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Sustainability Requirements of Concrete Structures

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Abstract The objective of this research paper is to discuss the main requirements which may affect the sustainability of concrete structures and develop the relative weights of these requirements. A questionnaire survey was conducted among construction experts, such as college staff, contractors and construction engineers. The survey was conducted to identify the relative weights of the concrete sustainability requirements. After reviewing literature, fifty nine factors which affect the concrete sustainability were prepared and divided them into 12 categories. A pilot study was conducted by 19% of sample size to enhance the questionnaire design. The pilot study was filled out by 10 college professors and 9 engineers with experience more than 10 years. This study helped us to modify the requirements which were directly connected with the concrete sustainability. Researchers found that the most important factors were related to "Aggregate" category. Aggregate category has the weight of 17.64% and waste category has the weight of 13.04%. These two categories have about 30% of concrete sustainability weight. The Green Pyramid Rating System (GPRS) was used in the present research to know what could be added.

Keywords: *sustainability, concrete sustainability, sustainability assessment, concrete sustainability requirements*

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1. Introduction

Lately, sustainability has become one of the most important aims to be achieved in structural projects. Sustainability development is supported by three pillars: environment, society and economics [3]. More technical elements are used to produce constructions to fulfill the society requirements from environmental, economic and social considerations [25].

Sustainability has been applied in various sciences, such as sustainability of water resources, sustainability of material, sustainability of waste and other sciences in which researchers need to put their touch reflecting their efforts in the technological and their mental development by the continuous scientific research.

Construction activities are also the main responsible for consuming around 30% of the emissions of global greenhouse [14]. Engineers agree that the concrete is the most important product all over the world. Sustainability in concrete means to get concrete which has high quality, moderate cost, material with high quality and cheap cost, high durability, high performance, high strength and eco-friendly concrete [2]. People spend 80-90% of their time inside construction so researchers want to have perfect constructions and high quality product and try to find the most suitable solutions to make this product's quality higher [3]. There is a relation between the material selected and the energy consumed during the producing, using and recycling stages.

Reducing cement in concrete has a great effect on theenvironment as it needs large amounts of energy and produces a lot of carbon. Selecting the optimum aggregate size, using cementitious materials, designing the appropriate admixtures and controlling the batching accuracy can help to make a sustainable concrete [14].

For the sustainable building design, engineers shall take into consideration reducing waste of materials, recycling, energy, ensuring in the building, water management and minimizing the costs of maintenance [28].

Wastes are about 80% from the demolished structures and 20% from the new facilities as mentioned by Sarja and Vesikari [26]. They claimed that it is possible to reduce the waste amount by choosing the suitable structural system and material. In mega projects, such as roads, large amounts of materials are used, so it is recommended to replace these raw materials by slag, fly ash and recycled aggregate with known specifications. Recycling could be easier by separating the structural components during demolition, using demountable structural components, using suitable connections and reducing the procurement of various materials.

2. Literature Review

In 2004, Sarja presented the problem of his research about lifetime engineering of sustainability infrastructure constructions [25]. His idea was about developing some elements to produce durable structures which fulfill human requirements through social, environmental and economic considerations because of the maintenance difficulty. To select the optimal solution, he wanted to achieve the best in all requirements, the best with reasonable cost level and the best in benefits/cost ratio. But to make a durable design, he should apply this design with structural detailing rules, apply the design of environmental conditions and the protection of materials against deterioration and apply safety.

Since 2008, the Spanish structural code (EHE) also has focused on respecting the environment by using sustainability thought and making an assessment for the concrete structures [1]. There is a method for sustainability assessment called the integrated value model for sustainability assessment (MIVES) which change the varied units for all parameters into single unit to be easy to deal with, taking into account the weight of each one. Aguado and Del Caño developed a questionnaire related to the environmental criterion. They defined some aspects under every criterion, as shown in Table 1.

Table 1. The most important aspect applied in MIVES

Criteria	Aspects
Characteristics of concrete suppliers (50%)	Origin of concrete
	Environmental condition of concrete-supplying factories
	Environmental condition of the contractor
	Distance between the concrete plants and site
Characteristics of reinforcement suppliers (50%)	Origin of the RFT
	Environmental of the RFT supplier
	Environmental condition of the contractor
	Distance between the supplier and site
Reinforcement reduction (17%)	Type of concrete
	Percentage of slabs reinforcement
	System of rebar joining
Steel characteristics (33%)	Environmental certification of the steel production
Construction control (50%)	Use concrete elements with quality mark
Recycled aggregate (33%)	Percentage of recycled aggregate
Cement characteristics (50%)	Environmental certification of the cement production
	Cement production with raw materials that produce fewer CO_2 emissions
Concrete characteristics (17%)	Cement type
	Environmental certificate of the concrete-supplying plant
	Using fly ash
	Using silica fume
Impact caused by construction (100%)	Use of sprinklers on-site to avoid generating dust
	Using pneumatic cleaning system
	Covering the materials exposed to weather
Waste management (67%)	Management of demolition waste
	Recycling the excavation products
	Percentage of concrete in wastes
Water management (33%)	Using the sufficient curing techniques

There is a model developed by Pons and De La Fuente which can be applied on the concrete columns to assess their sustainability based on MIVES assumptions [22]. Concrete columns are not only indicators for safety and structural functionality but also for improving sustainability by enhancing the geometry and manufacturing technique properties. Table 2 presents a tree of weights for concrete columns by assessing 10 indicators taking into account incorrectly positioned reinforcement, incorrectly compacted concrete and liquid concrete loss between joints.

Table 2. Requirements Tree with Weights Assignations

Requirements	Criteria	Indicators
R1. Economic (50%)	C1. Construction costs (67%)	I1. Building costs (85%) I2. Non acceptance costs (15%)
	C2. Efficiency (33%)	I3. Maintenance (60%) I4. Habitability (40%)
R2. Environmental (33%)	C3. Emissions (67%)	I5. Co2 emissions (100%)
	C4. Resources consumption (33%)	I6. Concrete consumption (90%) I7. Steel consumption (10%)
R3. Social (17%)	C5. Negative effects on the producer industry (80%)	I8. Workers' inconveniences (20%) I9. Workers' safety (80%)
	C6. Effects to third party (20%)	I10. Environment nuisances (100%)

The team work prepared 12 alternatives of reinforced concrete columns and got the sustainability index for each one. They entered 3 variables:

- Compressive strength: normal strength (fc,28= 25N/mm2), moderate strength (fc,28=50N/mm2) and high strength (fc,28= 75N/mm2).
- Cross-section shape: square or spiral.
- Compaction method: self-compacted (SC) and vibrated (V).

The economic assessment showed that the circular columns are more effective for low maintenance and construction costs and that HSC for the circular columns gives smaller cross-sections and higher fck, 28. The environmental assessment illustrated that the circular columns with HSC give less Co_2 emissions. It also showed that the square columns are less effective than the circular columns with NS and that SCC has more effect on the environment due to using superplasticizer.

The social assessment of this research explained that SCC has lower nuisance and that HSC columns are constructed in lower duration. The team work discovered that the highest sustainable column which has a circular cross-section, fck, 28 equals 75N/mm^2 and is constructed with SCC. This research explained that concrete type and compaction method affect the concrete sustainability.

In 2014, Hooton and Bickley discussed the problem of concrete contents [10]. They started with Co_2 emissions' problem and its effect on the environment because Portland cement production contributes 8% of energy use, and 90% of produced carbon is due to cement production only. The production of 1 ton of Portland cement produces about 1 ton of Co2 [19]. Building in the construction phase accounts 10% of Co_2 and the rest is responsible for heating and air conditioning (HVAC). They suggested a solution for reducing the emissions by using aggregate gradations and water-reducing admixtures, mixing clinker with limestone and using cementing materials (SCMs) and recycled aggregate. Hooton and Bickley found that aggregate type, admixtures, clinker and cementitious materials have effects on concrete sustainability.

Throughout the project of tunnel lining in Barcelona, De La Fuente and his assistants aimed to assess the sustainability of different concrete and reinforcement alternatives to be used in concrete [7]. In this project, they wanted to compare between vibrated fiber reinforced concrete (FRC), self-compacting fibre-reinforced concrete (SC-FRC) and conventional reinforced concrete (CRC). They wanted to assess the sustainability of each of the three alternatives to make a decision. They concluded from this research that the full replacement of steel bars by fibres guarantees higher sustainability index. Also using (SC-FRC) increases the sustainability index over (FRC) by 8% although the cost of (SC-FRC) is 15% which is higher than that of FRC. But using SC-FRC reduces the noise pollution and saves about 10% of fibres required in FRC. This research proved that compaction method and reinforcement have effects on concrete sustainability.

Another research conducted by Al-Tamimi and et al. assumed three different types of concrete mixes: Normal concrete of compressive strength 50 MPa, Lightweight concrete of compressive strength 50 MPa and High Strength Concrete (HSC) of compressive strength 100 MPa [2]. These 3 mixes were designed, produced and analyzed to quantify their effects on sustainability and economics. The most sustainable type of concrete is HSC as it was the lowest in the weight of carbon emissions, the lowest in the cement ratio and the most suitable in space saving. So the concrete type has an effect on concrete sustainability.

The new research conducted by Palankar and et al. is focused on the development of binder material alternatives instead of Ordinary Portland Cement (OPC) [21]. There are geopolymers binders which can be used as an alternative to OPC and these materials obtain high strengths, being eco-friendly and do not involve high energy for hydration. The incorporation of steel slag coarse aggregates in polymer mixes presents lower fresh and mechanical properties. Geopolymer concrete with steel slag achieves lower compressive and tensile strength with lower modulus of elasticity compared to using granite aggregates due to the thin calcite layer on the granite surface which leads to a weak aggregate-paste interface. So the cementitious material has an effect on concrete sustainability.

For example, in 2017, Ibrahim and his assistants used Palm Oil Clinker (POC) coarse aggregate to make high strength pervious concrete (PC) [11]. They prepared mixtures with w/c of 0.3 and replacing the natural aggregate with POC aggregate by percentages (0, 25, 50, 75 and 100%). They used different methods of curing, such as full water and air curing. Results proved that using POC aggregate decreased the compressive strength by 5% and abrasion resistance. Using POC aggregate also reduced Co2 emissions by 20%. This research proved that the curing method, clinker and aggregate type can be used as requirements for concrete sustainability.

A research was conducted in Canada in 2011 by Butler and et al. to explain the effect of using recycled aggregate to the reinforcement and concrete bond [5]. They prepared mixtures of natural aggregate (NA) of crushed limestone and two types of recycled aggregates (RA). The first type of RA was produced from the crushing of sidewalks and curb structures (RCA-1). The second type of RA was produced from the crushing of runway, apron and terminals of Toronto Airport (RCA-2) [20]. They used natural river sand as the fine aggregate. After administering tests, they concluded that the two types of recycled aggregates had lower densities and higher water absorption than the natural aggregate. Also they had lower slump values than the natural aggregate due to the angular shape of particles. Concrete made of RCA-1 and RCA-2 had higher compressive strength than the natural aggregate. Thus, they proved that replacing natural aggregate with RCA has a perfect impact on the bond of concrete with reinforcement steel. By this research, the recycled aggregate is a main requirement of concrete sustainability.

As engineers have to use reinforcement (RFT) in concrete, they shall search for alternatives for RFT. It is preferred to use Fibre Reinforced Polymers (FRP) because it is a non-corrosive material, having lower weight, higher strength and higher stiffness [15]. Basalt fibre reinforced polymer (BFRP) which is used for two decades has lower cost, stronger reinforcement material and lighter-weight material.

In 2017, a research was conducted by Inman and et al. about using BFRP rebar instead of traditional steel (TS) rebar in concrete beams [12]. The results proved that the beams of BFRP bars are lighter and stronger than the beams of TS bars, better for environment and consume fewer energy and materials during construction.

After presenting researches about concrete mixing, types and admixtures, concrete curing process is very important stage during concrete manufacturing. Selecting the best method for curing conserves the natural resources such as reducing cement quantity leading to have members with high durability and toughness [13]. Kewalramani selected the polythene sheets because these are available, reusable and able to cover all concrete items even the infrastructure items, prevent water loss by evaporation to help in curing and hydration, and provide the element by temperature, solar radiation and relative humidity [14].

There are 5 types of polythene sheets: red, yellow, black, white and blue. The team work found that the red sheet transmitted the incident radiation by 100% and that the black sheet is the lowest in radiation transmitting. They knew that the concrete needs specific amount of solar radiation to complete its hydration and they should not to forget that there is an angle for solar radiation which differs during the day light and changes the radiation amount [13].

There are many assessment codes to evaluate sustainability. LEED is the sustainability code in USA [6]. LEED is classified into eight categories: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and regional priority. According to the present research, it deals with the category of material and resources which has a weight of 13%. In Japan, CASBEE is a rating system for evaluating the environmental performance of buildings. BREEAM (Building Research Establishment's Environmental Assessment Method) is the first rating tool for sustainability for the environmental structures in UK [4].

BREEAM can be applied on projects in UK, Germany, Netherlands, Norway, Spain, Sweden and Austria. Green Star is a pilot rating tool launched in Australia in 2003. It has been developed by the Green Building Council of Australia (GBCA). Green Star is classified into nine categories: Management, indoor environment quality, energy, transport, water, materials, land use and ecology, emissions and innovation. It is agreed that to control anything you need to measure it. The Green Pyramid Rating System (GPRS) has been made to achieve this need [30]. The Pyramids are considered one of the most appropriate symbols of green building. They are constructed with natural materials; depending on natural ventilation and light.

3. Sustainability Requirements

Reviewing literature and previous studies indicated some sustainability requirements for the concrete, but most of them were related to the environment. The researchers of this study needed to make an assessment for the concrete so 59 requirements were chosen (after modification made by the pilot study) which related to the concrete before, during and after construction. Every requirement needed to be weighted according to its importance chosen by the population.

We conducted a pilot study on 19% of sample size to modify the suggested questionnaire. This study was filled out by 10 college professors and 9 engineers with experience more than 10 years. It helped researchers to modify the requirements which were directly connected with the concrete sustainability. Some mistakes and ineffective factors were removed and replaced with more effective factors. It was conducted during 2 months after making the suggested questionnaire survey.

For example, we had a requirement related to the verification of aggregate suppliers. A professor suggested removing this requirement depending on those aggregate suppliers in one city get their stocks from the same quarries. Another requirement was about the RFT suppliers, and removed to the same reason mentioned above. Also there was a requirement related to taking the needed precautions to prevent diseases, and removed because there was a requirement related to the safety and security precautions, so there would be duplication with the same meaning.

In addition to that, a requirement related to preparing a schedule for the project, the casting distance from the pump, precast concrete requirements, sources of mixing water and other requirements were added to control the duration and cost of the project. Ready-Mixed Concrete (RMC) requirements were added to the questionnaire, as it used in Egypt. Human resources and site requirements were added to the questionnaire in separated categories. These changes added a great value to the survey and arranged the factors to facilitate the filling up process. A questionnaire design was modified after every suggestion. Various designs of questionnaire were conducted due to these suggestions. They also suggested re-categorizing the factors again to be in the recent arrangement.

After conducting the pilot study, we had 59 requirements classified under 12 categories. All requirements are defined by codes, as shown in Table 3.

Table 3. The needed requirements of the Concrete Sustainability

Cement Industry (CI)	CI1	Clinker percentage in cement
	CI2	Cementitious additives percentage
	CI3	Cement type used
	CI4	Cement grade used
Aggregate Requirements (AG)	AG1	Aggregate surface feel
	AG2	Making tests for aggregate
	AG3	Type of aggregate used
	AG4	Reliability of aggregate laboratories
	AG5	Humidity percentage of aggregate
	AG6	Sulfates in aggregate
	AG7	Distance between site and quarries
	AG8	Transportation type
	AG9	Recycled aggregate used in concrete
	AG10	Components of recycled aggregate
	AG11	Location of aggregate storage
Reinforcement Steel (RFT)	RFT1	Transportation type
	RFT2	Distance between site and hangers
	RFT3	RFT corrosion removal before using
	RFT4	RFT surface feel
	RFT5	RFT attaching system
	RFT6	RFT storage location in site
	RFT7	RFT diameter
Formwork (FW)	FW1	Number of times the formwork is used
	FW2	Formwork wood type
	FW3	Formwork type
Concrete Manufacturing (CM)	CM1	Sources of mixing water
	CM2	Reuse the additional water
	CM3	Concrete mixing method
	CM4	Concrete compaction method
	CM5	Concrete curing method
Different Types of Concrete (DC)	DC1	The optimum selection of precast concrete plant
	DC2	Using precast concrete
	DC3	Using prestressed concrete
	DC4	The type of tension cables
Ready-Mixed Concrete (RMC)	RMC1	Using ready-mixed concrete
	RMC2	The distance between site and ready mixed plant
	RMC3	The casting distance from the pump
Construction Techniques (CT)	CT1	Humidity insulation for concrete
	CT2	Optimum selection of a contractor
	CT3	Making a schedule for the project
	CT4	Preserving the architecture style
	CT5	Selecting dewatering system
	CT6	Performing soil pore hole
The Site (SL)	SL1	Leveling temporary roads in site
	SL2	Cleaning the site
	SL3	Constructing homes for labors in site
H.R. (HR)	HR1	Employment of labors and engineers during construction
	HR2	Training labors and engineers during construction
Waste Disposal (WD)	WD1	Saving a location for waste disposal
	WD2	The distance between site and waste disposal site
	WD3	Concrete quantities in waste
	WD4	Recycled aggregate quantities in waste
	WD5	Toxic materials percentage in waste
	WD6	Obtaining dust removal system in site
	WD7	Cleaning the site
Security and Safety (SS)	SS1	Achieving the essential safety precautions
	SS2	Saving places for the hospitalization
	SS3	The nuisance in the site
	SS4	All risks occur in the site

The application of concrete sustainability in Egypt will affect – like any sustainability – on the economic, environmental and social aspects. The researchers of this study shall apply sustainability starting with extracting the components of concrete, passing by the construction stage and ending by the architectural finishing.

3.1. Cement Industry (CI)

The present research discusses some requirements which affect the cement industry. It represents the effect of cement requirements on the concrete sustainability.

3.1.1. Clinker Percentage in Cement (CI1)

Clinker is a mixture of limestone and clay blended to produce the cement. This clinker contains 4 main minerals: C3S, C2S, C3A and C4AF. We can replace a percentage of the clinker with fly ash, silica fume or any addition to provide a new type of cement. Two researches referred to clinker used [10,11].

3.1.2. Cementitious Additives Percentage (CI2)

Engineers can insert cementitious additives to cement during concrete mixing by percentages. The cementitious additives are by-product materials such as silica fume, fly ash and blast furnace slag. In GPRS, one credit point is obtainable for the use of recycled materials. In concrete industry, it is supposed that the quantity of Portland cement used has been reduced by replacing it with the cementitious materials like fly ash, granulated blast furnace slag. References [1,10,21] referred to the importance of cementitious additives for the concrete sustainability.

3.1.3. Cement Type Used (CI3)

There are many types of cements available to use. Some types are called sulfate-resistance, fast-setting and low-temperature cements. This requirement was mentioned in reference [1].

3.1.4. Cement Grade Used (CI4)

Cement has 3 grades: 32.5, 42.5 and 52.5. The higher the grade of cement is used, the more strength of concrete constructors have. These numbers indicate the compressive strength of a sample after 28 days in MPa. This requirement was suggested in the pilot study.

3.2. Aggregate Requirements (AG)

The present research discusses some requirements which affect the aggregate selection, testing, extracting, recycling and the storage processes. This category represents the effect of aggregate requirements on the concrete sustainability.

3.2.1. Aggregate Surface Feel (AG1)

The surface shape differs by the aggregate type. Every shape affects the absorption percentage, workability and strength of concrete. There are many shapes and surface feel of aggregates, such as angular shape, smooth aggregate and rough aggregate. This requirement was suggested in the pilot study.

3.2.2. Making Tests for Aggregate (AG2)

There are many tests which can be applied for aggregate. These tests are classified into two types: mechanical tests and chemical tests. Mechanical tests are shown in sieve analysis, determination of specific weight and determination of unit weight. Chemical tests are shown in determination of chlorides and sulfates in particles.

Aggregate must be submitted to tests to be verified. Many problems may be in the aggregates. The owner or the project manager must order the contractor (as the constructor participant) to test any aggregate which may be transported to the site. The owner or the project manager has the right to refuse any aggregate with results out of range showed in the Egyptian code. This requirement was suggested in the pilot study.

3.2.3. Type of Aggregate Used (AG3)

There are many types of aggregate, such as gravel, dolomite, granite, lime-stone, stones and other types. Every type used in concrete gives a different compressive strength and produces concrete with specific properties. In GPRS, credit points are obtainable for explaining that building materials are manufactured in Egypt. Points are awarded as follows: one point if the quantity of regional materials is not less than 25% of the total quantity, two points if quantity of regional materials is not less than 50% of the total quantity and three points if the quantity of regional materials is not less than 75% of the total quantity. References [10,11] referred to the importance of this requirement.

3.2.4. Reliability of Aggregate Laboratories (AG4)

As present researchers mentioned before, it is preferred to make tests for any aggregate may be transported to the site. Researchers took a sample of these aggregates from quarries and send it to laboratories. They have to deal with reliable laboratories to guarantee its results. This requirement was suggested in the pilot study.

3.2.5. Humidity Percentage of Aggregate (AG5)

All aggregates absorb moisture from the surrounded environment. Every type of these aggregate absorbs a different quantity of moisture. The percentages of moisture may affect the w/c ratio during the process of concrete mixing, the strength of concrete produced and the curing duration. This requirement was suggested in the pilot study.

3.2.6. Sulfates in Aggregate (AG6)

All aggregates may be subjected to sulfates according to the surrounded environment. There is a test specified to maintain the sulfate percentage of the aggregate. The Egyptian code has stated the allowable range for this percentage. This requirement was suggested in the pilot study.

3.2.7. Distance between Site and Quarries (AG7)

There is a distance between quarries and site. This distance may be short or long. There is a relationship between the distance and the transportation mean used to move these aggregates. In 2017 modified-copy of GPRS, credit points are obtainable for the distance between material origin and site [31]. Points are awarded as follows: two points if the distance is 300-500 km, four points if distance is 100-300 km and six points if the distance is less than 100 km. This requirement was mentioned in reference [1].

3.2.8. Transportation Type (AG8)

Procurement stakeholders extract all aggregates from quarries and prepare them to be used. There are many types of transportation means, such as trains, Lorries and ships. The well-known mean of transportation is Lorries. Every mean has a specific cost and environmental and social impacts due to crowding. This requirement was suggested in the pilot study.

3.2.9. Recycled Aggregate Used in Concrete (AG9)

Project workers can extract some materials after the excavation or the demolition processes. Before anything, they shall divide these deposits and exclude any harmful or toxic substances. The reusable materials are called recycled materials as we prepare them before using. This action saves the deposit storages required and protects the environment. This requirement was mentioned in references [1,5].

3.2.10. Components of Recycled Aggregate (AG10)

The reusable or recycled materials are those which are extracted from deposits. It may contain old concretes, smashed bricks or mixed aggregates. Every type of recycled material has a specific strength, durability and cost. This requirement was suggested in the pilot study.

3.2.11. Location of Aggregate Storage (AG11)

Some stakeholders prefer to prepare storage for their aggregates. They think that this storage protects aggregates from robbery, temperature and other weather conditions. This storage may charge stakeholders a lot of costs to be hired. The location of this storage may or may not be near to the construction site. This requirement was suggested in the pilot study.

3.3. Reinforcement Steel (RFT)

The present research discusses some requirements which affect the RFT shape, transportation, corrosion removing and the storage processes. The type of RFT bars has a great effect on sustainability. For example, the replacement of steel bars by fibres guarantees higher sustainability index [7]. This category represents the effect of RFT requirements on the concrete sustainability. References [7,12,15] mentioned the RFT effect on the concrete sustainability.

3.3.1. Transportation Type (RFT1)

We fabricate RFT and the procurement process is done in hangers. There are many types of transportation means like trains, Lorries and ships, as researchers of this study mentioned before in 3.2.8. This requirement was suggested in the pilot study.

3.3.2. Distance between Site and Hangers (RFT2)

There is a distance between the hangers of RFT and the site. This distance may be short or long. There is a relationship between the distance and the transportation mean used to move RFT bars [1].

3.3.3. RFT Corrosion Removal before Using (RFT3)

Engineers cannot use the corroded RFT bars. These bars may spoil the concrete and the repairs which will be needed will be too costly compared to the construction costs. To avoid these problems, they must remove any corrosion before using. The removal material may be a chemical substance or sand-shot removing. Every dust-removal method has its cost. This requirement was suggested in the pilot study.

3.3.4. RFT Surface Feel (RFT4)

Engineers deal with steel bars in two different surface feel: smooth or deformed. Every type has its unit weight. Using deformed bars increases the bond between the bars and the concrete. They have to check RFT bars before storage. This requirement was suggested in the pilot study.

3.3.5. RFT Attaching System (RFT5)

We distribute the steel bars in the structural element due to the design. We have to connect the RFT bars to be stable in the forms [1]. We attach the RFT bars by two methods: manual or using rebar tie gun. Rebar tie gun is a tool used electrically to attach bars quickly and with high quality. Every method has a crew of workers with known wages.

3.3.6. RFT Storage Location in Site (RFT6)

Some stakeholders prefer to prepare storage for their RFT bars. They think that this storage protects RFT from robbery, temperature and other weather conditions and this is recommended according to the Egyptian code of construction. This storage may charges stakeholders a lot of costs to be hired. The location of this storage may or may not be near to the construction site. This requirement was suggested in the pilot study.

3.3.7. RFT Diameter (RFT7)

According to design, designers have to use various diameters in their structures. Researchers need to know the effect of the RFT bars diameter on the economic, environmental and social aspects. This requirement was suggested in the pilot study.

3.4. Formworks (FW)

Formworks constructing is process done before placing the RFT bars. The main responsibility of formworks is to mark the concrete shape and carry the structural elements. This category represents the effect of formwork requirements on the concrete sustainability.

3.4.1. Number of Times the Formwork is Used (FW1)

Any type of formworks, engineers used in the site, will be corroded. The more they use the formworks, the less quality of concrete they have. The depleted formworks cannot be recycled. Contractors get rid of these formworks by moving to deposit landfills. There is a special productivity for each type of wood (if the contractor use timber formworks). This requirement was suggested in the pilot study.

3.4.2. Formwork Wood Type (FW2)

There are many types of timber formworks, such as oak, ash, beech, teek, sandal wood and other types. Every type has a defined cost. This requirement was suggested in the pilot study.

3.4.3. Formwork Type (FW3)

Contractor can use timber formworks or steel formworks. Every type has a defined cost. Contractor shall determine the formworks type due to the constructed element. This requirement was suggested in the pilot study.

3.5. Concrete Manufacturing (CM)

Concrete industry passes through many stages like mixing, compacting and curing. Each stage has its technique to be done. This category represents the effect of these requirements on the concrete sustainability.

3.5.1. Sources of Mixing Water (CM1)

Site engineer uses water in concrete by mixing it with cement to help the hydration processes to be done. Water used in concrete must be drinkable. Stakeholders avoid sea and sewage water. This requirement was suggested in the pilot study.

3.5.2. Reusing the Additional Water (CM2)

Some additional water can be obtained from concrete mixing and curing process. The present researchers want to know the effect of reusing the additional water existed on the economic, environmental and social aspects.

3.5.3. Concrete Mixing Method (CM3)

There are three methods for concrete mixing. The project manager creates a crew of labors to handle and mix concrete. He can also use the concrete mixer. A crew of labors needed to put all aggregates, cements, water and any additions into the mixer. He can use the ready-mixed concrete which is performed into a plant near the site and transported and pumped into the site. Every method has a specific cost and its environmental impact. This requirement was suggested in the pilot study.

3.5.4. Concrete Compaction Method (CM4)

Concrete compacting is a process of preparing a homogeneous concrete to fill the formwork. There are two main methods for concrete compacting. The project manager creates a crew to fill the formwork manually. The second method is using a vibrator which is put into the concrete vertically. The duration of compaction shall be moderate to avoid concrete segregation. Every method has a specific cost and its environmental impact. References [7,22] mentioned the importance of the compaction process.

3.5.5. Concrete Curing Method (CM5)

Concrete curing is the process needed to complete the hydration interactions. Completing the hydration interactions provides the concrete with the designed compressive strength. The minimum curing duration is 7 days starting when the concrete is hardening. Site engineers can cure the concrete surface by water sprinkling or using sackcloth. Also they can use polythene sheets which have a specific color allowing known range of the solar radiation [13]. Also they can cure the concretes by steam with temperature of 60°C for 4-6 hours – as mentioned in the Egyptian code for construction – and the curing process starts after 2 hours of concrete pouring, and then they have to keep the concrete wet. Every method has a specific cost and its environmental impact. Also references [1,11] mentioned the importance of the curing process.

3.6. Different Types of Concrete (DC)

Concrete has the second place of consumed materials worldwide after water [24]. The annual production of concrete is estimated by Meyer [17] to be 10 billion tons and expected to reach 18 billion tons by 2050 [16]. The production of concrete had doubled from 170 million m3 per year in 1990s to more than 330 million m^3 per year in 2004 [18].

Each type of concrete is used according to the environment where the concrete will be placed. Default concrete used in Egypt is Portland cement cast in place of concrete. Sometimes, engineers need to use precast or prestressed concrete to get its advantages. Only conventional concrete and prestressed concrete are certified in the Egyptian code. References [2,22] mentioned these requirement's importance for concrete sustainability.

3.6.1. The Optimum Selection of Precast Concrete Plant (DC1)

In Egypt, there are factories to prepare precast concrete, such as Arab Contractor Company, Samcrete Company, Al-Masria for precast concrete and others. Each company has its price lists for their products. The contractor has the right to select the suitable factory. Contractors select the suitable factory due to many considerations, such as the item price and the distance from the plant to the site. This requirement was suggested in the pilot study.

3.6.2. Using Precast Concrete (DC2)

Using precast concrete has its advantages and defects. Using precast concrete reduces the construction duration, allows using high quality concrete, facilitates the construction process and reduces the number of labors required in site. Also using precast concrete increases the construction costs, increases the risk impacts during the transportation and connection, and needs qualified and professional workers. Using precast concrete gives a permission to have a longer span among the beams which reduce the quantity of concrete used. The environmental impact of precast concrete is 12.2% which is lower than in-situ concrete [23]. This requirement was suggested in the pilot study.

3.6.3. Using Prestressed Concrete (DC3)

Most of precast concretes are prestressed concrete. Prestressed concrete is made by using cables in the element section and pre-tensioned/post-tensioned to deliver a negative stress to the section. Then, when the section is loaded, it will have zero stresses. This requirement was suggested in the pilot study.

3.6.4. The Type of Tension Cables (DC4)

The cables used in prestressed concrete are made from high strength steel. Prestressed concrete cables are a group of wires and strands collected together [29]. There are many companies which manufacture these cables. For example, a company called “ArcelorMittal”, which has branches in France, Belgium and Italy, is one of these companies. The constructor can request the tension cables from any company according to his calculations for the delivery time, the quality required and the cables costs. This requirement was suggested in the pilot study.

3.7. Ready-Mixed Concrete (RMC)

Using ready-mixed concrete has its own advantages, but has more risks than site-mixed concrete. Pumping concrete and transporting it from the plant to the site has some precautions. This category represents the effect of these requirements on the concrete sustainability. In GPRS, three credit points are obtainable for clearing the used materials, such as pre-mixed concrete for preventing loss within the stage of mixing.

3.7.1. Using Ready-mixed Concrete (RMC1)

Ready-Mixed Concrete (RMC) is a type of concrete manufactured in plants and its gradients are calculated by computer. All tests for aggregates and cement are administered. This concrete must be subjected to quality control tests. After mixing, engineers of quality control add some materials to delay the concrete setting then deliver this concrete to the site by RMC vehicles. The contractor shall take into consideration the time agreed for the RMC vehicles arrival. This requirement was suggested in the pilot study.

3.7.2. The Distance between Site and Ready Mixed Plant (RMC2)

The contractor has the availability to select the RMC plant to request the concrete needed. RMC plant is not necessary to be near to the site. This distance affects the concrete characteristics as mentioned in reference [1].

3.7.3. The Casting Distance from the Pump (RMC3)

When using RMC in the project, it is important to use pump to pour concrete in the formworks. For example, the distance is stipulated in the Egyptian code which is determined a maximum distance of 3.0m in columns and 1.0m in horizontal structural elements to avoid concrete segregation. This requirement was suggested in the pilot study.

3.8. Construction Techniques (CT)

There are some techniques conducted during the construction stage of any project. Insulation underground concretes, inserting project management, soil pore hole, dewatering systems and other requirements can affect the concrete sustainability. This category represents the effect of these requirements on the concrete sustainability.

3.8.1. Humidity Insulation for Concrete (CT1)

Any concrete placed under the ground level may be subjected to ground water. Ground water may carry sulfate, chlorides and other materials which harm the concrete. If these materials penetrate the concrete, it will be enough to corroding RFT bars and weakening the concrete. Therefore, the insulation is very important to protect the concrete items and its RFT bars. This requirement was suggested in the pilot study.

3.8.2. Optimum Selection of a Contractor (CT2)

When starting the construction phase, the owner searches for a suitable contractor as mentioned in reference [1]. Contractor selection depends on the lowest cost and the information presented about previous work. This contractor submits the contract, and then starts constructing the project according to the specifications determined by the owner.

3.8.3. Making a Schedule for the Project (CT3)

The schedule is preparing and arranging the project activities to calculate the estimated duration and cost for this project. This schedule facilitates the construction control and updating. Consequently, it will be very easy to know the reasons of the sequence delays or the cost increases. This requirement was suggested in the pilot study.

3.8.4. Preserving the Architecture Style (CT4)

In compounds, historical areas and modern cities in Egypt, it is recommended to use a defined type of concrete which can preserve the value of the historical areas and the style of the modern cities. This requirement was suggested in the pilot study.

3.8.5. Selecting Dewatering System (CT5)

There are many systems used for dewatering. Two of these systems are well-defined and called: Collecting orchard and deep wells. Collecting orchard system is used when the quantity of water in site is low. Water is collected from the site and is discharged away from the site. Deep wells system is used by excavating deep wells in site and putting a pump in each well to pull water. In this system, the contractor is assumed to provide spare pumps into the site for work continuity. Each system has its costs, crew and duration. This requirement was suggested in the pilot study.

3.8.6. Performing Soil Pore Hole (CT6)

Soil pore hole is performed to know the nature of soil layers. The arrangement of soil layers determines the layer of the highest bearing capacity, the excavation depth and the foundation type. This step consumes money paid by the contractor. Most of structures’ failures are resulted from neglecting the soil pore hole process. So it is important to know the effect of soil pore hole on the economic, environmental and social aspects. This requirement was suggested in the pilot study.

3.9. The Site (SL)

The construction site and its arrangement and cleanliness indicate the contractor professionalism. Saving rest and stabilization for worker and their equipment is very important to create a controlled site. This category represents the effect of site layout requirements on the concrete sustainability. This category was suggested in the pilot study.

3.9.1. Leveling Temporary Roads in Site (SL1)

Contractor shall take into his consideration the importance of leveling some roads in the site. These roads facilitate entering and exiting the vehicles and equipments in and out the site. Also leveling roads reduces the dust upcoming from the site. This step may increase the costs for the contractor but in the same time it reduces the costs of vehicles and equipments maintenance when hiring them.

3.9.2. Cleaning the Site (SL2)

The contractor and workers shall work in a clean environment to increase their productivity. Cleaning the site is represented into removing wastes out from the site to disposal locations, arranging the movement and maneuvering of equipments in the site and material storage in the specific locations. In GPRS, one credit point is obtainable for demonstrating a strategy to minimize pollution during construction stage.

3.9.3. Constructing Homes for Labors in Site (SL3)

Labors' movements from homes to the site consume much time and money. Adding to that, these movements affect the productivity of workers. Constructing homes for workers shall be done once the contractor has the site discretion. He shall prepare the best location for these caravans to avoid work obstruction in the site. These homes/caravans need much money. Saving homes for workers helps to achieve the schedule.

3.10. H.R. (HR)

Human resources (HR) are important for labors and workers serving. This category represents the effect of this corporation on the concrete sustainability. This category was suggested in the pilot study.

3.10.1. Employment of Labors and Engineers during Construction (HR1)

Like most projects, constructing projects saves opportunities for working. These opportunities help to reduce the unemployment rates. Also this work will add to the project as stakeholders will exploit all experts in the required fields. Salaries and wages will be needed. All nominated experts must be committed to safety requirements and instructions in the site.

3.10.2. Training Labors and Engineers during Construction (HR2)

Like most projects, constructing projects saves opportunities for training. These opportunities help trainees get more experiences. Any training needs responsibilities to control the large numbers of trainees. Trainees must be committed to safety requirements and instructions in the site.

3.11. Waste Disposal (WD)

Many wastes can be disposed and others can be recycled and reused again due to its recyclability and its components. Transport unusable wastes to landfills consume money and time. This category represents the effect of waste requirements on the concrete sustainability.

In GPRS, two credit points are obtainable for presenting "The Project Waste Management Plan" that obtains strategies for reducing, recycling and re-using the waste produced from the site. Other two credit points are obtainable for hiring a company which has an experience in recycling of building materials and waste disposal.

3.11.1. Saving a Location for Waste Disposal (WD1)

Waste disposal shall be done before construction when the site is filled with wastes, and after construction to get rid of any unused residuals. Transport these wastes has its costs. We shall plan the waste management and provide a space for the storage of recyclable and reusable materials [9]. The disposal site may be private (hired by the contractor) or public landfills. This requirement was suggested in the pilot study.

3.11.2. The Distance between Site and Waste Disposal Site (WD2)

Moving wastes to landfills consumes money and time. The less the distance between the site and landfills is, the less money and duration are consumed to transport these unusable wastes. This requirement was suggested in the pilot study.

3.11.3. Concrete Quantities in Waste (WD3)

After construction process, especially the concreting process, quantities of concrete are kept without using. This concrete hardens and becomes unusable to be mixed again. Site engineers can use it as recycled aggregates. Increasing the rate of these concretes indicates that there is over waste during the concreting process, thus there is wasting in costs. This requirement was mentioned in reference [1].

3.11.4. Recycled Aggregate Quantities in Waste (WD4)

After construction stage, there are quantities of wastes in the site. They shall be divided to know recyclable materials and unusable wastes. The recyclable materials are subjected to some processes to be reused. These recycled aggregate will be replaced with natural aggregate in concrete mixtures. This requirement was mentioned in reference [1].

3.11.5. Toxic Materials Percentage in Waste (WD5)

Toxic materials and deposits may appear after the construction process. These toxic materials are extracted from insulation materials and other cementitious additions used in the construction. If these materials are existed in the upcoming wastes, they must be excluded. Using these toxic materials affect the environment and population health. This requirement was suggested in the pilot study.

3.11.6. Obtaining Dust Removal System in Site (WD6)

There are some systems used to remove dust from the construction sites. The default system used in a small project is sprinkling water on the land. In other projects, engineers use large fans to pull out the dust. It is assumed that there is a difference in each system's cost. This requirement was mentioned in reference [1].

3.11.7. Cleaning the Site (WD7)

This requirement is previously mentioned to know people who are not interested in this questionnaire. Any different answers in this requirement in "waste disposal" and "The site" categories were neglected.

3.12. Security and Safety (SS)

There are souls in the site, so it is a must to save them and work without disturbing the surrounded environment. This category shows the effect of safety requirements on the concrete sustainability. This category was suggested in the pilot study.

3.12.1. Achieving the Essential Safety Precautions (SS1)

Committing with safety precautions is an essential thing in the site to preserve workers' life. The contractor must provide the site with warning plates, warning lighting, safety uniform and fences. These items cost the contractor much money but save the treatment costs in cases of injuries. The project manager must force all engineers and workers in the site to commit with all mentioned precautions.

3.12.2. Saving Places for the Hospitalization (SS2)

In case of injuries, it is assumed to provide a place for the hospitalization. This place must be ready at any time to receive injuries. Doctors must be existed – by shifts – to present the required first aids. These doctors have their own salaries.

3.12.3. The Nuisance in the Site (SS3)

During the construction process, workers produce more nuisances which disturb the nearby neighbors. The contractor shall define the working hours in the site to avoid this problem. Some neighbors may resort by legal way to prosecute the responsible person for these nuisances and get compensations.

3.12.4. All Risks Occur in the Site (SS4)

Risks are anything unexpected to happen. Risks may be – for example – the failure in excavation sides, pumps blocking out, obstructions on the roads connected to the site, increasing the material prices, weather conditions force the construction to stop and other complicated reasons. Each risk needs much money to be solved and wastes much time. So, the contractor adds "risk allowance" to his contract to avoid these risks.

In 2015, El-nagar identified some factors considered for the safety performance in the construction projects in Egypt [8]. She made a questionnaire survey to identify the relative importance of the suggested factors. After analysis, she found that the most effective factor for safety performance is the working environment. Also it is very important to make a safety training plan for workers, supervisors and project managers. It is important to know the effect of these risks on the economic, environmental and social aspects.

4. Questionnaire Survey

4.1. Sample Size

To define the number of questionnaires needed, the population must be calculated. The present researchers have to calculate the sample size to make sure that the questionnaire will give all needed satisfaction, so authors of this study need to use a simple equation to calculate the sample size. After preparing the questionnaire, they see that the population with whom they deal is undefined [27]. The equation of the undefined population should be:

$$N=\frac{Z^2\times\sigma(1-\sigma)}{E^2}V \quad (1)$$

As:
N = Sample size
σ = standard deviation,
E = Margin of error,
Z = Confidence level,
If: Confidence 0.90 (90%): Z = 1.645
Confidence 0.95 (95%): Z = 1.96
Confidence 0.99 (99%): Z = 2.58
Assume:
Confidence 0.95 (95%): Z = 1.96
E = 5%, σ = 0.5
By substituting:

$$N=\frac{1.96^2\times0.5(1-0.5)}{0.1^2}=96.04=96 \text{ Samples} \quad (2)$$

It was found after reviewing literature and previous studies that the questionnaire number of undefined population is 100 at least. At this point, it is needed to fill 100 questionnaires at least to be scientifically accepted.

After having the final shape of the questionnaire, filling it out was directly with people or by e-mails. Also it was sent to people in some universities by post. Therefore, the survey was prepared on the Google form and filled as soon as it has been finished. The number of population components is determined, as shown in Figure 1.

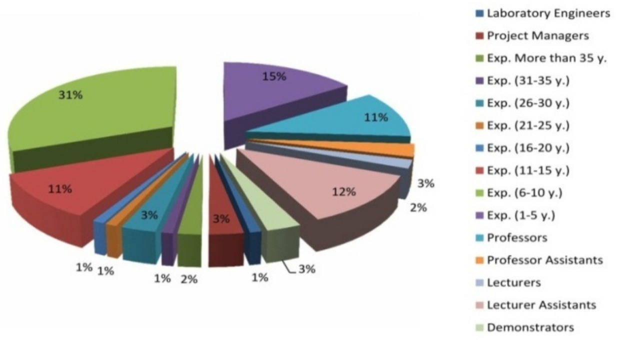

Figure 1. Percentage of population classification

4.2. Data Collected

Authors of this study got the entered answers from Google form and collected them in charts. These answers were the viewpoints of 100 persons; every one filled out a questionnaire of 59 questions, and each question was concerned with the effectiveness of the economic, environmental and social aspects. Each aspect per each question shows the number of persons who answered (I don't know), (has no effect), (has weak effect), (has medium effect) and (has strong effect).

To summarize the effectiveness labels, they gave (I don't know) [NA] symbol, (has no effect) [N] symbol, (has weak effect) [W] symbol, (has medium effect) [M] symbol and (has strong effect) [S] symbol.

They made a statistics for the sample answers in Excel sheet. For each question, they classified the research subjects due to their answers. For example, if they need to know how many subjects selected that the effect of using RMC is strong for the economic aspect, they would know that 79 subjects selected the strong effect on the economic aspect, and so on, as shown in Table 4. They investigated that every aspect of each question had 100 answers.

Table 4. Results of Questionnaire Survey

ID	Requirement	On economic aspect				
		N	W	M	S	NA
1	Effect of using RMC	0	0	18	79	3

4.3. Weighted Mean

The authors of the present study have to get the weighted mean for each requirement. As shown in the previous table, the choice for the effectiveness varies depending on the requirement studied. They got the weighted mean for each requirement by multiplying [NA] subjects by (0.0). The result was added to [N] subjects multiplied by (1.0). The result was added to [W] subjects multiplied by (2.0). The result was added to [M] subjects multiplied by (3.0). Also the result and added to [S] subjects multiplied by (4.0). Then the final result was divided by the sum of [N], [W], [M] and [S] subjects multiplied by (4.0).

Then, [NA] subjects were neglected in the weighted mean they did not have any idea about these requirements, and taking them into consideration would affect the mean. Authors wanted to know the most effective requirement for the economic, environmental and social aspects. Therefore, after calculating the weighted means, they decided to sort all 59 requirements from larger to smaller in the 3 pillars

Each requirement had 3 values, and authors expressed the requirement by 1 value only. So, they gave the economic aspect 50% of sustainability effectiveness, 33% for the environmental aspect and 17 % for the social aspect as done in weighting aspects by Pons [22]. Thus, authors got one value to each requirement by sum of multiplying the economic value by (0.5) added to the environmental value multiplied by (0.33) added to the social value multiplied by (0.17)

From the final equation, authors got one value for each requirement expressing the effectiveness of the 3 aspects on the concrete sustainability, as shown in Table 5.

Table 5. Relative Values of Requirements

Category	ID	Eco.	Environ.	Social
Cement Industry (CI)	CI1	0.84	0.81	0.51
	CI2	0.91	0.81	0.54
	CI3	0.84	0.84	0.52
	CI4	0.82	0.66	0.45
Aggregate Requirements (AG)	AG1	0.77	0.63	0.46
	AG2	0.83	0.76	0.51
	AG3	0.83	0.71	0.51
	AG4	0.76	0.64	0.53
	AG5	0.87	0.76	0.60
	AG6	0.66	0.59	0.39
	AG7	0.81	0.78	0.51
	AG8	0.84	0.72	0.63
	AG9	0.89	0.86	0.69
	AG10	0.87	0.86	0.63
	AG11	0.83	0.87	0.71
Reinforcement Steel (RFT)	RFT1	0.84	0.69	0.58
	RFT2	0.86	0.71	0.54
	RFT3	0.87	0.81	0.58
	RFT4	0.79	0.57	0.40
	RFT5	0.82	0.52	0.54
	RFT6	0.84	0.72	0.61
	RFT7	0.69	0.37	0.34
Formwork (FW)	FW1	0.95	0.80	0.65
	FW2	0.94	0.67	0.58
	FW3	0.94	0.71	0.61
Concrete Manufacturing (CM)	CM1	0.83	0.85	0.69
	CM2	0.78	0.82	0.65
	CM3	0.73	0.81	0.66
	CM4	0.82	0.77	0.56
	CM5	0.85	0.74	0.53
Different Types of Concrete (DC)	DC1	0.89	0.81	0.59
	DC2	0.92	0.85	0.68
	DC3	0.94	0.78	0.65
	DC4	0.89	0.62	0.48
Ready-Mixed Concrete (RMC)	RMC1	0.95	0.86	0.75
	RMC2	0.89	0.79	0.63
	RMC3	0.79	0.71	0.52
Construction Techniques (CT)	CT1	0.90	0.90	0.69
	CT2	0.94	0.82	0.82
	CT3	0.92	0.70	0.69
	CT4	0.86	0.80	0.86
	CT5	0.94	0.88	0.73
	CT6	0.94	0.80	0.76
The Site (SL)	SL1	0.87	0.82	0.69
	SL2	0.79	0.92	0.82
	SL3	0.84	0.80	0.86
H.R. (HR)	HR1	0.87	0.60	0.86
	HR2	0.73	0.66	0.89
Waste Disposal (WD)	WD1	0.91	0.98	0.81
	WD2	0.93	0.91	0.73
	WD3	0.86	0.90	0.70
	WD4	0.83	0.90	0.63
	WD5	0.83	0.96	0.77
	WD6	0.84	0.95	0.81
	WD7	0.81	0.94	0.84
Security and Safety (SS)	SS1	0.87	0.76	0.91
	SS2	0.79	0.71	0.85
	SS3	0.65	0.92	0.84
	SS4	0.83	0.80	0.90

5. Results and Discussion

Every requirement was put in its category, and added its final rank in a table. The weighting of each requirement was calculated due to its category. Then, a weight for each category was conducted. The weights of each requirement were calculated, as shown in Table 6, by:

$$\frac{\text{the final value of requirement}(i)\times 100}{\text{the sum of requirements' values in the same category}} \quad (3)$$

Table 6. Percentages of Indicators

Category	ID	Final Value	Percentages
Cement Industry (CI)	CI1	0.77	25.16%
	CI2	0.81	26.47%
	CI3	0.78	25.49%
	CI4	0.70	22.88%
Aggregate Requirements (AG)	AG1	0.67	8.16%
	AG2	0.75	9.14%
	AG3	0.74	9.00%
	AG4	0.68	8.28%
	AG5	0.79	9.62%
	AG6	0.59	7.19%
	AG7	0.75	9.14%
	AG8	0.76	9.26%
	AG9	0.84	10.23%
	AG10	0.82	9.99%
	AG11	0.82	9.99%
Reinforcement Steel (RFT)	RFT1	0.75	15.31%
	RFT2	0.75	15.31%
	RFT3	0.80	16.33%
	RFT4	0.65	13.26%
	RFT5	0.67	13.67%
	RFT6	0.76	15.51%
	RFT7	0.52	10.61%
Formwork (FW)	FW1	0.85	34.69%
	FW2	0.79	32.25%
	FW3	0.81	33.06%
Concrete Manufacturing (CM)	CM1	0.81	21.10%
	CM2	0.77	20.05%
	CM3	0.74	19.27%
	CM4	0.76	19.79%
	CM5	0.76	19.79%
Different Types of Concrete (DC)	DC1	0.81	25.08%
	DC2	0.85	26.31%
	DC3	0.84	26.01%
	DC4	0.73	22.60%
Ready-Mixed Concrete (RMC)	RMC1	0.89	36.78%
	RMC2	0.81	33.47%
	RMC3	0.72	29.75%
Construction Techniques (CT)	CT1	0.86	16.77%
	CT2	0.88	17.15%
	CT3	0.81	15.79%
	CT4	0.84	16.37%
	CT5	0.88	17.15%
	CT6	0.86	16.77%
The Site (SL)	SL1	0.82	32.93%
	SL2	0.84	33.74%
	SL3	0.83	33.33%
H.R. (HR)	HR1	0.78	51.66%
	HR2	0.73	48.34%
Waste Disposal (WD)	WD1	0.92	15.16%
	WD2	0.89	14.66%
	WD3	0.85	14.00%
	WD4	0.82	13.51%
	WD5	0.86	14.17%
	WD6	0.87	14.33%
	WD7	0.86	14.17%
Security and Safety (SS)	SS1	0.84	26.09%
	SS2	0.78	24.22%
	SS3	0.77	23.91%
	SS4	0.83	25.78%

We calculated the weight of each category to know the effectiveness of each category on the concrete sustainability. We calculated the weights of categories as shown in Table 7 by:

$$\frac{\text{the sum of requirements' values in category}(i)\times 100}{\text{the sum of all requirements' values}} \quad (4)$$

Table 7. Weights of Categories

Cat. NO.	Category	Category Coding	Effect Percentage
1	Cement Industry	CI	6.58%
2	Aggregate	AG	17.64%
3	Reinforcement Steel	RFT	10.53%
4	Formwork	FW	5.27%
5	Concrete Manufacturing	CM	8.25%
6	Different Types of Concrete	DC	6.94%
7	Ready-Mixed Concrete	RMC	5.20%
8	Construction Techniques	CT	11.03%
9	Site	SL	5.35%
10	H.R.	HR	3.25%
11	Waste Disposal	WD	13.04%
12	Security and Safety	SS	6.92%

6. Conclusion and Recommendations

The main aim of this study was identifying the main requirements which may affect the sustainability of concrete and developing the relative weights of these requirements. A list of requirements was identified from the literature review and the pilot study conducted by discussing the experts in the construction field.

A questionnaire survey was prepared to calculate the relative weight of the concrete sustainability requirements. The questionnaire included 59 requirements divided into 12 categories. The questionnaire was prepared in Arabic and English versions.

After having the final design of the questionnaire, filling it out was done by subjects. Some people refused to say their personal data, such as their names or mobile numbers. The analysis was carried out manually using simple functions on Microsoft Excel.

After analysis, researchers found that the most important factors were related to "Aggregate" category. Aggregate category has the weight of 18% approximately and waste category has the weight of 13% approximately. These two categories have about 31% of concrete sustainability weight. "RMC" category has the least effect on the concrete sustainability as its weight was 5.20%. RMC could be neglected, as its usage is limited in Egypt. The weights of categories are shown in Figure 2.

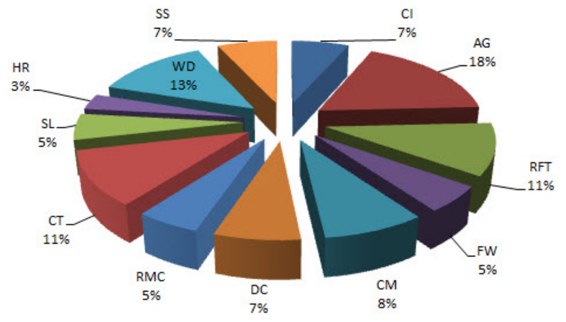

Figure 2. Weights of Categories

In CI category, the most important requirement was the cementitious additives. In AG category, the most important requirement was the recycled aggregate in which is used in concrete. In RFT category, the most important requirement was the corrosion removal. In FW category, the most important requirement was the number of times the formwork is used. In CM category, the most important requirement was the sources of mixing water. In DC category, the most important requirement was the effect of using precast concrete.

In RMC category, the requirement of casing distance had the less effect on the concrete sustainability. In CT category, the most important requirements were the contractor selection and the dewatering-system selection. In SL category, the most important requirement was the site cleaning. In HR category, the most important requirement was the employment of labors and engineers during the construction phase. In WD category, the most important requirements were the distance between the site and dumpsite, and the effect of saving a location for waste disposal. Finally, in SS category, it is very important to take into consideration achieving the essential safety precautions during the construction phase.

It was very clear after researching in The Green Pyramid Rating System "GPRS" that the concrete sustainability was neglected, and its committee dealt with the building sustainability like most rating system applied all over the world.

Authors of this study should add more requirements in the construction techniques like the concrete covering. They should also investigate the effect of saving places on cement storage, effect of the cement fineness on the concrete sustainability and the effect of all requirements for the concrete strength and durability. They should also increase the sample size from various and separated locations to increase the confidence of level.

References

[1] Aguado, A., Del Caño, A., De la Cruz, M.P., Gomez, D., and Josa, A., "Sustainability assessment of concrete structures within the Spanish structural concrete code", *Journal of Construction Engineering and Management*, 138(2), 268-276, 2011.

[2] Al-Tamimi, A. K., Ibrahim, A. and Al-Sughaiyer, N., "Evaluation of Sustainability of Multistory Reinforced Concrete Structure," *Physics Procedia*, 55, 445-450, 2014.

[3] Andrade, J.B. and Bragança, L., "Analysis of the impacts of economic and social indicators to sustainability assessment," *in International Conference Sustainability of Constructions Towards a Better Built Environment*, University of Malta, Faculty for the Built Environment, 163-168, 2011.

[4] BREEAM, U.K., New Construction: Non-domestic buildings, Technical Manual SD 5076:0.1, 2014.

[5] Butler, L., West, J.S. and Tighe, S.L., "The effect of recycled concrete aggregate properties on the bond strength between RCA concrete and steel reinforcement," *Cement and Concrete Research*, 41(10), 1037-1049, 2011.

[6] Council, U.G.B, LEED v4 User Guide, 2013.

[7] De la Fuente, A, Blanco, A., Armengou, J.B. and Aguado, A., "Sustainability based-approach to determine the concrete type and reinforcement configuration of TBM tunnels linings. Case study: Extension line to Barcelona Airport T1," *Tunnelling and Underground Space Technology*, 61, 179-188, 2017.

[8] El-nagar, R., Hosny, H. and Askar, H.S., "Development of a Safety Performance Index for Construction Projects in Egypt," *American Journal of Civil Engineering and Architecture*, 3(5), 182-192, 2015.

[9] Gurgun, A.P., Komurlu, R. and Arditi, D., "Review of the LEED category in materials and resources for developing countries," *Procedia Engineering*, 118, 1145-1152, 2015.

[10] Hooton, R.D. and Bickley, J.A., "Design for durability: the key to improving concrete sustainability," *Construction and Building Materials*, 67, 422-430, 2014.

[11] Ibrahim, H.A., Abdul Razak, H. and Abutaha, F., "Strength and abrasion resistance of palm oil clinker pervious concrete under different curing method," *Construction and Building Materials*, 147, 576-587, 2017.

[12] Inman, M., Thorhallsson, E.R. and Azrague, K., "A mechanical and environmental assessment and comparison of basalt fibre reinforced polymer (BFRP) rebar and steel rebar in concrete beams," *Energy Procedia*, 111, 31-40, 2017.

[13] Kewalramani, M.A., "Environmentally Sustainable Concrete Curing with Coloured Polythene Sheets," *APCBEE Procedia*, 9, 241-246, 2014.

[14] Kusuma, G.H., Budidarmawan, J. and Susilowati, A., "Impact of Concrete Quality on Sustainability," *Procedia Engineering*, 125, 754-759, 2015.

[15] Lapko, A. and Urbański, M., "Experimental and theoretical analysis of deflections of concrete beams reinforced with basalt rebar," Archives of Civil and Mechanical Engineering, 15(1), 223-230, 2015.

[16] Mehta, P.K. and Monteiro, P.J., "Concrete: microstructure, properties, and materials. 2006," 2006.

[17] Meyer, C., "The greening of the concrete industry," *Cement and concrete composites*, 31(8), 601-605, 2009.

[18] Mobasher, B., "USA-concrete construction industry-cement based materials and civil infrastructure," *CBM-CI International Workshop, Karachi, Pakistan*, 73-90, 2008.

[19] Naik, T.R., "Sustainability of cement and concrete industries," *in Proceedings of the international conference global construction: ultimate concrete opportunities, Dundee, Scotland*, 141-150.

[20] Ontario Ministry of Transportation, Material Specification for Aggregates - Concrete, OPSS 1002, 2004.

[21] Palankar, N., Shankar, R. and Mithun, B.M., "Studies on eco-friendly concrete incorporating industrial waste as aggregates," *International Journal of Sustainable Built Environment*, 4(2), 378-390, 2015.

[22] Pons, O. and De la Fuente, A., "Integrated sustainability assessment method applied to structural concrete columns," *Construction and Building Materials*, 49, 882-893, 2013.

[23] Rashid, A.F. and Yusoff, S., "A review of life cycle assessment method for building industry," *Renewable and Sustainable Energy Reviews*, 45, 244-248, 2015.

[24] Sakai, K., "Towards environmental revolution in concrete technologies," *in Proceedings of the 11th Annual International fib Symposium, Concrete: 21st Century Superhero, London*, 2009.

[25] Sarja, A, "Lifetime engineering of buildings and civil infrastructures as a realization of sustainable construction," *Texnika xponika*, 1-13, 2004.

[26] Sarja, A., and Vesikari, E., “Durability design of concrete structures,” *CRC Press*, 14, 2004.

[27] Smith, S.M., "Determining Sample Size: how to ensure you get the correct sample," 2013. [online]. available: https://www.qualtrics.com/blog/determining-sample-size/ [Accessed Apr. 8, 2013].

[28] Tasci, B.G., "“Sustainability” Education by Sustainable School Design," *Procedia-Social and Behavioral Sciences*, 186, 868-873, 2015.

[29] The Egyptian Code of Design and Construction the Concrete Structures, 2009, 10.3.

[30] The Green Pyramid Rating System (GPRS) (1), 2011. [online]. available: http://eg.saint-gobain-glass.com/download/file/fid/1246.

[31] The Green Pyramid Rating System (GPRS) (2), 2017. [online]. available: http://www.egypt-gbc.gov.eg/ratings/.