Peer-reviewed version available at *Sustainability* **2018**, *10*, 4765; doi:10.3390/su10124765

*Type of the Paper (Article, Review, Communication, etc.)*

# Use of steel and polyolefin fibres in the La Canda Tunnels: applying MIVES for assessing sustainability evaluation

**Marcos G. Alberti [1], Jaime C. Gálvez [1,*], Alejandro Enfedaque[1], Ana Carmona[2], Cristina Valverde[2] and Gabriel Pardo[2]**

[1] Departamento de Ingeniería Civil: Construcción, E.T.S de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid. c/ Profesor Aranguren, s/n, 28040, Madrid, España.; marcos.garcia@upm.es; alejandro.enfedaque@upm.es; jaime.galvez@upm.es

[2] Sika S.A.U.Carretera de Fuencarral, 72, 28108, Alcobendas, Madrid, España; carmona.ana@es.sika.com; valverde.cristina@es.sika.com, pardo.gabriel@es.sika.com

* Correspondence: jaime.galve@upm.es; Tel.: +34-910674125

**Abstract:** Construction involves the use of significant quantities of raw materials and entails high-energy consumption. For the sake of choosing the most appropriate solution that considers environmental and sustainable concepts, tools such as the integrated value model for sustainable assessment (*Modelo Integrado de Valor para una Evaluación Sostenible*, MIVES) used in Spain, plays a key role in obtaining the best solution. MIVES is a multi-criteria decision-making method based on the value function concept and the seminars delivered by experts. Such tools, in order to show how they may work, require application to case studies. In this paper, two concrete slabs manufactured with differing reinforcement during the construction of the La Canda Tunnels are compared by means of MIVES. The two concrete slabs were reinforced with a conventional steel-mesh and with polyolefin fibres. The results showed that from the point of view of sustainability, the use of polyolefin fibres provided a significant advantage mainly due to the lower maintenance required.

**Keywords:** concrete sustainable evaluations, steel-mesh, polyolefin fibres.

---

## 1. Introduction

Concrete, as is widely known, is manufactured by merging cement, aggregates, water and, in some cases, chemical additives. The diversity of cements since developed and combination of such cements with certain chemical additives with other components have enabled numerous types of concretes to be manufactured that are suitable for a wide variety of uses. Based on the reduced cost of the concrete components, and their availability and adaptability, in the last century it became the most used construction material. Hence, concrete structures for buildings and infrastructure can now be found across contemporary society. One reason for the success of concrete is that the total amount of cement consumed, which is mainly used as a raw material for concrete, has not stopped rising since the beginning of the 20$^{th}$ century. Moreover, the economic importance of cement consumption has reached such a point that it has been widely accepted as a parameter linked to the economic growth countries [world report August 2013]. Nevertheless, the cement production process is one of the main impacts of humankind in the environment and contributes to global warming with 5-6% of the total share of $CO_2$ emissions (Mehta, P. K. (2009) Global Concrete Industry Sustainability, Tools for moving forward to cut carbon emissions, Concrete International, ACI, pp.: 45-48, February). However, there are ways to soften the impact of infrastructure construction, maintenance and management on society and the environment alike.

One of the most studied options entails incorporating by-products or waste materials as aggregates. Some authors claim that it is possible to develop a sustainable recycled concrete by incorporating ceramic waste as a coarse aggregate; they even consider the $CO_2$ footprint and consumption of volume of raw materials (1). Others have sought to use waste from thermal power plants (marble aggregates, marble dust and fly ash) as fillers in concretes for replacing natural aggregates, consequently reducing the impact on mountains and extending the exploitation period of quarries (2). Numerous factors, such as the mechanical properties of concrete with recycled aggregates (3), their long-term properties (4), the optimization of formulation by means of packing models (5), the effect of such type of aggregates in the fracture properties of concrete (6) or even the correct methodology for introducing recycled aggregates in the concrete formulation have been studied (7). Another way to reduce the environmental impact of infrastructure involves trying to soften the impact of cement production. Some researchers have done so by substituting or reducing the amount of cement used. There are studies that tried to change cement microstructure by using nanoparticles (8). Another approach entails use of a by-product such as fly ash in high volumes as a way to obtain a sustainable product (9). Similarly, waste glass powder has been another partial replacement of cement considered (10). As can be seen, while this research field is blooming these approaches have dealt only with the impact of the production of the constituents of concrete and use of recycled aggregates, ignoring other aspects of the matter that are of importance.

Recently, study of sustainability in the developed world has considered not only the economic point of view but also the environmental (Bruntland Report, 1987). [United Nations (1987): Report of the World Commission on Environment and Development Our Common Future. UN General Assembly Resolutions 42/187.]. With such an approach, given that sustainability covers human activity in all its various forms all associated advantages and disadvantages should be considered before taking any decision. If applied to civil engineering, it could involve infrastructure which (from a technical and economic point of view) could be beneficial. However, if its impact on society and the environment were considered it would be discarded due to an ensuing negative influence.. One of the most effective ways to achieve sustainable solutions in the building industry is by designing and building durable infrastructure projects with the goal of obtaining a long service life. Moreover, after finishing such a service life, infrastructure still need to be demolished and transported to a landfill site where the debris produces a remarkable impact on the surrounding environment (11). Following this rationale, the later the demolition of a structure occurs the greater is the degree of sustainability of the infrastructure. The importance of the social, environmental and economic costs that the construction phase, maintenance, refurbishment and the eventual demolition and transport to a landfill site generate during the entire life cycle of the structure can be determined by using multivariable methods.

The main objective of the present work is to apply a method, such as MIVES, which permits multi-criteria methods to be used in the assessment of sustainability in a case study. In the mentioned application, the parameters chosen (as well as the life cycle and maintenance cost) play a major role in the decision-making process and change the optimum alternative from a conventional reinforced concrete option to another where reinforcement has been substituted by polymeric fibres.

## 2. The integrated value model for sustainable assessment (*Modelo Integrado de Valor para una Evaluación Sostenible*, MIVES) method

Construction has a significant impact on the environment. It should be highlighted that around 40% of the total energy consumption in European Union corresponds to this sector and civil works and building construction consume 60% of the raw materials extracted from the lithosphere [12]. The production, transport and installation of materials such as steel, concrete and glass require large amounts of energy. Nonetheless, this implies a minimal part of the cost of construction which leads to new policies being required (12). New solutions and materials could provide environmental benefits. Tools such as the integrated value model for sustainable assessment (*Modelo Integrado de Valor para una Evaluación Sostenible*, MIVES) are required to assess the sustainability of each construction alternative. Given that any construction project can be built with several alternatives,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2018 doi:10.20944/preprints201811.0023.v1

Peer-reviewed version available at Sustainability 2018, 10, 4765; doi:10.3390/su10124765

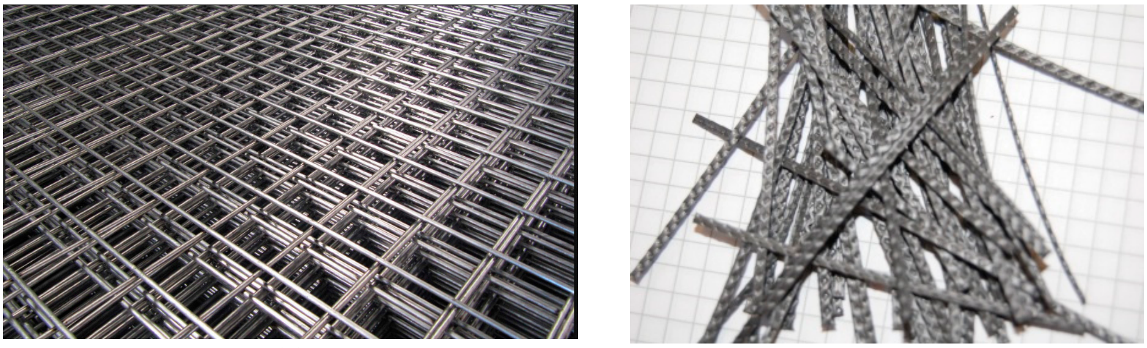
comparing such alternatives by means of an index of sustainability that evaluates the whole life cycle of the structure is of significant interest.

MIVES combines use of a discriminatory tree of requirements, the assignation of weights and use of value functions. This methodology involves defining the three previously mentioned aspects with several seminars of experts in the field. These seminars should provide accuracy and objectivity to the definition of the indicators, criteria and requirements. The steps defined in reference (13) could be summarised in seven:

1. Define the problem
2. Produce a basic diagram
3. Establish the value functions
4. Define the relative weights
5. Define alternatives
6. Evaluate the alternatives
7. Decide on the optimum alternative

## 3. Description of the case study in the La Canda Tunnels

During the construction of the La Canda two twin tunnels for the high-speed rail link that connects Madrid and Galicia, two concrete slabs were built at the same time. Both slabs were subjected to the same loads during their service life. However, one of them was reinforced with the conventional steel-mesh reinforcement and the other was reinforced with polyolefin fibres. Therefore, a substitution of the conventional reinforcing bars was performed. This allowed an unadulterated comparison of the two solutions in terms of economic, environmental and social impact as all design and operative conditions were the same. That is to say, it provided an opportunity to assess sustainability by means of MIVES. Figure 1 shows the visual aspect of the steel-mesh and the polyolefin fibres. The steel-mesh was made of by B500S steel bars (150 x 150 x 6mm) and the fibres were commercial fibres called SikaFibre T-48 which are available in the construction market.



(a) (b)

**Figure 1.** Visual aspect of the two different reinforcement: (**a**) steel-mesh; (**b**) polyolefin fibres

Given that the main differences were based on the reinforcement type, some of the parameters remained similar. The data related to the reinforced concrete (steel and synthetic fibres), dimensions, weight, reparation and waste come from the La Canda Tunnels case study were supplied by Sika as a contractor. Some specifications varied given the variation of the reinforcement and the dimensions and are shown in Table 1. The synthetic fibres were modelled based on data collected for the polypropylene fibres produced according to a standard polypropylene fibres producing process. In this case, the synthetic fibres used were SikaFibre T48 which are produced in Spain. Global Warming Potential (GWP) measures the potential contribution to climate change, focusing on emissions of greenhouse gases, such as carbon dioxide ($CO_2$), which enhance the heat radiation absorption of the atmosphere, causing the temperature at the earth's surface to rise and the values supplied can also be seen in Table 1.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2018 doi:10.20944/preprints201811.0023.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4765; doi:10.3390/su10124765

**Table 1.** Specifications considered for the two systems

| | **Polyolefin fibre reinforced concrete slab** | **Steel mesh reinforced concrete slab** |
|---|---|---|
| Dimension (m) | 200 x 50 x 0.20 | 200 x 50 x 0.20 |
| Concrete type (13) | HA-25/B/20/IIa | HA-25/B/20/IIa |
| Reinforcement (kg/m²) | 0.80 | 3.11 |
| Global Warming Potential (kg $CO_2$ eq) | 2.39 | 5.30 |

One of the major variations are based on the costs of the slab maintenance. The appearance of both alternatives after three years of service can be seen in Figure 2. In such figure it is easy to perceive that the conventional construction has suffered from a cracking process while the polyolefin fibre reinforced slab show no hints of cracks. The construction and maintenance costs per square-metre can be seen in Table 2. The fibre-reinforced solution involved the same thickness, 0.20m, though the maintenance costs were remarkably lower than those of the steel-reinforced concrete.

(**a**) (**b**)

**Figure 2.** Visual aspect of the slabs after three years of service: (**a**) steel mesh reinforced concrete slab; (**b**) polyolefin fibre reinforced concrete slab.

**Table 2.** Costs for one square-meter of reinforced concrete

| | | **Polyolefin fibre reinforced concrete slab** | **Steel mesh reinforced concrete slab** |
|---|---|---|---|
| Purchase cost (€/m²) | Reinforcement | 3.2 | 3 |
| | Concrete | 60 | 60 |
| Maintenance cost (€/m²) | Reinforcement | 0 | 6 |
| | Labour | 0 | 348 |
| | Energy | 0 | 70 |

Peer-reviewed version available at Sustainability 2018, 10, 4765; doi:10.3390/su10124765

## 3. Results of the application of MIVES

The use of MIVES for the sustainability assessment in building and civil engineering applications was carefully described in reference (14). Therefore, the economic, environmental and social impact have been assumed to be those stated in the reference. The indicators were adapted to this case and increasing linear value functions were chosen in order to evaluate each criteria. The weights and the requirements tree, as well as the main criteria and the description of the indicators, can be seen in Table 3.

The maximum, minimum and slope of each criteria were chosen in a seminar given by the authors. The maximum of cement per square meter was fixed at 150 kg/m² and the minimum at 55 kg/m². The aggregates ranged from 240 kg/m² and 600 kg/m² and the water-to-cement ratio was considered between 0.3 and 0.8. The data supplied assumed that 10% of the slab was being reconstructed every year, although it was considered for the method that 3% would be needed for such a period. Contrary to what Table 2 shows (compiled from the data supplied), in the method it was considered to be 10% of steel-mesh reinforced concrete slab maintenance-cost in the polyolefin fibre-reinforced concrete slab.

The results of the application of the MIVES method to this case study can be seen in Table 4 which supplies final and partial scores for each of the solutions. The score for the steel-mesh reinforced slab was 75 in contrast with a final score of 45 in the case of the slab made from polyolefin fibre-reinforced concrete.

**Table 3.** Requirements tree and weights

| REQUIREMENT | (R. weights) | CRITERIA | (C. Weights) | INDICATORS | (I. Weights) | |
|---|---|---|---|---|---|---|
| R1. Economic | 50% | C1 Total costs. Direct + Indirect | 40% | I1 Total costs including construction time | 100% | 100% |
| | | C2 Quality | 10% | I2 Non-quality costs | 100% | 100% |
| | | C3 Dismantling | 10% | I3 Dismantling costs | 100% | 100% |
| | | C4 Service life | 40% | I4 Cost of service. Maintenance. Energy. Change of use. | 80% | 100% |
| | | | | I5 Resilience. Risk of disaster x cost of reconstruction + lack of use | 20% | |
| | | | 100% | | | |
| R2. Environmental | 30% | C5 Material consumption at construction time | 20% | I6 Cement | 25% | 100% |
| | | | | I7 Aggregates | 10% | |
| | | | | I8 Reinforcement (steel mesh, steel fibres, polyolefin fibres) | 15% | |
| | | | | I9 Water | 25% | |
| | | | | I10 Auxiliary materials | 15% | |
| | | | | I11 Reused materials | 10% | |
| | | C5 Material consumption for maintenance | 20% | I6 Cement | 25% | 100% |
| | | | | I7 Aggregates | 10% | |
| | | | | I8 Reinforcement (steel mesh, steel fibres and polyolefin fibres) | 15% | |
| | | | | I9 Water | 25% | |
| | | | | I10 P Auxiliary Materials | 15% | |
| | | | | I11 Reused material | 10% | |
| | | C6 Emissions at construction time | 20% | I12 Global warming potential | 80% | 100% |
| | | | | I13 Total waste | 20% | |
| | | C6 Emissions for maintenance | 20% | I12 Global warming potential | 80% | 100% |
| | | | | I13 Total waste | 20% | |
| | | C7 Energy | 20% | I14 Embodied energy. | 20% | 100% |
| | | | | I15 Construction energy. | 40% | |
| | | | | I16 Service and maintenance energy. | 40% | |
| | | | 100% | | | |
| R3. Social | 20% | C8 Third parties | 50% | I17 Comfort. Thermal, air and , among others, noise | 10% | 100% |
| | | | | I18 Noise pollution. Construction | 15% | |
| | | | | I19 Particles pollution. Construction | 15% | |
| | | | | I20 Traffic disturbances. Construction | 15% | |
| | | | | I18 Noise pollution. Maintenance | 15% | |
| | | | | I19 Particle pollution. Maintenance | 15% | |
| | | | | I20 Traffic disturbances. Maintenance | 15% | |
| | | C9 Risks | 50% | I21 Health and safety during construction | 40% | 100% |
| | | | | I22 Health and safety during maintenance | 40% | |
| | | | | I23 Occupational safety. Risk of disaster x cost of life disruption | 20% | |
| | 100% | | 100% | | | |

**Table 4.** Results of the MIVES application

| REQUIREMENT | INDICATORS | Steel Mesh Score*Rweighs | Steel Mesh Score*Cweights | Steel Mesh Score*Iweights | Steel Mesh Score (0-100) | Polyolefin fibres Score*Rweighs | Polyolefin fibres Score*Cweights | Polyolefin fibres Score*Iweights | Polyolefin fibres Score (0-100) |
|---|---|---|---|---|---|---|---|---|---|
| R1. Economic | I1 Total costs including construction time | 40,03 | 28,80 | 72,00 | 72 | 22,47 | 28,67 | 71,67 | 72 |
| | I2 Non quality costs | | 7,20 | 72,00 | 72 | | 4,55 | 45,50 | 46 |
| | I3 Dismantling costs | | 8,00 | 80,00 | 80 | | 3,00 | 30,00 | 30 |
| | I4 Cost of Service. Maintenance. Energy. Change of use. | | 36,05 | 76,80 | 96 | | 8,73 | 8,48 | 11 |
| | I5 Resilience. Risk of Disaster x cost of reconstruction + lack of use | | | 13,33 | 67 | | | 13,33 | 67 |
| R2. Environmental | I6 Cement | 13,87 | 4,65 | 3,00 | 12 | 8,37 | 3,27 | 3,00 | 12 |
| | I7 Aggregates | | | 3,17 | 32 | | | 3,17 | 32 |
| | I8 Reinforcement (steel mesh, steel fibres, polyolefin fibres) | | | 9,30 | 62 | | | 2,40 | 16 |
| | I9 Water | | | 4,03 | 16 | | | 4,03 | 16 |
| | I10 Auxiliary Materials | | | 3,75 | 25 | | | 3,75 | 25 |
| | I11 Reused Material | | | 0,00 | 0 | | | 0,00 | 0 |
| | I6 Cement | | 4,92 | 9,22 | 37 | | 0,98 | 1,84 | 7 |
| | I7 Aggregates | | | 4,92 | 49 | | | 0,98 | 10 |
| | I8 Reinforcement (steel mesh, steel fibres, polyolefin fibres) | | | 1,55 | 10 | | | 0,31 | 2 |
| | I9 Water | | | 5,76 | 23 | | | 1,15 | 5 |
| | I10 P Auxiliary Materials | | | 3,13 | 21 | | | 0,63 | 4 |
| | I11 Reused Material | | | 0,00 | 0 | | | 0,00 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | I12 Global warming potential | | 11,13 | 42,40 | 53 | | 5,02 | 19,12 | 24 |
| | I13 Total waste | | | 13,25 | 66 | | | 5,98 | 30 |
| | I12 Global warming potential | | 11,13 | 42,40 | 53 | | 5,02 | 19,12 | 24 |
| | I13 Total waste | | | 13,25 | 66 | | | 5,98 | 30 |
| | I14 Embodied Energy. | | 14,40 | 20,00 | 100 | | 13,60 | 20,00 | 100 |
| | I15 Construction Energy. | | | 40,00 | 100 | | | 40,00 | 100 |
| | I16 Service and maintainance energy. | | | 12,00 | 30 | | | 8,00 | 20 |
| R3. Social | I17 Comfort. Thermal, air, noise, etc | 20,00 | 50,00 | 10,00 | 100 | 13,20 | 32,00 | 10,00 | 100 |
| | I18 Noise pollution. Construction | | | 15,00 | 100 | | | 15,00 | 100 |
| | I19 Particles pollution. Construction | | | 15,00 | 100 | | | 15,00 | 100 |
| | I20 Traffic disturbances. Constuction | | | 15,00 | 100 | | | 15,00 | 100 |
| | I18 Noise pollution. Maintainance | | | 15,00 | 100 | | | 3,00 | 20 |
| | I19 Particles pollution. Maintainance | | | 15,00 | 100 | | | 3,00 | 20 |
| | I20 Traffic disturbances. Maintainance | | | 15,00 | 100 | | | 3,00 | 20 |
| | I21 Health and Safety during construction | | 50,00 | 40,00 | 100 | | 34,00 | 40,00 | 100 |
| | I22 Health and Safety during maintainance | | | 40,00 | 100 | | | 8,00 | 20 |
| | I23 Occupant Safety. Risk of Disaster x cost of life disruption | | | 20,00 | 100 | | | 20,00 | 100 |
| | | **74** | | | | **44** | | | |





Peer-reviewed version available at *Sustainability* **2018**, *10*, 4765; doi:10.3390/su10124765

Peer-reviewed version available at Sustainability 2018, 10, 4765; doi:10.3390/su10124765

## 4. Discussion

Table 4 shows the partial and final results of each of the indicators. The final score of the conventional solution for the slab, with steel-mesh reinforced concrete, received a total score of 74 points out of 100. This production manner can be considered as standard and the total score shows the solution is accurate in most of the terms. Nevertheless, one of the major drawbacks is the need of continuous maintenance works in order to keep the operational requirements of the structure. This shows how the conventional decision-making procedures in construction projects lacks the consideration of future costs of conservation and sustainable exploitation.

Regarding the final score of the polyolefin fibre reinforced concrete slab, it showed a significant improvement. The final score was 44, representing 68% of reduction and considering the three main requirements. If the table is observed, it can be found that the economic requirement shows the most considerable reduction of the score with 78% less score. Hence, in all probability this shows that this study was possible mainly because it was profitable for the contractor. However, it should also be highlighted that reductions of 45% and 52% of the requirements in environmental and social issues were achieved and should be considered in future works.

Although some further studies might enhance the conclusions, the use of MIVES has been shown to be a powerful tool in order to take the best decision as a comparative model. It considers the most relevant parts of the works and supports the final solution. Nonetheless, it is true that further works could enhance the use of this type of multi-criteria decision-making method based on the value function concept and the seminars given by experts. That is to say, the development and availability of enhanced data basis and life-cycle analysis of construction materials and procedures may supply more accurate results. In addition, the continuous use of MIVES could also supply accepted rules for the seminars provided by experts. Moreover, this case study shows how the applicability of those ideas and weights accepted as general in reference (14) and EHE-08 (13) meets those expected with reliable results.

## 5. Conclusions

The use of a multi-criteria decision-making method based on the value function concept and the seminars provided by experts, such as MIVES, has proved to be a powerful tool in assessing the sustainability of several construction options. The conventional solution for the slab, with steel-mesh reinforced concrete, received a total score of 75 points out of 100, showing that one of the major drawbacks is the need for continuous maintenance works in order to keep the operational requirements of the structure.

The final score of the polyolefin fibre-reinforced concrete slab was 45, representing 63% of reduction and considering the three main requirements. The economic requirement showed a significant reduction of the score with 78% less score. The reductions of the requirements in environmental and social issues were 45% and 52%. The development and availability of enhanced data basis and life-cycle analysis of construction materials and procedures may supply more accurate results. In addition, the continuous use of MIVES could also supply accepted rules for the seminars provided by experts.

## 6. Acknowledgements

The authors gratefully acknowledge the financial support provided by Ministry of Economy, Industry and Competitiveness of Spain by means of the Research Fund Project BIA2016-78742-C2-2-R. They also offer their gratitude to SIKA SAU, and UTE TUNEL DE LA CANDA VD VI for supplying the data from the case study.

**References**

1. 1. Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate. Rashid, Khuram, y otros. 2017, Construction and Building Materials, Vol. 154, págs. 829-840.
2. 2. Concretes with synthetic aggregates for sustainability . Tekin, Ilker, y otros. 2017, Construction and Building Materials, Volume, Vol. 133, págs. 425-432.
3. 3. Strength and stiffness of concrete with recycled concrete aggregates. McGinnis, Michael J., y otros. 2017, Construction and Building Materials, Vol. 154, págs. 258-269.
4. 4. Self-compacting concrete with recycled concrete aggregate: Study of the long-term properties. Manzi, Stefania, Mazzotti, Claudio y Bignozzi, Maria Chiara. 2017, Construction and Building Materials, Vol. 157, págs. 582-590.
5. 5. Optimization of normal and high strength recycled aggregate concrete mixtures by using packing model. Amario, Mayara, y otros. 2017, Cement and Concrete Composites, Vol. 84, págs. 83-92.
6. 6. Influence of recycled coarse aggregates incorporation on the fracture properties of concrete. Ghorbel, Elhem y Wardeh, George. 2047, Construction and Building Materials, Vol. 154, págs. 51-60.
7. 7. Methodology for the integrated assessment on the use of recycled concrete aggregate replacing natural aggregate in structural concrete. Wijayasundara, Mayuri, Mendis, Priyan y Crawford, Robert H. 2017, Journal of Cleaner Production, Volume, Vol. 166, págs. 321-334.
8. 8. Modification of microstructure and mechanical properties of cement by nanoparticles through a sustainable development approach. Sadeghi-Nik, Aref, y otros. 2017, Construction and Building Materials, Vol. 155, págs. 880-891.
9. 9. Characterization of high-volume fly-ash cement pastes for sustainable construction applications. Aydin, Ertug y Arel, Hasan Şahan. 2017, Construction and Building Materials , Vol. 157, págs. 96-107.
10. 10. Waste glass powder as partial replacement of cement for sustainable concrete practice. Islam, G.M. Sadiqul, Rahman, M.H. y Kazi, Nayem. 2017, International Journal of Sustainable Built Environment, Vol. 6(1), págs. 37-44.
11. 11. Life Cycle Assessment of Concrete Structures – Step towards Evironmental Savings. P, Hájek, C., Fiala y M., Kynčlová. [ed.] fib. 2011, Structural Concrete, , Vols. 12, no. 1, p., págs. 13-22.
12. 12. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential . Bribián, I. Z., Capilla, A. V. y Usón, A. A. 2011, Building and Environment, Vol. 46(5), págs. 1133-1140.
13. 13. EHE-08. Spanish Structural Concrete Code. s.l. : Spanish Minister of Public Works, 2008.
14. 14. The use of MIVES as a sustainability assessment MCDM method for architecture and civil engineering applications. Pons, O., de la Fuente, A. y Aguado, A. 460, 2016, Sustainability, Vol. 8(5).
15. 15. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. Bribián, I. Z., Usón, A. A. y Scarpellini, S. Building and Environment, Vol. 44(12), págs. 2510-2520.