facade offer the possibility for collecting rainwater, becoming in effect extensions of the roof. The rainwater can be collected by the concave protrusions, then flow into the pool and re-used in a loop to sustain the artificial waterfalls for the building's ornamental water usage.

Figure 57 - Waterfall on a Facade of Justice Palace in Brasilia *(expedia.com)*
The building is designed by Oscar Niemeyer in 1962 as headquarter to Ministry of Justice and opened in 1972. The square volume sitting on a reflective pool, reinforced concrete structure, arches and pillars on facades are the main characteristics of the building. (Ferreira and Maximo, 2013)

Since the collection surface is the major structure-depended parameter of the rainwater harvesting efficiency, rainwater-collecting architectural elements are the first to undergo an alteration in order to emphasize the method's presence and importance. Moreover, the term "collection" itself represents the method's most vital step and therefore this phase is more prominent than the others.

During the present research, the author encountered that terms "collection" and "harvesting" are often thought to be similar such as "catchment". However, it is noteworthy that "harvesting" is a periodic action while "collection" is not necessarily repetitious. In this case, the collection is just a phase of a rainwater harvesting.

Considering the associative aspects of architecture and how forms can make a connotation both in collective memory and individual perceptions, the collection phase and the related architecture elements can become a distinct sign of rainwater harvesting buildings, according to the author. Consequently, the ways to increase the collection surface and also to indicate the notion of collection are major topics that have drawn the attention of the author.

6.2. Conveyance

Even before starting this research, the house designed by Cafer Bozkurt and Mustafa Kavadarlı in 1974, shown in Figure 58, was attracting author's mind. Located in Ilıca, a neighborhood of Çeşme near İzmir, has an inward-inclined roof that is uncommon in the area. But beyond the roof's unusual shape, it was actually the emphasis on conveyance that the author appreciated most. İn an imaginary refurbishing project, the column at the lowest point of the roof could support conveyance pipes, becoming the focus point of the design and center of the house, with its position giving a sense of an ending point to the roof composition. Whether the design was aimed to collect or remove the water on the roof surface, this one-point configuration makes the author to believe that this type of roof and column layout can be a symbol of rainwater harvesting buildings.

Conveyance as the second stage of rainwater harvesting, can be fairly visible and therefore more distinct as an architectural element, especially when the distance between collection and storage is long. Such an example is Aldo Leopold Center in Baraboo, Wisconsin, US, designed in 2007 by Kubala Washatko Architects, where a gradually descending wall is used for conveyance (The Aldo Leopold Foundation). Hereby, the conveyance phase becomes a landscape element and a visual sign of rainwater harvesting [Figure 59].

Figure 58 - Ilıca House by Bozkurt & Kavadarlı *(photo by the author)*
Top, the front view of the house; bottom, the corner view.

Figure 59 - Aldo Leopold Center *(Boldt)*
In the Kubala Washatko Architects' design for Aldo Leopold Center, conveyance gutters are placed on top of descending separating wall, which also serves as a landscape element.

Although conveyance phase is not a criterion as decisive as collection in terms of system efficiency, it has a potential of becoming a significant sign of the rainwater harvesting in applications. It is possible to develop techniques in more visually evident ways and turn its accessories such as pipes into design elements, which may indicate greater concepts like unity and importance of acting together as a society in water-related issues [Figure 60].

Alternatively, the conveyance pipes can be used for emphasizing collective operation of the system. Especially in dense settlements, collecting rainwater individually may not be sufficient to meet water demand due to limited size of collecting surfaces. However, collected water can be transferred into a common water tank by conveyance pipes between blocks under the ground level as shown schematically in Figure 61.

Figure 60 - Stephen Glassman's Thornton Creek *(publicartarchive.org, 2010)*
The free-standing sculpture in the garden of Fire Station 39 in Seattle, Washington, is visually and functionally integrated with the rainwater delivery system, moving runoff from the building's roof to an underground water tank.

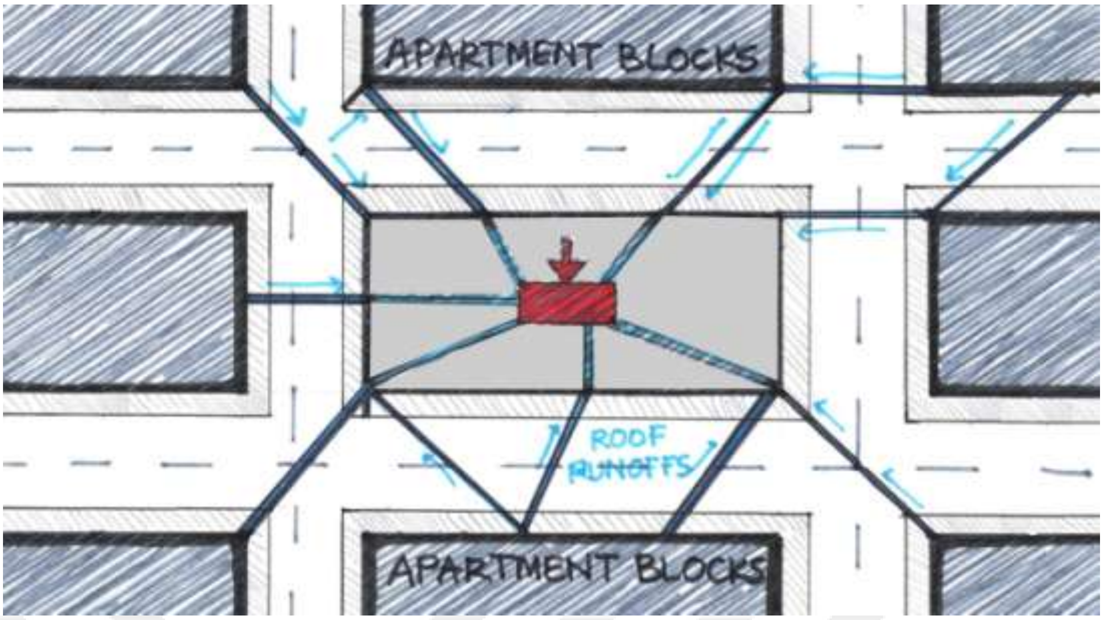

Figure 61 - A Site Plan Sketch of Apartment Blocks (sketch by author)
Buildings are connected to a common water reservoir though conveyance pipes and harvest rainwater collectively.

6.3. Storage

Based on the previous examples, it would be logical to say that rainwater harvesting affects building layouts more than form, therefore it is hard to determine the existence of a water storage unit from outside of a building. Unlike collection and conveyance phases, the storage units are often intentionally hidden. For instance, the Basilica Cistern in İstanbul, which was built by Byzantine Emperor Justinian I in AD 540, has an ordinary entrance above ground that has nothing to do with the remarkable large cistern structure underground. [Figure 62] Since Turkish people do not regard slack water as freshwater, the cistern was not used after AD 1450s although it was supplying water for the entire city in Byzantine times. When the Dutch traveler Petrus Gyllius, who introduced the cistern to the Western world, wandered around Hagia Sophia; he could not locate the cistern in first place because of the extremely common entrance. (Hut, 2010: 116-118).

Figure 62 - The Basilica Cistern, İstanbul *(Novikov, 2013; İpek, 2014)*
Above, the entrance of the cistern; below, the cistern interior.

In spite of its usually ‘discreet’ presence, the storage facilities can offer a practical option for underlining rainwater harvesting's presence in the buildings. Focusing on the building’s layout, rainwater harvesting can affect form in less evident ways. For instance, the terrace of the chapel in Figure 63 is used for increasing the water collecting surface in addition to the vaulted roof, with the cistern located right under it.

As indicated by the chapel example of Figure 63, the water storage can be integrated with landscaping as terraces where rainwater is collected and immediately stored. Considering that terrace surfaces can be larger than roof surfaces, collecting water from ground surfaces can also increase the efficiency of rainwater harvesting system by expanding rainwater receivers beyond the roof perimeter with the help of elements like terraces, which can offer visual hints about the existence of a rainwater harvesting system in a discreet manner.

Figure 63 - A Chapel in Santorini
(Photo courtesy of Thanos Stasinopoulos, 2003)
A cistern stores rainwater collected from the chapel's roof and the terrace, which is used for religious festivities. Water is taken from the small shaft on the left.

Alternatively, if a storage unit is built above ground, it is possible to highlight the storage phase of rainwater harvesting applications like in the Water Tower by Paul Bretz Architects [Figure 64]. The surface and groundwater storing structure located in the small town of Dippech in Luxembourg which does not have its own water supply plant, it was designed in 2013 and constructed between 2015–2017 (paulbretz.com). Because of the increasing population, the existing water storage capacity was no longer sufficient, thus the local authorities hired the firm to design a water tank that can supply potable water to the community. It consists of three massive rectangular boxes designed specifically for their function, making the building the town's new landmark. (paulbretz.com)

6.4. Treatment

Since the treatment phase happens in the storage unit and is about physical and chemical processing, the author has no suggestions about how this phase can contribute to the architectural expression of rainwater harvesting.

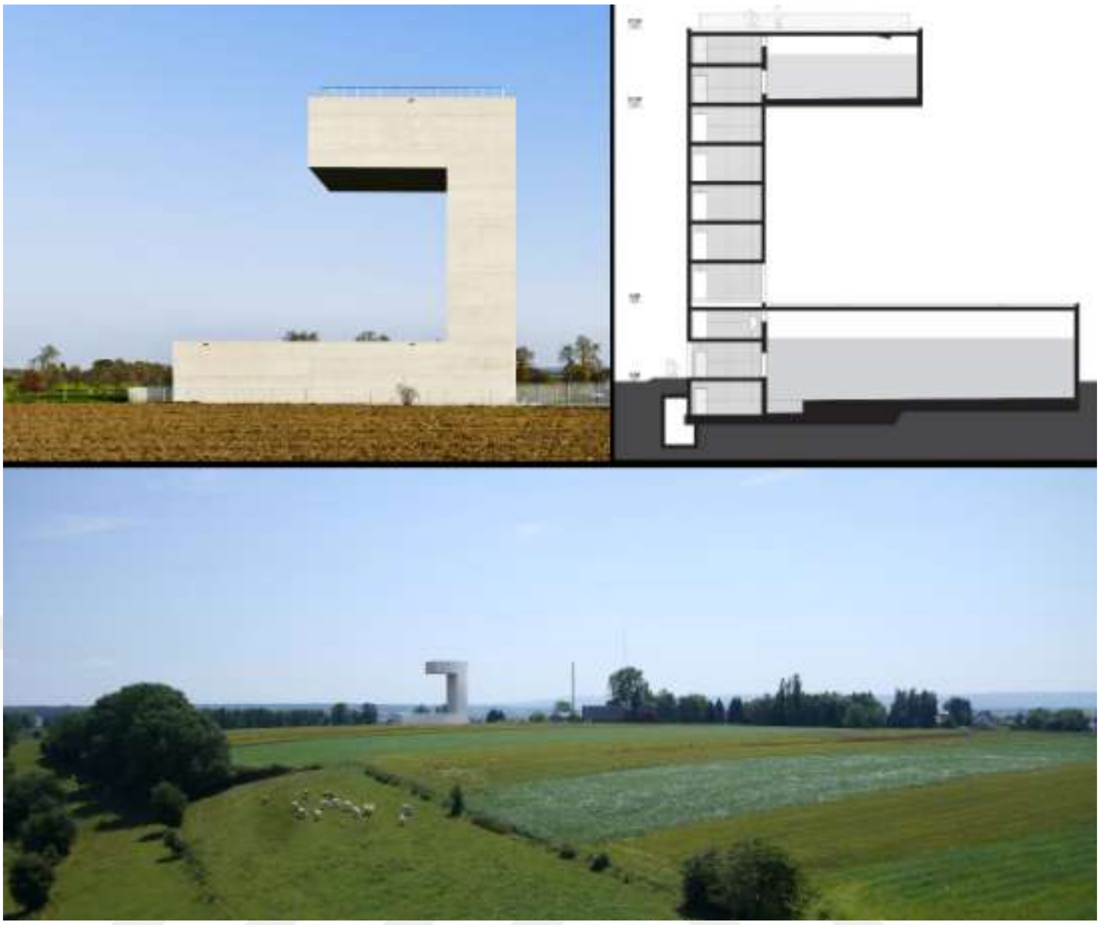

Figure 64- Water Tower, Dippech *(paulbretz.com)*
Top row: A photograph of the side view of the water tower (left) and a section of 20m tall water tank with an aesthetic shape (right). The structure express itself with its design and volume, with its height being visible from afar above the nearby houses.

6.5. Distribution

The distribution phase is about the various water uses inside the building, with the occupants usually unaware of how the water distribution system operates. Unless a building's installations are exposed like in Piano & Rogers' Centre Pompidou in Paris [Figure 65], it is not likely to detect all distribution systems. If it is designed in an 'exhibitionist' way, the collection, the conveyance and the distribution can be observed at the same time, and even the storage can be on display under an unbreakable glass, with solar disinfection as a treatment technique. [Figure 66] A similar effect can be created indoors too, by making the infrastructure visible in the interior space. [Figure 67]

Figure 65 - Centre Pompidou *(arrivalguides.com, 2017)*
This 1977 building by Piano and Rogers broke the habit of hiding all the mechanical systems of a building.

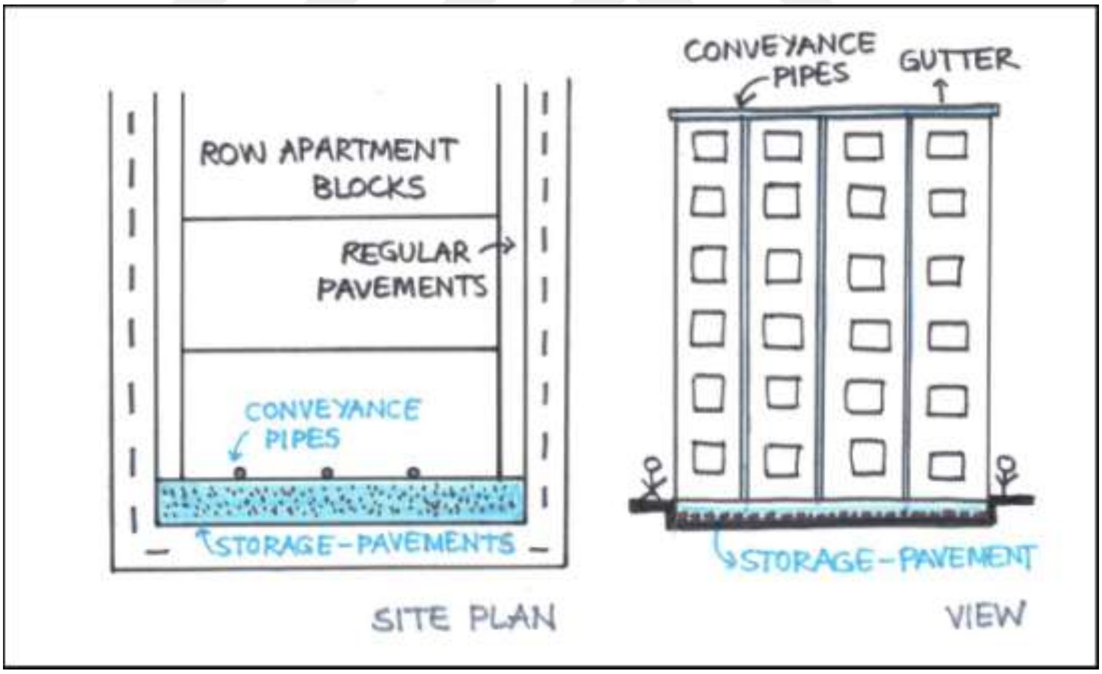

Figure 66 - Sketches of a Rainwater Harvesting Building *(sketch by author)*
When installations are exposed, it is possible to observe the collection and conveyance phases through their components. The storage unit can be an open pond as part of the landscaping, or covered with unbreakable glass as a pavement, emphasizing the existence of a rainwater harvesting system. In order to obscure a disturbing view due to organic residues in time, the bottom of the storage can be covered with natural materials such as pebbles.

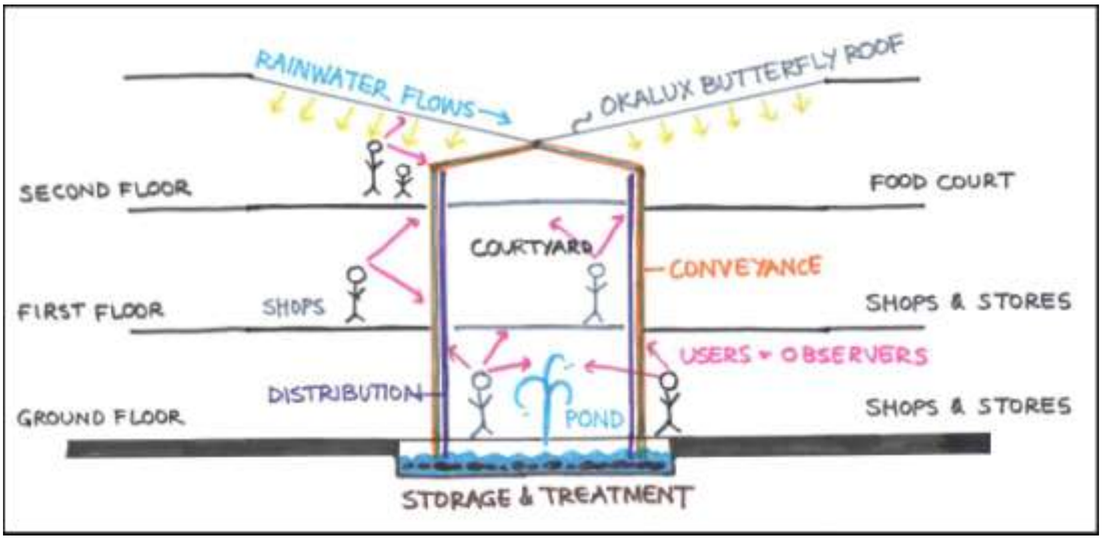

Figure 67 - A Rainwater Harvesting Shopping Mall *(sketch by author)*
This sketch idea shows a butterfly roof over a mall. It is covered by Okalux, a translucent glass-sandwich material that can provide daylight and thermal insulation, concealing the dirt marks formed by rainwater flowing on the upper surface. The downpipes are visible in the interior, exposing the collection and conveyance of harvested rainwater. The rainwater can be stored and used in a decorative pond. Thus, the rainwater harvesting system can be observed in the interiors in various ways.

7. CONCLUSION

Today, the world's freshwater resources, previously considered as free and abundant but now becoming scarce, are not sufficient to meet the demands of a growing number of humans. Water is a renewable source within its continuous cycle, yet cities are facing or about to face water stress because of emerging issues like growing population, rapid urbanization, accelerating industrial activities, or wasteful uses of water. Therefore, the efficient use of freshwater resources, as well as the implementation of alternative water-related solutions and technologies, are vital in achieving environmental sustainability.

In this context, rainwater harvesting is a considerable, environmentally responsible alternative freshwater resource, which can be used to promote self-sufficiency, to reduce water demand, and especially to tackle the water scarcity in developing countries. It reduces stress on underground aquifers and domestic water consumption in buildings. The water quality is another advantageous point of the method. Although the harvested water can be polluted with bacteria or other pollutants during the collection and conveyance phases, it is possible to treat it with various techniques. Due to its low hardness level, rainwater reduces the use of soaps and detergents, eliminates the need for a water softener and increases durability of plumbing fixtures.

The main objective of rainwater harvesting is collecting water before it meets the ground and its pollutants. It is one of the oldest water harvesting methods and can be applied with simple techniques and materials. On the other hand, depending on various parameters such as capacity, purpose and location, the additional construction costs can be a handicap for applying rainwater harvesting systems, even if the cost will be offset in following years by water savings -unless of course there is no less costly alternative.

Although rainwater harvesting methods are widespread and traditionally operated, it is not commonly applied in contemporary architectural practices according to author's research. It is a fact that rainwater use can reduce the water demand and hence reduce the water stress. But since today's buildings are mostly located near a central distribution network, the attraction to rainwater harvesting methods is low, especially given the absence of long-term public strategies. At this point, tax allowance or financial state support can encourage the use of rainwater and help its dissemination, following the strategies applied for alternative energy sources. Certain exemplarily laws and regulations regarding the use of rain water in different countries are listed in Table 5.

Table 5 - Laws, Regulations and Government Promotions Regarding the Use of Rainwater *(Based on the data by Şahin and Manioğlu, 2011)*

COUNTRY	LAWS, REGULATIONS & GOVERNMENT PROMOTIONS
ENGLAND	Due to expensive water bills, over 1.5 million rainwater harvesting systems have been built in houses and workplaces. The discounts can be up to €1200 by the location of the site.
GERMANY	"BS 8515: 2009 Rainwater Harvesting Systems Application Standards" is a regulation about the addition of rainwater to the buildings' water use in terms of design, installation and maintenance.
INDIA	The use of rainwater has become compulsory for: - In New Delhi, all new buildings with more than 100m^2 roof surface, - In Gujarat, all official buildings, - In Indore, all new buildings with more than 250 m^2 construction site, - In Hyderabad, all new buildings with more than 300m^2 floor area, - In Chennai all new buildings with more than 3 storey, - In Mumbai, all new buildings with more than 1000 m^2 parcel area.
JAPAN	For buildings bigger than 30.000 m^2, rainwater harvesting and gray-water reuse systems have been made legally compulsory by the Japanese Ministry of Public Works
TURKEY	Since 2014, the Turkish Ministry of Environment and Urbanization provides interest-free loan to every building which fulfills all the "green building" requirements including rainwater harvesting under the scope of urban transformation projects. (Anadolu Ajansı, 2014)

Even if the authorities introduce laws and policies supporting the installation of rainwater harvesting systems, still their wide implementation requires the acceptance, awareness and willingness of the people. How users engage with such systems can be an additional issue of rainwater harvesting.

"Even though rainwater harvesting is a helpful technique for areas with scarce water resources, there are some problems hindering the integration and implementation. Sometimes there is a lack of acceptance, motivation and involvement among users. People's knowledge with regard to rainwater harvesting and use is inadequate and outdated giving away the benefits of rainwater resources." (Helmreich and Horn, 2009).

For instance, Barthwal et al. (2013) investigated the attitudes towards rooftop rainwater harvesting systems and their acceptance among the people of Dehradun, India, where average annual rainfall is 2051 mm. The population of Dehradun increased by 52% between 1991 and 2001, and the area density increased from 415 persons per sq. km in 2001 to 550 persons per sq. km in 2011. According to the survey, 97% of the respondents agreed that rainwater could be an alternative resource for water supply and 86% said harvested rainwater would be safe for non-potable consumption. (Barthwal et al., 2013) Despite an awareness of water scarcity-related issues and a willingness to adopt rainwater harvesting systems, inconveniences in implementation of these systems may be a reason of the less preference. Therefore, studies and technologies regarding rainwater harvesting must be developed.

Besides the issues mentioned, in the light of the research of traditional applications and contemporary cases, the author realized that it is hard to determine a building's water-related merits by its form. Therefore, in order to increase rainwater harvesting's prominence in architectural form, a number of possible changes in rainwater harvesting's visibility and how it can become a form-determining factor for architecture were discussed. For instance, according to author, butterfly or other concave roofs can be a mark of rainwater collection, along with protruding elements on vertical facades to increase the collection surface. Furthermore, conveyance accessories like pipes or ducts can be turned into design elements, used for creating spaces that emphasize rainwater harvesting. Although storage units are usually out of sight, large terraces can be a sign of storing collected water, and exposing conveyance and distribution networks can indicate the prominence of rainwater harvesting.

As a conclusion; the awareness of people on the multiple benefits of rainwater harvesting, as well as their acceptance and willingness to employ it in practice, are the primary requirements for its widespread application in architecture. This must be followed by the regulatory framework and governmental incentives to promote rainwater harvesting applications. Furthermore, the design must be distinctive to determine a building's water-related merits. Therefore, in order to provide architectural solutions regarding the issues associated with rainwater harvesting:

- Rainwater harvesting should be promoted in general as a sustainable way to reduce water stress.
- Certain practical and appealing ways to implement rainwater harvesting in building and urban design should be developed.
- A visual dialect regarding rainwater harvesting and building environmental identity in general should be developed. As it is illustrated by existing and proposed examples in Chapter 6, although rainwater harvesting has not a distinctive effect on structures' form, it is fairly possible to create an architectural visual identity for rainwater harvesting by modifying and developing certain architectural elements based on the method's successive phases.
- Making rainwater harvesting and other alternative water harvesting methods an important part of architecture design should be in the agenda of every architect who is concerned about environmental crisis.

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