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Recycling Concept Starts from the Design Stage: Five Architectural Applications based on the Reuse of Construction and Demolition Waste

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Abstract: ***The concept of recycling and reusing starts from the design stage and sustainably continues through the stages of construction, operation and maintenance, to create an architectural process in which the architect directs his efforts and creations to create architectural applications based on the reuse of construction and demolition waste. The design process also plays an important role in determining the quantities of building material and the required energies for the construction and operation processes. In addition, most designs depend on modern raw materials which means the depletion of raw materials and energy for manufacturing and transport in spite the fact that the use of recycled or reused materials may fulfill the same purpose with the same efficiency. Accordingly, this paper focuses on how to propose some innovative designs and architectural applications, for recycling construction and demolition waste to be a reference or guide for professionals in the field of construction. Furthermore, this study serves as an inspiration for architects to design buildings and applications based on the idea of recycling. Five architectural applications based on the reuse of construction and demolition waste have been suggested in this paper: The first application: recycled wall from rubble and drainage pipes; The second application: pipes as openings; The third application: pipes as a precast slab; The fourth application: pipes as a green roof; The fifth application: pipes as a space structure. All of these proposals can be subjected to testing in future studies.***

Keywords: Construction and Demolition Waste CDW; Architectural Applications; Reuse; Recycle

1. Introduction

In nature, everything is recycled; waste is used as resources. Waste from one organism is used as food for another. Nature is closed ecosystems that do not produce waste but recycles all waste [1]. Therefore, the concept of recycling and its applications in architecture is one of the most important trends that respect the environment on the planet and maintain it by reducing the consumption of new raw materials, as well as by rationalizing the consumption of the required energies to extract and manufacture these materials.

The construction sector spends billions and consumes millions of tons of materials in construction. Whereas, the world demands for construction aggregates will rise 5.2 percent annually to 51.7 billion metric tons in 2019. According to the study of the world construction aggregates industry which presents historical data (2004, 2009 and 2014) and forecasts (2019 and 2024) for markets demand [2].

Thus, Construction activities are one of the most crucial activities in resources consumption. This activity produces huge amounts of waste, which are usually disposed of by burial; a squandering of resources and energies. Whether for the materials that were buried, or for energies and resources that are used in the process of transporting and burning waste. Over time, waste accumulates in the landfill, posing a threat to the environment.

Recycling is an alternative to traditional waste disposal where it is the process of converting waste materials into new materials and objects. This is a process that can save material and help in reducing greenhouse gas emissions. Recycling can reduce waste and can reduce the consumption of fresh raw materials, thereby reducing energy consumption, air pollution, and water pollution [3, 4]. Therefore, all countries, institutions, construction workers or individuals must adopt the idea of waste recycling. Thus, there is no choice for humanity except to adopt this principle, otherwise, the earth will turn into a large landfill.

Many researchers in many disciplines non-architectural, studied the mechanical behavior of recycled materials such as concrete coarse aggregates. Moreover, many authors have pointed to the possibility of using recycled materials to produce construction elements. Furthermore, the concept of recycling starts from the design stage and continues through the stages of construction, operation and maintenance. Architect did not direct his efforts and creations to create architectural applications based on the reuse of construction and demolition waste. The design process also plays an important role in determining the quantities of building material and the required energies for construction and operation. In addition, most designs depend on modern raw materials which means depletion of raw materials and energy for manufacturing and transport, although the use of recycled or reused materials may perform the same purpose and with the same efficiency.

Therefore**, the main objective of this study is to propose some innovative designs and architectural applications, for the recycling of construction and demolition waste** to be a reference or a guide in the field of construction. In addition, it serves as an inspiration for architects to design buildings and applications based on the idea of recycling. Accordingly, this research is an introduction to successive research to test these applications, both by practical experience or simulation programs.

2. Background: Construction and Demolition Waste CDW -Ways to deal with it.

It is common in the field of construction that the construction waste is usually combined with demolition waste and described as “construction and demolition" (C&D). There are many definitions for C&D [5, 6, 7, 8, 9, 10, 11]. Accordingly, C&D waste can be defined as the waste resulting from the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance. Construction waste materials tend to be more homogeneous (The surplus of new bricks and clean sand, cement, all new wood, glass, metals, plastic or new drywall, etc.) and for the most part is easier to separate and recycle. While the demolition waste is more difficult to separate and recover, this is due to the materials of the demolition waste which tend to be mixed with a variety of materials [12, 13].

Construction waste: consists of unwanted material produced directly or incidentally by construction or demolition. This includes building materials such as bricks, rubble, electrical wiring, drainage pipes, and concrete as well as waste originating from site preparation such as dredging materials and rubble.

Demolition waste: is waste debris from destruction of buildings, roads, bridges, or other structures. Debris varies in composition, include concrete, wood products, brick and clay tile, and steel. Recycling these wastes helps to reduce the negative effects on the environment, by reducing the environmental impact of manufacturing new building materials. In addition, this reduces the consumption of natural resources as well as the disposal of waste in landfills [14].

2.1 Strategies for dealing with construction and demolition waste

There are many strategies for dealing with construction and demolition waste [15, 16, 17, 18]. Moreover, it is important that workers in the construction field realize that the technology for the separation and recovery of construction and demolition waste is well established, readily accessible and in general inexpensive. Waste management strategies include three options:1) final disposal in landfills; 2) disposal in the landfill after processing to reduce its size; 3) waste treatment includes three options: (reduce, reuse, recycle).

Reduce: one of the best ways to manage construction and demolition waste is to reduce it rather than thinking about the disposal. This is done by carefully determining the required quantities of building materials, also ensure that there is no conflict between the works at the site to avoid wasting material. This can be achieved by using many construction management techniques such as BIM (Building Information Modeling).

Reuse: is a strategy to employ construction and demolition waste in many applications. For example, the use of broken concrete and brick waste in soil preparation layers, and the reuse of the undamaged demolition waste from doors, windows and pipes.

Recycling: The process of treating demolition and construction waste through a combination of physical, mechanical and chemical processes, preceded by sorting and separation, then drying and grinding, allowing the extraction of materials. These processes consume energy but they are far less than the needed energy to extract and manufacture new raw materials.

Factors and constraints which affect the activation of recycling and reuse strategies, are designs, implementation plans, employment, quantity and specifications of materials, energy crisis and available technology. The fact that in the field of architecture is important and fundamental areas in the field of construction, but is considered as the most influential areas where projects rely on the designs and ideas of architects. **Therefore, the problem is clearly shown in the designs which lack the activation of recycling and reuse strategies.**

2.2 Types of construction and demolition waste

Construction and demolition waste vary depending on the type of project and its location, these wastes include concrete, broken stones, metal, plastic, wood and bricks, in addition to the rubble from the road construction and the preparation of the sites. Construction and demolition wastes are produced every day around the world. Thus, the idea of using concrete and brick aggregate in new production appears to be an effective utilization of waste. The study focuses on three main types of construction and demolition waste (**concrete, bricks and drainage pipes**). As a result, the study suggests the use of pipes as an element of construction. In addition, it proposes the use of pipes as ventilation openings and basins for agriculture. As for the bricks and concrete, the study suggests that it could be turned into rubble, then used inside the gabion baskets as walls.

Concrete and brick may come from different sources. It can be obtained through the demolition of concrete elements of roads, bridges, buildings and other structures, or it can come from the residue of fresh and hardened rejected units in precast concrete plants [19]. It can be recycled by crushing it into rubble. Once sorted, screened and contaminants are removed, concrete or brick can be used in concrete aggregate, fill, road base, or riprap [20]. Accordingly, crushing concrete to produce coarse aggregates for the production of new concrete is one of the common methods to achieve environment-friendly concrete.

3. Innovative architectural applications for the reuse of construction and demolition waste CDW

After studying the fundamentals and the definitions of C&D. Moreover, emphasizing that the strategies dealing with waste are necessary for maintaining a sustainable life. The study focused on three materials from the demolition and construction waste: concrete, bricks and sewage pipes. Consequently, this study deals with proposals for the reuse of these materials in innovative architectural applications by explaining the design idea and the executive designs of the idea. Accordingly, the study emphasizes the importance of testing these proposals in subsequent studies. Fig.1 summarizes the five architectural proposed applications that are based on the reuse of construction and demolition waste:

- The first application: recycled wall from rubble and drainage pipes.
- The second application: pipes as openings.
- The third application: pipes as a precast slab.
- The fourth application: pipes as a green roof.
- The fifth application: pipes as a space structure.

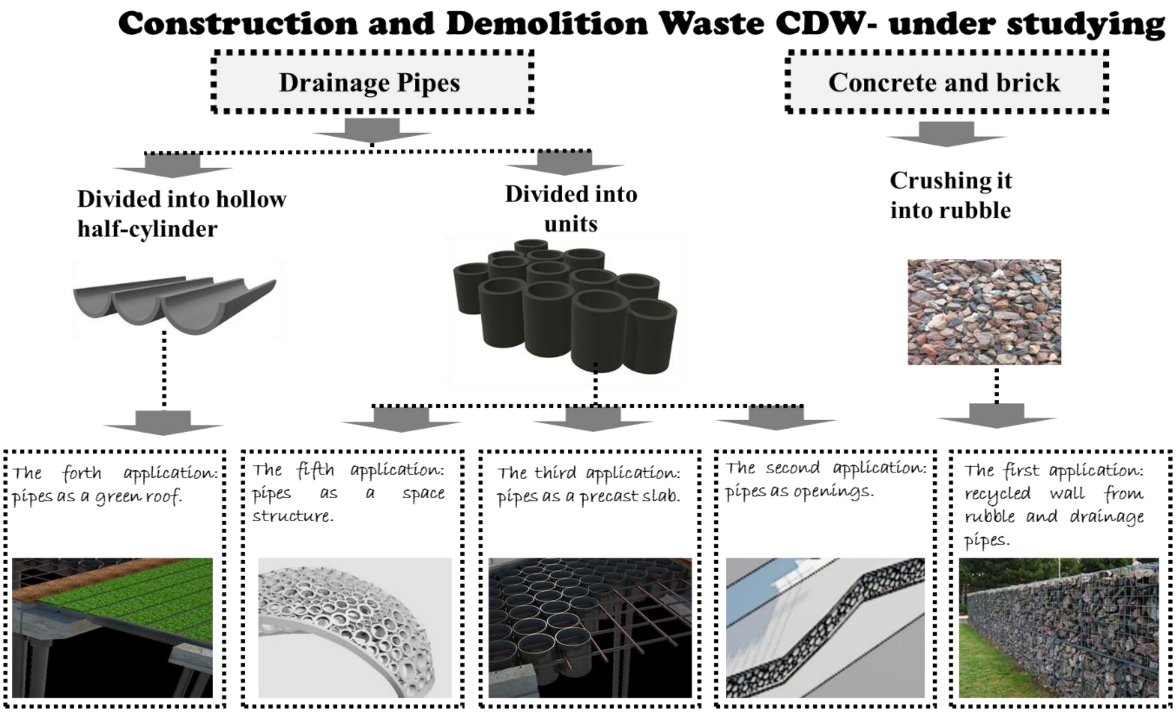

Figure 1: The use of the rubble to fill the Gabion Baskets
Source: Designed and drawn by the author

3.1. The first application: Recycled walls from rubble and drainage pipes.

Concrete and bricks can be reused by crushing it into rubble, and then manufacturing the baskets of metal mesh. The metal mesh can be manufactured in welded mesh or woven wire, this is the Gabion Baskets. The idea of Gabion Baskets is not a new idea but the study suggests **the possibility of integrating these walls within the construction of the building with reused materials**??? (see fig. 2). The study suggests two installation methods for installing the gabion baskets with the structural system. These proposals help to reduce the negative effects on the environment, by reducing the environmental impact of manufacturing new building materials which are used to build new buildings. In addition, reducing the negative effects of the presence of tons of concrete and bricks waste that is not exploited.

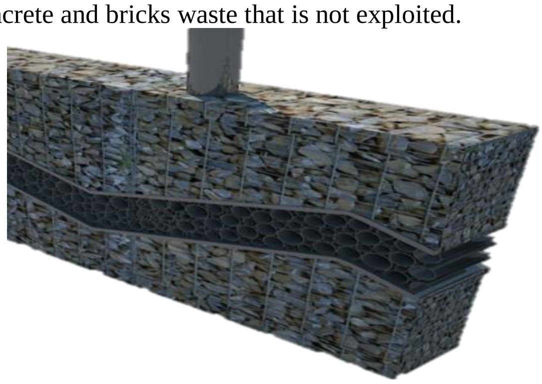

Figure 2: The use of the rubble to fill the Gabion Baskets
Source: Designed and drawn by the author

3.1.1. The first proposal of installation methods

The first proposal is to reuse drainage pipes as columns within the structural system of the building where concrete is poured inside the pipes until it becomes a vertical structural member. Furthermore, the reinforcing steel can be placed inside the pipes to strengthen the structural system and to be connected with the reinforcing steel inside the tiles. It is known that the rebar (reinforcing bar) is a steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and aid the concrete under tension. As shown in the fig. 3 the study proposes installing the iron mesh of the gabion baskets around the columns. Fig. 4 and 5 show working drawing and installation details of the first proposal.

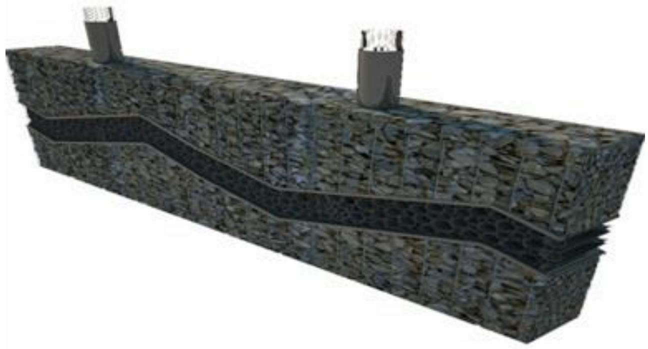

Figure 3: Perspective shot of the first proposal. The use of drainage pipes as columns with gabion baskets around them.
Source: Designed and drawn by the author

Fig. 4. Illustrates Section A-A, it is a horizontal section that shows the relationship between the proposed column from the reused drainage pipes and a wall of gabion baskets.

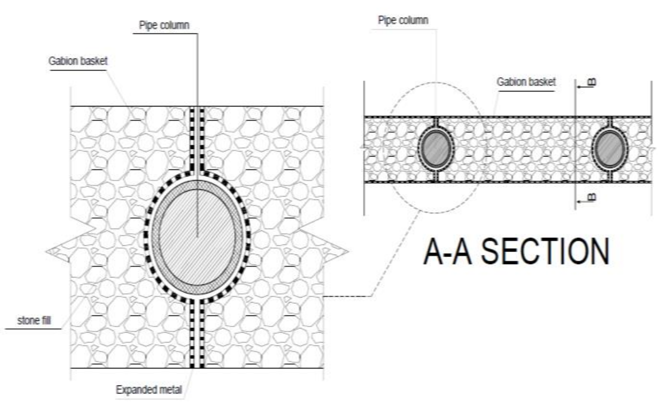

Figure 4: The first proposal (Section A-A)
Source: Designed and drawn by the author

Fig. 5. illustrates Section B-B, it is a vertical section of the proposed wall that shows the relation between the column and the gabion baskets with the ceiling slab.

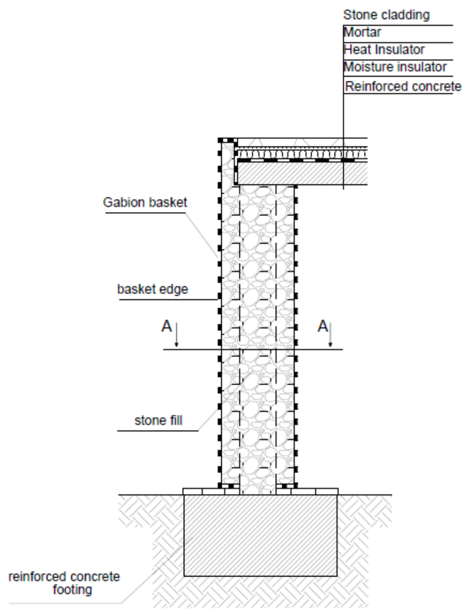

Figure 5: The first proposal (Section B-B)
Source: Designed and drawn by the author.

3.1.2. The second proposal of installation methods

In the second proposal, drainage pipes were used as columns such as the first proposal, but the difference in this proposal is to place the column outside the gabion baskets (see fig.6). The study suggested connection methods between the gabion baskets and pipes, to create an architectural application that can be useful in the development of buildings which depend on the reuse of waste. In this model, it proposes the use of vertical anchors (stands) to support the wall. These stands can be made of wood, metal or concrete.

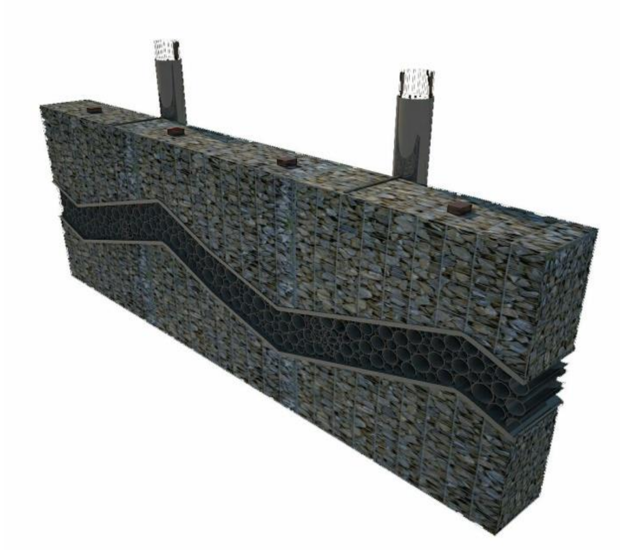

Figure 6: Perspective shot of the second proposal. Drainage pipes were used as columns and the gabion baskets were installed through angles and panels with the columns
Source: Designed and drawn by the author

Fig. 7. illustrates section (A-A,1), it is a horizontal section that shows the relationship between the proposed column from the reused drainage pipes and a wall of gabion baskets. The connections between the column and the gabion baskets can be angles and panels. While, fig. 8 illustrates section (A-A,2) which shows the connection between the column and the gabion baskets by metal plate.

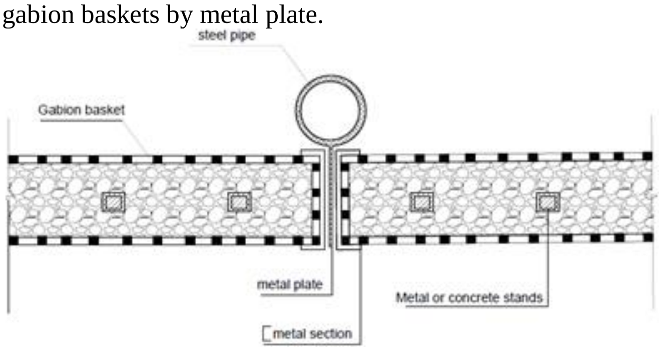

Figure 7: The second proposal section (A-A,1):
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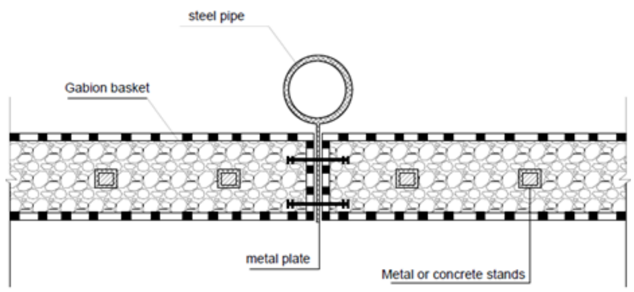

Figure 8: The second proposal (section A-A,2)
Source: Designed and drawn by the author

Fig. 9 illustrates section B-B, it is a vertical section of the proposed wall that shows the connection between the pipe and the gabion baskets by the metal plate and illustrates the relationship of all that and the ceiling slab.

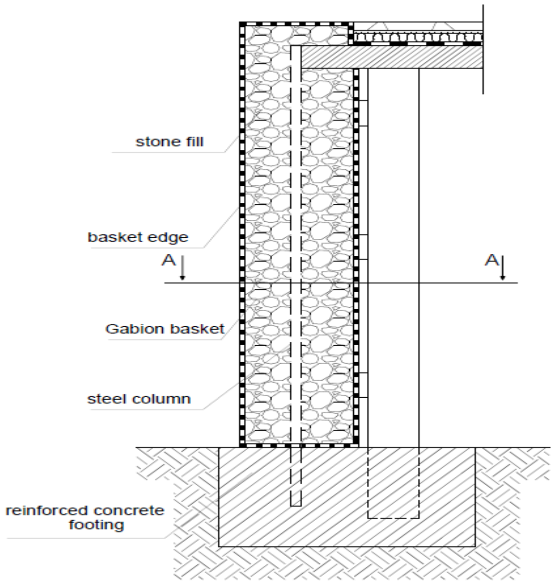

Figure 9: The second proposal (Section B-B)
Source: Designed and drawn by the author.

3.2. The second application: pipes as openings

The study suggests the reuse of drainage pipes as openings for ventilation and lighting (see fig. 10). The idea of the model is to reuse the drainage pipes by cutting the pipes into small sections. The unit size is determined based on the width of the window opening, then assembled and placed on top of each other. The efficiency of lighting and ventilation will be tested in a subsequent study of researchers, to determine the optimal design for the width and the ratios of openings.

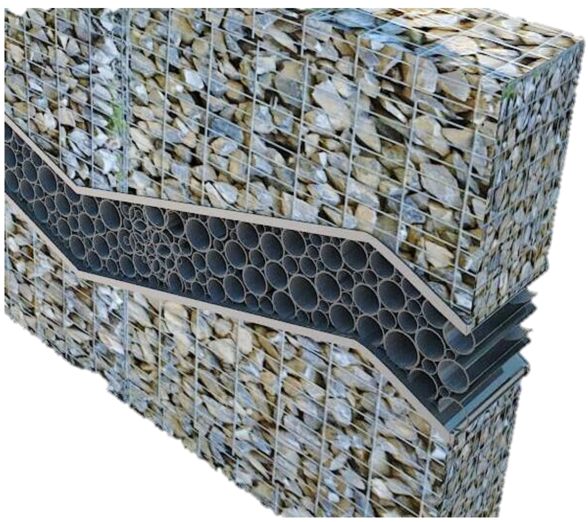

Figure 10: Perspective shot of the use of pipes as openings for ventilation and lighting
Source: Designed and drawn by the author.

Fig. 11 shows the use of the lower metal plate for sealing the gabion baskets and to facilitate the placement of pipe units above it. And the upper metal plate to facilitate the complement of the gabion baskets. Fig. 12 shows a horizontal section in the level of pipes and present the relation between pipes units and the column, which was suggested in the first proposal.

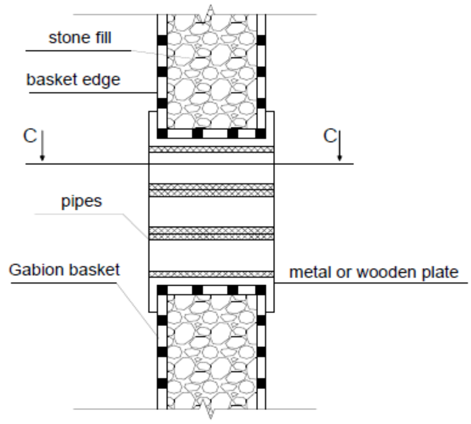

Figure 11: Vertical Section in the level of pipes
Source: Designed and drawn by the author

Section in the level of pipes

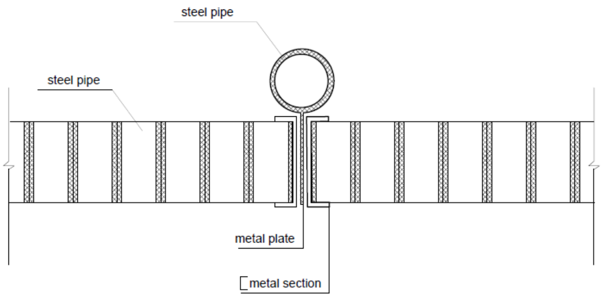

Figure 12: Horizontal Section in the level of pipes
Source: Designed and drawn by the author

3.3. The third application: pipes as a precast slab

The study suggests the reuse of pipe units as a precast slab. The idea of the model is to reuse the drainage pipes by cutting the pipes into small sections. The pipes were grouped together next to each other in a horizontal plane, then metal wires were used to connect pipes. This wire works to withstand tensile tension on pipes. For pressure forces, the pipes work together to withstand pressure.

To confirm the hypothesis of this model, which is a proposal to re-use the pipe as a ceiling slab. The most important challenge was the weight of the roof slab compared to the reinforced concrete.

- By calculating the weight per square meter of a reinforced concrete thickness of 10 cm. The output was 250 kg per square meter, that means almost a quarter of a ton.
- If we assume the use of steel pipes as sections for the ceiling slab and It is the heaviest type of drainage pipe.
- And by a table to calculate the weight of the steel pipes for the longitudinal meter according to the thickness and the diameter of the pipes.
- If we divide the longitudinal meter with a diameter of 30 cm to units of 10 cm (10cm represents the thickness of the slab), the weight per square meter will be (32.4 kg). And if we divide the longitudinal meter with a diameter of 30 cm to units of 20 cm, (20cm represents the thickness of the slab), the weight per square meter will be (64.8 kg).
- Consequently, the proposed innovative structural system will be lighter than the reinforced concrete.

- This proposal will be tested in a subsequent study of researchers.

Fig.13 illustrates the components of the proposed structural system which depend on the reused materials. First: a column from the reuse of drainage pipes. Second: a precast concrete section with a cylinder in the middle to make a strong connection between the column and the slab, the cylinder is installed on the column and it is linked with nails. Third: the precast slab of drainage pipes and the surrounding beams which are placed for assembling pipes and where wires are connected in it. Minutely, the wire is tightened and is connected from the outside in a cavity inside the beams (see fig. 14).

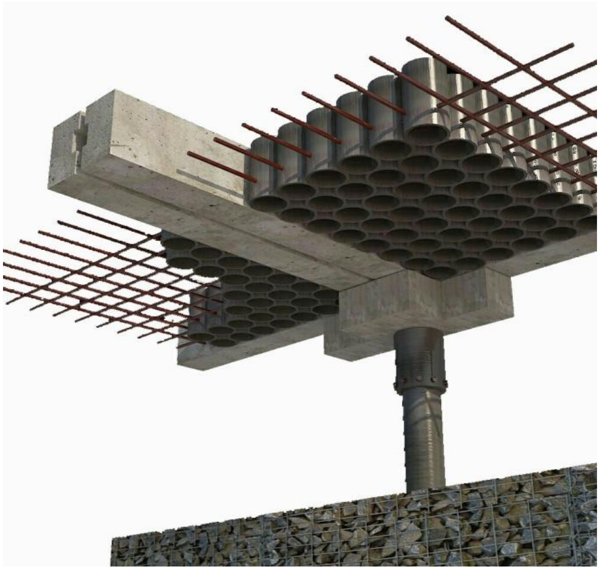

Figure 13: Perspective shot of the precast slab from pipes. The method of connecting pipes with wires and the beams that packed the pipes
Source: Designed and drawn by the author

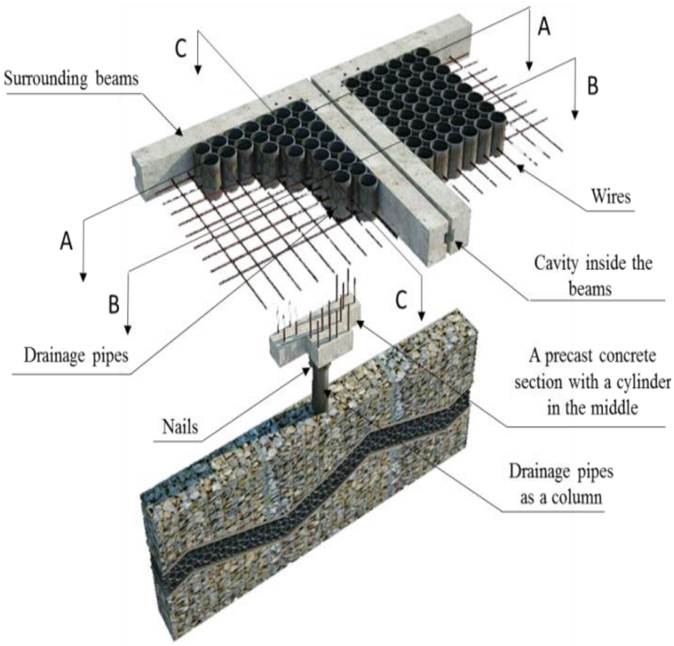

Figure 14: Illustrates the components of the proposed structural
Source: Designed and drawn by the author

Figs 15 -18 illustrates the components of the proposed structural plan x-x, sections A-A, B-B, C-C.

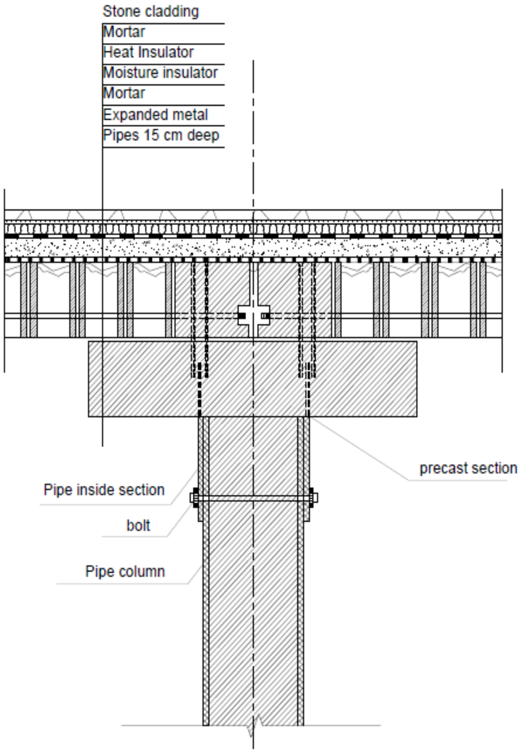

Figure 15: Precast slab from pipes. Section A-A
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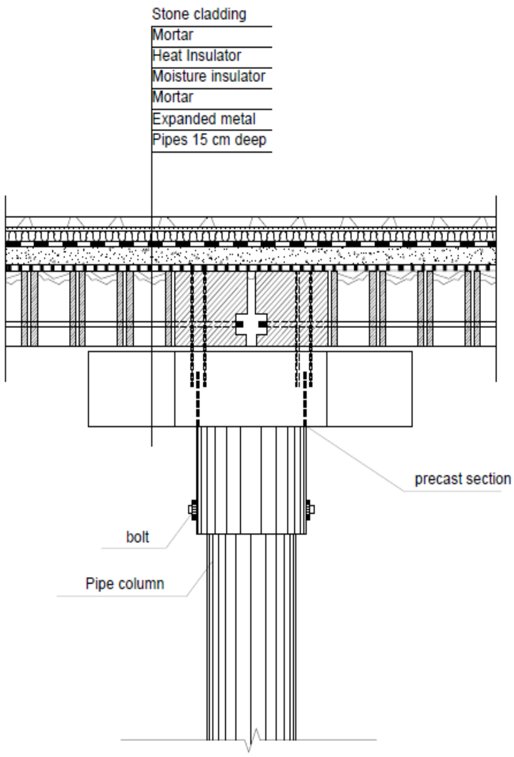

Figure 16: Recast slab from pipes. section B-B.
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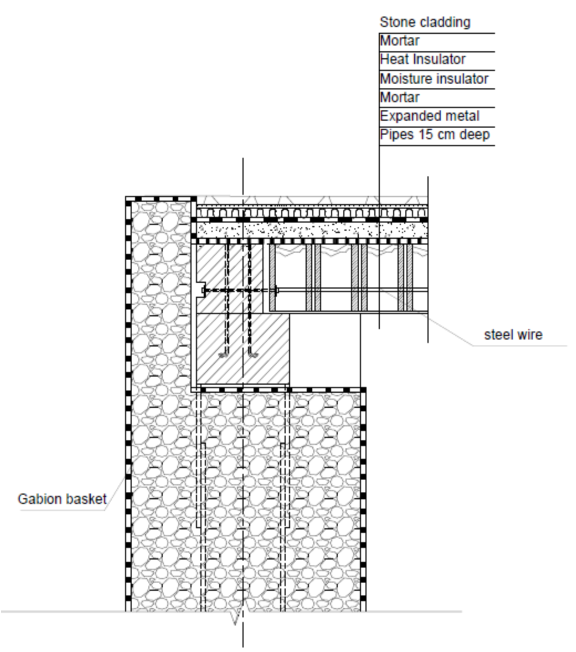

Figure 17: Precast slab from pipes, Section C-C. its relation to the gabion basket
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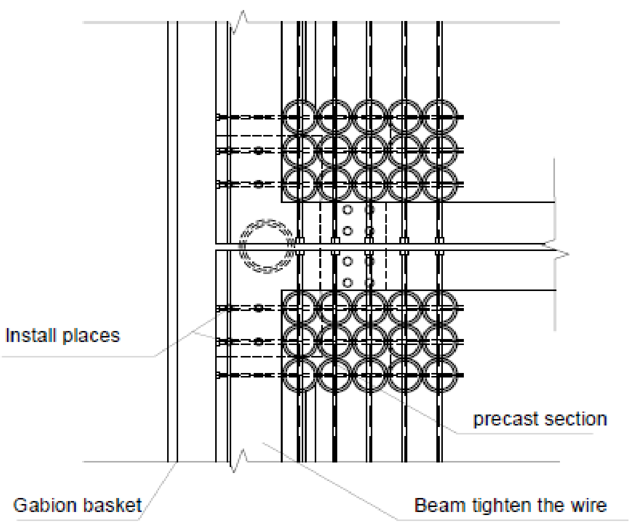

Figure 18: Precast slab from pipes, plan X-X.
Source: Designed and drawn by the author

3.4. The fourth application: pipes as a green roof.

The study suggests the use of pipes as a green roof without slab. The pipes were used as basins for agriculture, by dividing the pipes into two halves in the longitudinal direction, so that each half becomes -a hollow half-cylinder, (see fig. 19).

Until the slab is dispensed and replaced it with hollow half-pipes that were placed horizontally without a ceiling slab. The study suggests that the use of the main and secondary beams to support the pipes and transfer the loads to columns. Fig. 20 illustrates the details of the installation of drainage pipes as basins for planting.

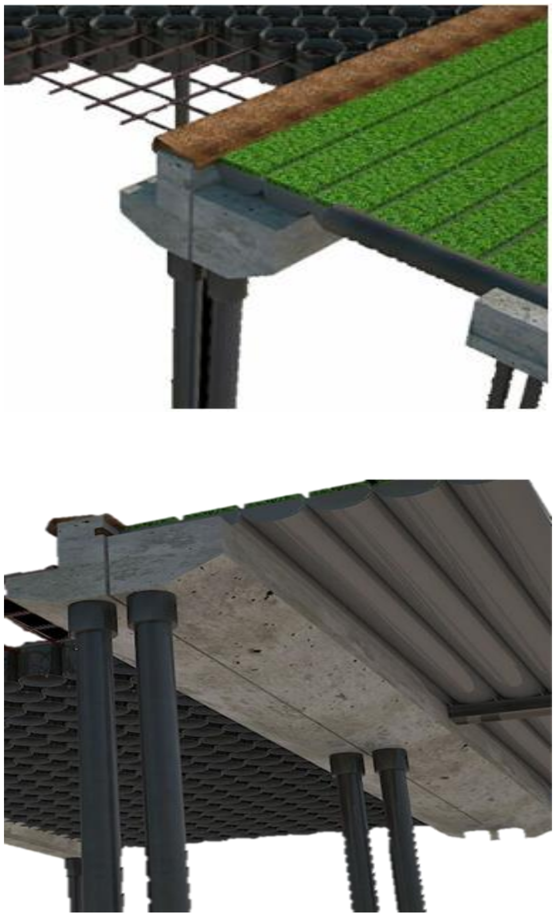

Figure 19: Perspective shot of the use of pipes as basins for planting
Source: Designed and drawn by the author

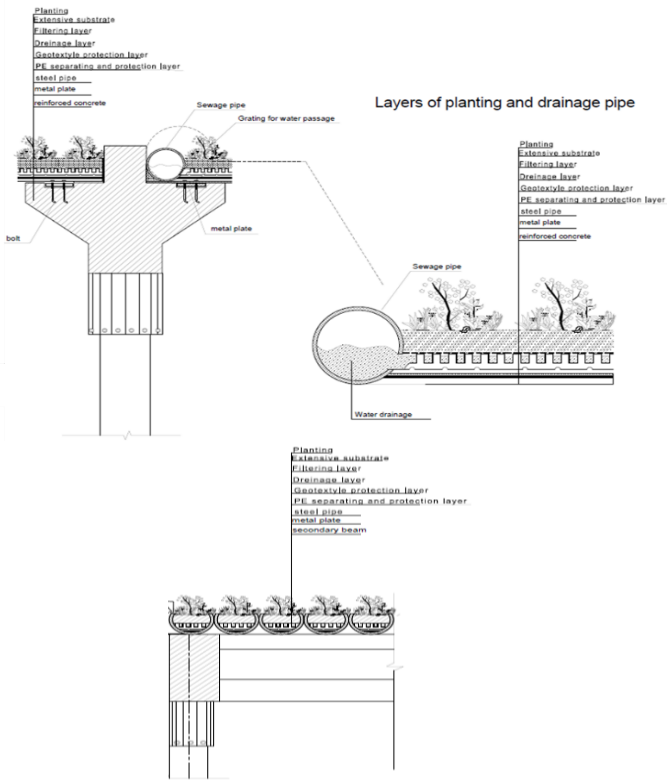

Figure 20: Details of the installation of drainage pipes as basins for planting.
Source: Designed and drawn by the author

Fig 21 and 22. show the connection between- the two previous applications- the proposed construction systems from the precast slab of the drainage pipes, and the basins for agriculture of drainage pipes as well.

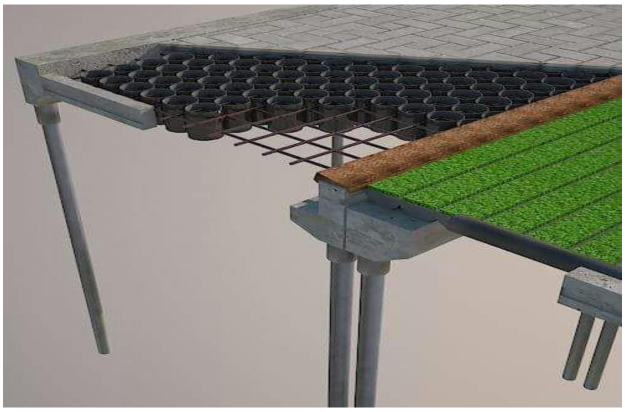

Figure 21: Show the connection between- the two previous applications. Source: Designed and drawn by the author.

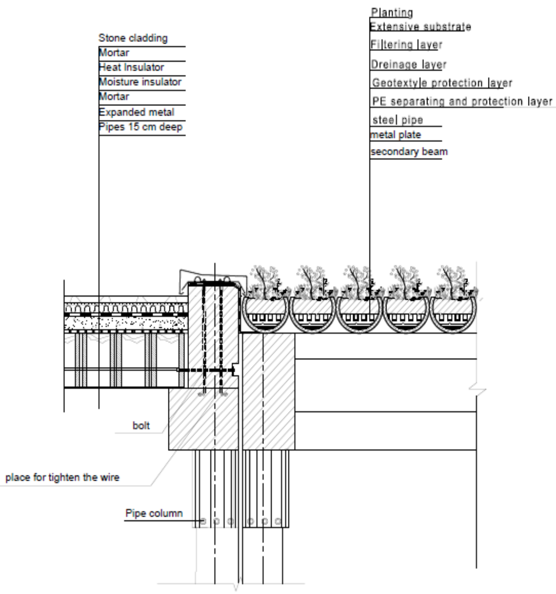

Figure 22: Section A-A show the connection between- the two previous applications.
Source: Designed and drawn by the author

3.5. The fifth application: pipes as a space structure.

The study proposes an innovative construction method as a dome structure. By cutting pipes with different diameters to units, these units are used as construction elements. Thus, the principle of equilibrium by accumulation is used, to get a strong structure facing gravity. This construction helps to illuminate the spaces below it, by entering the daylight through the pipes, (see fig. 23). This proposal will be tested in a subsequent study of researchers, to test the capability to support two types of load (Static Load- Dynamic Load). The dead loads are relatively fixed and include the weight of the building structure itself and the live loads are moveable loads which may not be present all the time. They include the weight of building occupants and furnishing, also include wind loads, earthquake loads, and etc.

Figure 23: Pipes units as a space structure
Source: Designed and drawn by the author

Fig. 24 shows the details of the units' connection with each other. The joints are designed by placing a rubber layer around the pipes from the upper side. This layer forms the required bending.

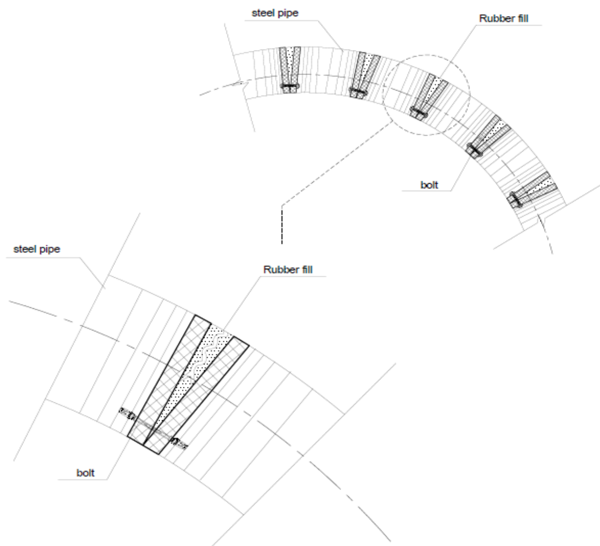

Fig. 24. The details of the units' connection with each other.
Source: Designed and drawn by the author.

4. Conclusions

1) The construction sector consumes resources and energies more than any other sector, which is responsible for the largest share of environmental pollution and the depletion of resources and energies.Therefore, the principle of recycling and reuse of construction and demolition waste should be adopted by the state, institutions, investors and individuals from the first stage of design to construction stages.

2) Architects should be advocates of sustainable living through new designs and ideas. Practicing the ideas of reduce, reuse and recycle is imperative in all fields of life, but especially in the practice of architecture. Architects are already acknowledging the fact that we need to reduce our consumption of materials and reduce waste from construction. But also, architects need to be fully aware

that they have the power to motivate their clients into creating buildings from recycled and reused materials.

3) Architects should provide new ideas to activate the principle of recycling and reuse of materials as well as test these ideas to encourage investors to apply them in their projects.

4) The study proposes five architectural applications based on the reuse of three materials from the construction and demolition waste which are concrete, bricksand drainage pipes. These proposals help to reduce the negative effects on the environment, by reducing the environmental impact of manufacturing new building materials. In addition, reducing the negative effects of the presence of tons of waste that is not exploited in the environment. The results of these applications are summarized below:

- The small and medium diameter drainage pipes can be reused in the design of openings for lighting and ventilation, which will benefit the architectural design in achieving thermal and visual comfort as well as rationalizing the use of new metal and wood frames in the windows.
- Drainage pipes can be reused in the design of basins for agriculture as a green roof, which helps to rationalize the use of new building materials and accordinglyhelps to improve the thermal performance of the spaces with a green roof.
- Drainage pipes can be reused in roof design as pre-fabricated units. The proposed load has been calculated and the results of calculating loads compared to normal concrete traditional tiles were satisfactory.
- The waste of concrete and bricks were reused in the design of walls supported by the drainage pipes, to rationalize the use of building materials.
- The study also suggests design a dome-shaped structure from units of drainage pipes, this construction can improve the environmental performance of the dome. It also works to rationalize the consumption of traditional building materials to build a structure like this.

5. Acknowledgments

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