Innovative Geotechnical Solutions for Sustainable Infrastructure Development

ABSTRACT

Aim: To examine innovative geotechnical solutions for sustainable infrastructure development.

Problem Statement: The advancement in the world urbanization together with high rise in global population has alarmed the need for new infrastructures with additional innovative research to be conducted with already existing assets. Thus, It is important that geotechnical engineering should include basic practicestargeting resource-efficient and environment-friendly techniquesin order to add to sustainable development.

Significance of Study: This technical review critically examines the innovative geotechnical solutions for sustainable infrastructure development. The content presented in this manuscript will be beneficial to professionals in the area of geotechnical engineering.

Methodology: Recent relevant published articles in the area of innovative geotechnical solutions for sustainable infrastructure developmentwere consulted.

Discussion: The six main environmental objectives of the Taxonomy Regulation to ensure the contours of an environmentally sustainable infrastructure were stated to include: (1) sustainable protection and use of marine and water resources (2) pollution control and prevention (3) switch to a circular economy (4) mitigation of climate change (5) restoration and protection of ecosystems and biodiversity and (6) adaptation of climate change. The three phase methods for sustainability infrastructure development in geotechnics were critically discussed. An imaginary excavation site in the municipality of Rozzano was referenced as a case study to reveal the application of the proposed methodology to the soil treatment systems. It was noticed that the adoption of an LCA introduces additional deep knowledge and the required quantitative analysis for sizing the assessment.

Conclusion: The examined innovative geotechnical solutions were contributory to sustainable infrastructure development.

Keywords: Geotechnical Solutions, Sustainable Infrastructure Development, Life Cycle Assessment, Building Information Modeling,EU Taxonomy

1. INTRODUCTION

The increase in the global urbanization trend alongside population growth with scarcity of resources greatly influences the quest for new infrastructures together with a more significant requirement for the renovation of the existing assets [1].This usually leads to the establishment of underground urban planning policies for the management of different current flows which include energy,goods,waste, water,people. This makes the utilization of underground infrastructures to be a priority. Although the methods utilized in building these infrastructuresare becoming more progressive and effective, environmental and sustainability footprint do not follow the same pattern. Particularly, the instruments for an incorporatedevaluation of the sustainability in environmental, social and economic terms are inadequate [2]. This is due to the fact that underground engineering environment is still a new field of engineering and it is required that it is calibrated on basic requirements, in other words it can be described as prototypical field of science and engineering. This transition is supported by the EU Green Procurement System which stands as a mechanism for the encouragement of the construction industryto make referenceto operational decisions which are productive, technological and organizational, based on the optimization and reduction of the general environmental footprint associated with the corporate sustainability strategy [3].

It is highly essential that geotechnical engineering should include a principal practice that is focused on resource-efficient and environment-friendly approachesin order to add to sustainable development. This is addressed clearly to geotechnics towards the selection of construction materials and applicable technology that can add to impact reduction. Therefore, a consistent and holistic sustainability evaluation framework is important. This has previously been emphasized for geotechnical projects in order to assure the relative benefits of variousavailable options for underground construction projects. With their growing variability and variations of technologies, ground improvement methods stand as an ideal testing area for a sustainability-based design method. On the other hand, it is necessary focusing on the technologies and processes efficiency, while a complicated variety of materials is involved on the other side [4].

1.1 INNOVATIVE GEOTECHNICAL SOLUTIONS

In order to ascertain the contours of an environmentally sustainable infrastructure, the Taxonomy Regulation spells out six main environmental objectives to include (1) sustainable protection and use of marine and water resources (2) pollution control and prevention (3) switch to a circular economy (4) mitigation of climate change (5) restoration andprotection of ecosystems and biodiversity and (6) adaptation of climate change [3]. With reference to the above points, the regulation also states that an economic activity shall be stated as being environmentally sustainable if the following requirements are met: (1) significantly contributes to at least one environmental objective (2) obeys nationally and locally applicable technical screening criteria (3) do not significantly harm any other environmental objective and (4) complies with the least social safeguards stated on a local national basis. The EU taxonomy framework makes provision forthe construction industry to have a general criterion for sustainability assessment which serves as a precondition in accessing financial leverage and funding [5].

In the last decade, general sustainability procedures for construction and infrastructure industry sectors have acquired momentum. There are various reasons that justify this array allowing the infrastructure construction industry to beunwilling to change and conservative. Infrastructure usually belongs to public owners, cost control, safety and operational performance which represent a complicated set of drivers during selection and designing of construction processes basically via public procurement [6]. Nonetheless, construction in recent years has influenced the development of green building rating systems to enable measuring building life cycle performance with reference to the necessity for sustainable development and green construction. The transformation of the way communities and cities are designed, operated and created has been improved with the implementation of certificationsin methodological design techniques in building industry such as Green Building Council, BIM, Lean and LEED. This is purposely to improve the quality of life of people globally. These programs give a framework for designing,planning, measuring, and managing economic, social and environmental scenarios at both city and community levels. The given points by LEED via an online scoring system include waste reduction,resources and materials,site selection, energy and atmosphere,design innovation, locations and linkages,interior environment qualityand regional significance [7].

Building Information Modelling (BIM) methodology is applied in designing modern buildings. The architectural, engineering, and construction (AEC) industry observes this as a vast possibility being an end-to-end process and platform. Building information modeling (BIM) provides a collaborative channel for perfect digital modeling in virtual environments for construction projects [8]. This makes BIM to be among the most interesting advancements in the architectural, engineering, and construction (AEC) industry. BIM advancementas a system has brought the possibility of information integration and management in the entire building existence which makes using existing design data to be possible for performance and planning analysis that is both effective and sustainable.The designer utilizes tools to her BIM for the creation ofthe structure 3D model for the utilization of design materials [9].

In a similar way, waste minimization and construction process improvement are attained in the construction industry using lean principles. Waste inflicts negative influence on the environment and minimizes productivity. Although '*energy-waste*' and '*waste-to-resources*' have been proved to be more relevant waste solutions, they can improve the project costs and lead to extra environmental challenges. Lean construction has also exhibited additionalbroadly accepted attributes in recent years. A method that allows less money,time, space and resources tagged "*doing more with less*' has been linked with Lean Thinking focusing on delivering value-added materials to customers with the objective of waste minimization via better effective processes that optimize the principal production value chain competencies [7]. Lean thinking plays a key role as a transformative system which operationalizes organizational learning and promotes innovation that allows managing of limited resources by businesses. Many approaches and tools have been developed purposely to advance the construction process for safer, better quality, less costly and easy management than the conventional ones. These tools and approaches were establishedwith reference to the lean thinking methodology and reports indicating that the construction industry is among the least efficient. Decrease in resources and energy usage is usually achieved with the combination of lean initiatives (which requires little space for storage and operation) with a less prone defects production [8].

By so doing, significant environmental advantages are promoted with the modification of such methods to handle current environmental challenges. Other methodologies such as BIM, as a result synergy of reducing waste and improving construction processes, has been lately combined withLean Construction. While boosting sustainability based on the goals by BIM and Lean, there is a huge opportunity of increasing efficiency and productivity. Numerous enterprises in the construction sector have the ability of revolutionizing the way operations are conducted via the incorporation of Lean, BIM and sustainability practices within theirorganizations. This is due to the fact that an adequate integration needs counting via this technique [10]. There is morechances of boosting efficiency and productivity while enhancing sustainability based on BIM and Lean objectives. The incorporation of voluntary Envision protocol is becoming prevailing in advanced world in order to develop dedicated frameworks.

A framework that makes provision for the required guidance to start a systemic transformation in the design, planning and delivery of resilient and sustainable infrastructure is called envision, as demanded by the EU Green Deal.This framework involves 64 resilience and sustainabilityindicators referred to as "credits" formed around five categories which are Quality of Life, Resource Allocation, Leadership, Climate and Resilience, and Natural World. These indicators jointly explaincommunity development,emissions,mobility,human wellbeing,materials,ecology,economy,siting,conservation, planning,resilienceenergy, collaboration and water. Each of the 64 credits has numerousachievement levels of representing the spectrum for possible performance objectives, from faintly improving past traditional practice to restoring and conserving and environments and communities. The rate at which a certain project expresses the complete range of sustainability indicators can be evaluated via the assessment of the achievement in each credit. This stands to be more challenging for the pursuance of higher performance [5].

The major challenge of infrastructural set-ups is to attain cooperation between comprehensively and adequatelyexpressing the sustainability principles with the provision of an accessible and understandablescheme to professionals and clients.Assessment instrument of this kind and category are vital in sustainability knowledge dissemination and practices amidst the subjects that utilize them in the communities in which they are interacting, in projects and within the organizations in which they are working. The infrastructure sustainability assessment tools impactsare unlimited to projects experiencingcertification and assessment which also extend to the whole infrastructure sector via their informal usage at organizational and individual sectors [7]. Nonetheless, there is limitation of combining and integrating these methods with more standardized environmental design and environmental performance assessment. Thus, the integration of these methods with LCA methodology can be a powerful and an effective means of successfully executingconstruction and infrastructural projects.

2.0 SUSTAINABILITY INFRASTRUCTURE DEVELOPMENTIN GEOTECHNICS

2.1 Tailoring of a Combined Method

An explicit analysis is required by the EU regulation to know whether an economic activity could be significantly considered dangerous via the already incorporated frameof the DNSH criteria while noting the life cycle of the services and products it provides including proof from existing life-cycle assessments.Both the environmental impact of the services or products and the environmental impact of the activity that were made available throughout the life cycle of the economic activity should be taken into account during its assessment against the targets. Particularly, the use, production and end of life of those services and products should be considered.The regulator intends to mandateowners, investors, constructors and designers to design a sustainability technique for their projects rather than just generic benefits or a distributed series of environmentally friendly schedules. Likewise as designers, pure compliance verification against the six targets will not be in accordance with the decision-makers to evolve their projectsnature [11]. Thus, the adoption of an overall sustainability rating protocolfor the project based on well-recognized and consistent indicators within a sustainable, comprehensive and structured technique that adequately mergeseconomic needs and performance with environmental and social perspectiveswas suggested as a first step.The Envision protocol could equally be in accordance with this specific need.

The Envision protocol is solid and well-structured and allows a simple preliminary technique that is very resourceful in this framing phase. This can be executed via the selection of the most significant indicators and signifying the suitable leverages that play a vital role in sizing the project sustainability rating [12].This phase is important because it enables the perfection of the project's general strategy and focuses the stakeholders' attention on the social and environmental hotspots asides the cost or technical performance. The attention on the project sustainability strategy will be more accessible and strongto share amidst the stakeholders with this firstframing. Envision application is also usefulwith reference to the EU Taxonomy. It is feasible to signify a connection between the six targets cited EU Regulation and the Envision indicators following the path traced by ICMQ. This is a candid way of checking the project against the DNSH criteria with the adoption of the Envision analysis as the metric basis for EU compliance. Nonetheless, there is a vital integration of the DNSH assessment dealing alone with the environment into the Envision protocol considering the social and economic aspects thus substantiating the three ESG factors. Many of the Envision credits directly influence the objectives stated in the 2020/852 Regulation. Additional credits indirectly contribute but effectively to attaining the objectives within the protocol [13].

2.2. The necessity for an LCA cradle-to-gate analysis

The proposed simplified assessment tool required in the first step of the methodology forms the outlining for the specific construction case. With reference to the Envision protocol rules, a shift in the optimal strategies evaluation from a qualitative type to a quantitative one by the decision maker is executed When it comes to indicator ratings definition. Within this transformation, the LCA technique is essential to sustain the decision with a quantitative cradle-to-gate life cycle span precisely expressed to the construction process site which is also referred to as “cradle-to-site”. The setting of an LCA boundary to the site construction process can be significant based on the process. Even if the products and materials utilized may have central significance based on impact regarding construction processes, the application at the site can formdifferent options and make a change towards the environmental burden such as the case of ground improvement techniques [14]. A product's general sustainability regarding an LCA study is usuallylinked to the EU ecolabelling type III also called the Environmental Product Declaration (EPD). However, this is some level of ambiguity to this approach because of its usual inaccuracy in measuring the general sustainability.

A complete life cycle analysis for the entire project needs relevantmultidisciplinary design and modeling options that make the full LCA a tasking tool for sustainable decisions for large infrastructural and construction processes. An LCA analysis targeted a cradle-to-site phase that segregates a specific construction process can assist in fine-tuning materials, technologies and site work options that are still significant to the general sustainability efficacy of the entire project and can assista specific slot transformation of a large construction projectsupply chain [15]. This is the reason behind the proposition of cradle-to-gate LCA analysis at the siteas the second methodology step. It can help the ground to the Envision indicators' rating and, finally, being linkedvia the framework to the EU taxonomy, giving quantitative outputs to the EU Regulation pursues.

2.3 Assessment of Fine Tunings

Once the completion of the LCA analysis is achieved, a final evaluation revision must be transferred to the final assessment. The three steps have been adequately followed and adopted for the pilot case of a ground improvement via permeation grouting in an open-air excavation beneath groundwater for the scenario of the Milan area. Figure 1 represents a graphical synthesis ofan applicable methodology.

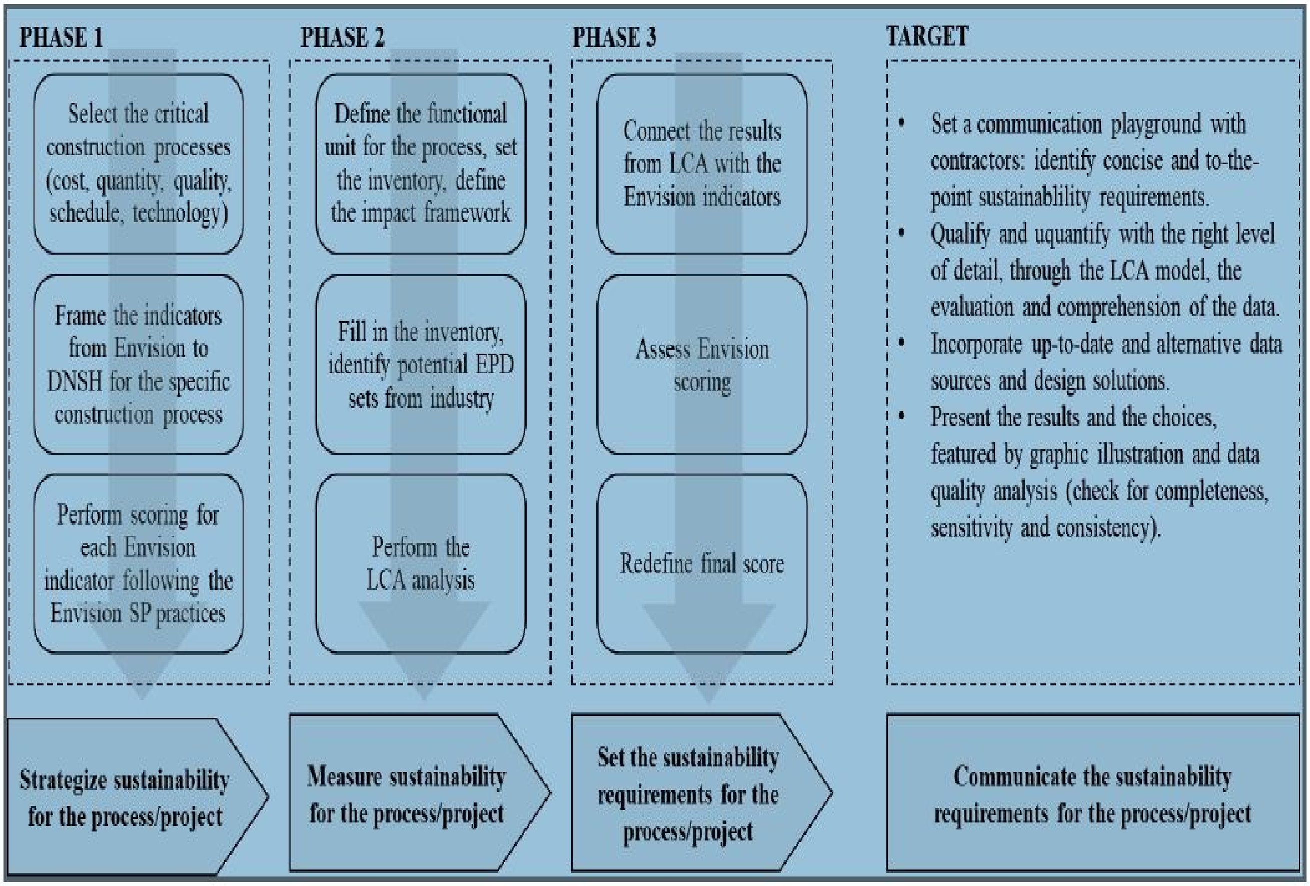

Figure 1: The three phase methods for sustainability infrastructure development in geotechnics

3.0 A CASE STUDY OF INNOVATIVE GEOTECHNICAL SOLUTIONS FOR GROUND IMPROVEMENT TECHNIQUES

For case study purpose, an imaginary excavation site in the municipality of Rozzano was referenced in this manuscript as an application of the proposed methodology to the soil treatment systems. The earlier discussed phases in relation to the case study are examined in this chapter. The selection of the location resulted from the knowledge of the area emanating from previous experiences, which provided the hydrogeological and geological information required [16]. The excavation site is anticipated to have the following specified characteristics which include square shape having10 meters side each and 5 meters depth as shown in Figure 2. Based on the site-specific attributes, all the behavioral and geotechnical parameters of the geomaterials used and treated soils were measured to model a permeation injection intervention also called permeation grouting. Ground treatment is ascertained via the placement of 82 columnar elements in the ground called valved pipes. The geotechnical solution of treated soil was made up with columns having aplan distance of 1.2 m and a radius of 75 cm to make up 472 m^3 oftreated soil formed from a ground thickness of 2.50 m.

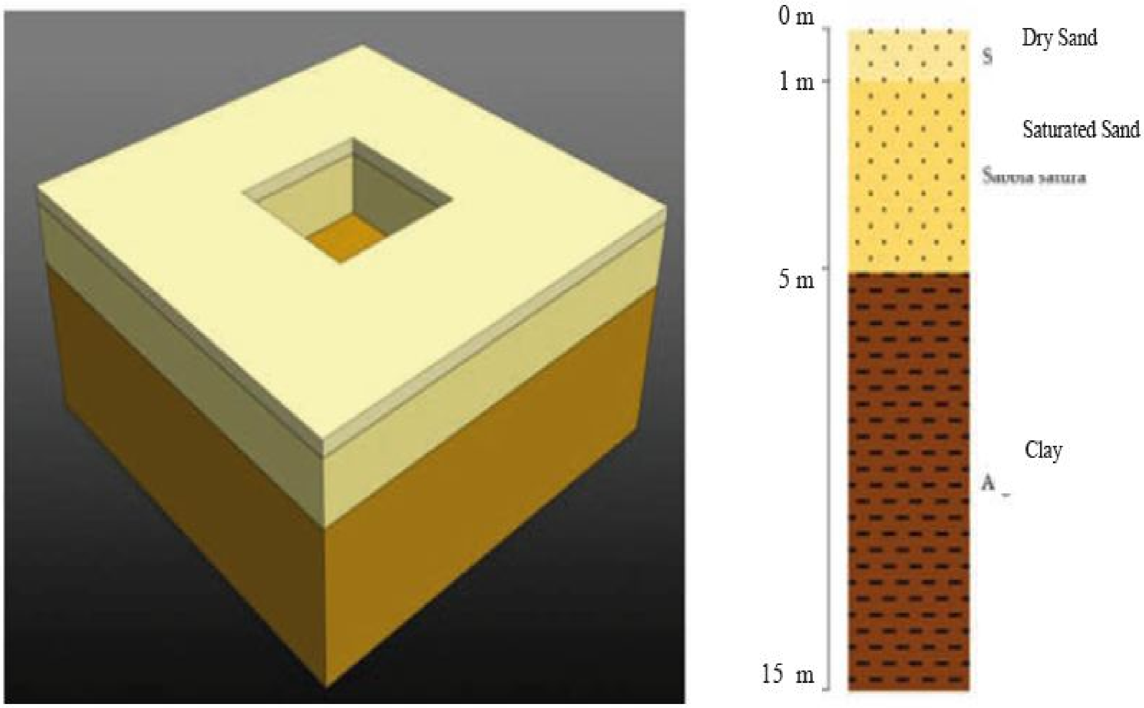

Figure2. The open-air excavation used as a case study

3.1 Phase One: Qualitative Application and Sustainability Rating

The framework which combines Envision and DNSH as an innovative geotechnical solution for sustainable infrastructure development was applied as a first step to the proposed case study. The indicators that are functions of the landscape and community context will be set to the lowest score stated by Envision in the design of the case study. Those that can be excavated via the LCA cradle-to-site analysis of the process will be selectedwith reference to the limitations and nature of the technologies adopted and the anticipated results from the LCA analysis [17]. These values will be polished in phase three after the numerical analysis. At the end, the radar graph shown in Figure 3 illustrates the evaluated scores and compared them with the optimumattainable values of the framework.

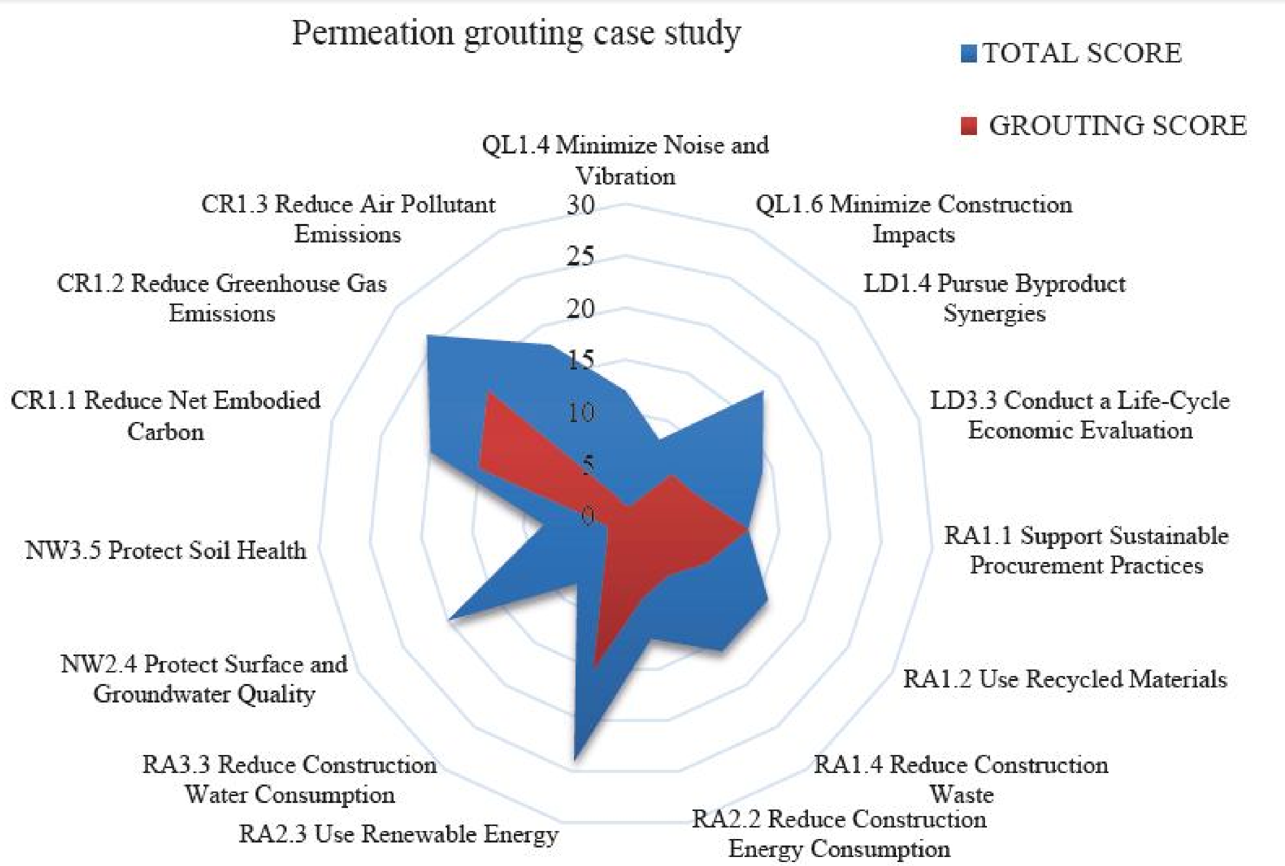

Figure 3: The open-air excavation for the proposed case study

3.2 Getting Quantitative as Phase Two of the Assessment

The performance of the LCA analyses for the study was executed using *Simapro. SimaPro*is basically a commercial software used in the execution of life cycle analysis. This instrument was selected because it is a well-recognized reference by industry professionals. *Ecoinvent 3.6* was applied as the project inventory involving the allocation, cut-off by classification and system process [12]. In their study, Environmental Footprint (EF) method 3.0 which emanated from an initiative of the European Commission was finally adopted as the Life Cycle Impact assessment method. The permeation grouting treatment process is divided into sub-processes which include mix preparation on-site,grout injection, on-site transportation, drilling and TAMs positioning. The significance of on-site grout mix preparation is approximately 83 %, and drilling is about 14 % of the general single-point score [18].

3.3 Putting All Together and Reviewing the Envision Framework Results

The Envision assessment is revised after the completion of the LCA analysis. Definitely, the rating higher credits, exceeds the optimum reachable target (20%) which is the basic entry level for Envision ratings, are finally assigned after being refined in detail.The adoption of an

LCA introduces additional deep knowledge and the required quantitative analysis for sizing the assessment [19]. The impacts range and the chance to compare various construction strategies (which are timing,material and technology adoption, phasing,schedule and so on) enables for process fine-tuning and optimization of the environmental performances giving major consideration to the economic and social components inserted in the protocol application. This can sincerelysignifyhot and critical spots that can encourage the industry in the form of transparent indicators/requirements present for the procurement criteria of owners and contractors. LCA is empowered with this when it is targeted at the process: it can become the language via which the construction industry and owners can make suitable and measurable proposals.

3.4 Limitations of Innovative Geotechnical Solutions

Two main limitations have been noticed identified based on this method involving merging Envision and DNSH as an innovative geotechnical solution for sustainable infrastructure development. The limitation of the analysis boundaryto the construction site is the first one and also possesses a potential strength. The analysis was limited to the cradle-to-gate (or the cradle-to-site) basically due to the fact thatthe more significant part of the impact in the case of civil infrastructure occurs in the course of construction phases. In contrary to this, the operational phase inclines to be targeted on the energy consumption and the maintenance in itself which can be easily signified and evaluated with other techniques.This shortcoming can be tackled in two ways which include (1) expansion of the analysis limits to further steps like maintenance and utilization and, (2) creation of dimensionless indicators that can surround these phases [20].

The second challenge is the area of more significant research for future studies. LCA is basically based on 'standardized' data from recognized and international databases that tend to far away from 'reality' with reference to construction sites. This cannot be escaped when the analysis via LCA spans the whole infrastructure life: the number of processes and products involved and related data is so huge that average statistics andsimplificationbecome compulsory. However, more is needed by the industry. A typical example is more digging of the area and staying closer to the working site reality in order to engage the procurement office of a contractor. This is the reason behind the selection of focus on construction processes. An origin of additional specific data, considered the present condition of the construction industry, is available for usage: it is the Environmental Product Declaration (EPD) system. The information gotten from the EPD can be utilized as input to the LCA and fine-tune the analysis comparing various 'real' constituents to the construction process. Once this is achieved, products comparison can be executed by the analyst which improve the impact score and the Envision assessment and also enhanced their green supply chain. This can be executed for asphalt, concrete and reinforcement for all the frontline players of an infrastructure impact [21].

4. CONCLUSION

The advancement in the world urbanization together with high rise in global population with limited resources has been major contributors to the need for new infrastructures calling for additional innovative research to the already existing assets. Thus, It is highly imperative that geotechnical engineering should include basic practicestargeting resource-efficient and environment-friendly techniquesin order to add to sustainable development. This manuscript critically examines the innovative geotechnical solutions for sustainable infrastructure development. The six main environmental objectives of the Taxonomy Regulation to ensure the contours of an environmentally sustainable infrastructure were stated to include: (1) sustainable protection and use of marine and water resources (2) pollution control and prevention (3) switch to a circular economy (4) mitigation of climate change (5) restoration and protection of ecosystems and biodiversity and (6) adaptation of climate change. The three phase methods for sustainability infrastructure development in geotechnics were critically discussed. An imaginary excavation site in the municipality of Rozzano was referenced as a case study to reveal the application of the proposed methodology to the soil treatment systems. It was noticed that the adoption of an LCA introduces additional deep knowledge and the required quantitative analysis for sizing the assessment. In conclusion, the examined innovative geotechnical solutions were contributory to sustainable infrastructure development.

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