

# Analysis for implementing green roofs on reinforced concrete slabs. A case study in the city of Tuxtla Gutiérrez, Chiapas, Mexico

## Análisis para implementar techos verdes sobre losas de concreto reforzado. Un caso de estudio en la ciudad de Tuxtla Gutiérrez, Chiapas, México

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### Abstract

*In the search for adopting methods that provide more comfort in the housing system, they require better structural performances in current buildings. Construction practices in the region have been discredited over time, conceiving vulnerable buildings whose inhabitants are subject to risk.*

*The objective of this research is to comprehensively analyze the technical, construction, and design characteristics of reinforced concrete slabs regarding their implementation as a reinforcing structure for green roofs in the city of Tuxtla Gutiérrez, Chiapas, Mexico. To carry out the structural analysis, the intrinsic properties of the supporting members (slabs) were considered, as well as their current condition, and design based on durability standards. The research results revealed that the slab depth and the amount of steel were lower for average spans, as stipulated by the corresponding technical standards. Corrosion damages in steel bars are expected and they were found under an inadequate design standard, combined with deficiencies throughout the construction process. The constructions analyzed and developed with formal construction or self-build processes show similar pathologies.*

*The city of Tuxtla Gutiérrez lacks training centers for homeowners and workers to be able to adopt self-build methods. Moreover, the authority is not rigorous regarding the compliance with building codes. These members have become a key knowledge gap. Finally, the implementation of green roofs in these structures is unlikely without prior significant changes in the entire construction.*

*Keywords: Green roofs, reinforced concrete slabs, structural design, corrosion, self-build*

### Resumen

En la búsqueda de asumir métodos que brinden un mejor confort en el sistema de vivienda, éstos requieren de mejores prestaciones estructurales en las edificaciones actuales. Las prácticas constructivas en la región se han ido desprestigiando con el paso del tiempo, concibiendo edificaciones vulnerables, que dejan expuesto a quienes las habitan.

El objetivo de esta investigación fue analizar de forma integral las características técnicas, constructivas y de diseño de losas de concreto armado, en su implementación como estructura de soporte para techos verdes en la ciudad de Tuxtla Gutiérrez, Chiapas, México. Para realizar el análisis se consideraron las propiedades intrínsecas del miembro de soporte (losas), el estado actual en las que estas se encuentran y su diseño bajo regímenes de durabilidad. Tras realizar la investigación se encontró que los espesores de la losa y las cuantías de acero son menores para claros promedio, según lo estipulado por las normas técnicas correspondientes. Los daños por corrosión del acero son esperados y se encuentran bajo un régimen de diseño inadecuado, aunado a la deficiencia durante el proceso constructivo. Las construcciones analizadas y desarrolladas por procesos de construcción formal o de autoconstrucción evidencian patologías similares.

La falta de centros de capacitación para los propietarios y los obreros que adopten los métodos de autoconstrucción, así como el poco rigor de las autoridades en el cumplimiento de los reglamentos de construcción se han convertido en una brecha del conocimiento clave. Finalmente, es poco probable la implementación de techos verdes en estas estructuras sin antes realizar cambios significativos en toda la construcción.

**Palabras clave:** Techos verdes, losas de concreto armado, diseño estructural, corrosión, autoconstrucción

## 1. Introduction

*Tuxtla Gutiérrez is the political capital, located in the center of the southeastern state of Chiapas, in Mexico, latitude 16.75973 and longitude -93.11308, bordering Guatemala. The city lies in a tropical area with precipitations in the summer. Its climate is classified as Aw, therefore, it has high temperatures during the day most of the year, exceptionally reaching up to 42°C (Sánchez-Trujillo et al., 2019). That is why prioritizing the use of green roofs is a key factor.*

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In recent years, Tuxtla Gutiérrez has evidenced a population growth due to multiple factors, which in turn generates a territorial demand within the municipality (González-Herrera et al., 2010); (González et al., 2012); (Silva et al., 2015), where the vegetation cover area is increasingly limited. In addition, in the worst of cases, it reveals the phenomena caused by the excessive use of concrete (Zielinski et al., 2012); (Shafique et al., 2018). At the same time, the population deals with the consequences of these urban changes in the last decades.

The larger number of residential complexes and shopping malls, as well as irregular settlements in the periphery, mostly developed in recent years in high parts of the city valley (ICIPLAM, 2012), have greatly favored the use of impermeable materials. These materials are inefficient for reducing the temperature, and present the hazard of surface run-off towards the lower parts of the city, causing high temperatures during the low water season and severe floods in the rainy seasons (Cortés and Castillo, 2011); (Stovin et al., 2007).

A possible solution to the flood problem and urban heat isle phenomenon is the use of sustainable construction systems, such as green roofs (Cerón-Palma et al., 2013); (Flores et al., 2016); (Zielinski et al., 2012). The urban and building codes, as well as the decision making from the authorities of Tuxtla Gutiérrez have been unable to achieve a land-use planning, thereby taking the city to a point where the population lacks the comfort of living in an integral and safe space, including the necessary services and quality they deserve.

This paper presents and discusses the results of a review of the dimensions observed in relation to the parameters defining the efficiency in reinforced concrete rooftops. The compliance with these values would allow satisfying the demands for the installation of green roof systems on rooftops. The research carried out an analytical study and fieldwork addressing the minimum standards that the supporting structure should fulfill, based on the structural overload demands and the interaction between the reinforced concrete member and the green roof system, considering the possibility of corrosion, in accordance with the Mexican construction regulations.

## 2. Green roofs

According to the Federal District Environmental Law (NADF-013-RNAT-2007, 2008), a green roof system consists in urban greening undergoing a technical treatment on horizontally built surfaces or having a certain inclination degree, either individually or grouped. This treatment incorporates, either in one traditional construction member or a group thereof, a growing medium and greenery layers, especially adapted to the physical and weather conditions of the place in which it is installed, thus creating an induced vegetal surface, classified as extensive, semi-intensive and intensive green roofs.

In order to implement the green roofs, it is necessary to modify the structure of the buildings' roofs. Authors like (Munby, 2005); (Stovin et al., 2007); (Cox, 2008); (Castleton et al., 2010); and (Cascone et al., 2018) mention the need to evaluate these structures in view of the service demands generated by the green roof. However, studies about green roofs frequently assume that the supporting structures are adequate, rather than considering the need to prepare them before implementing them more widely in a region's social interest housing. Thanks to the advantages of this technology, low-income families living in these housing could experience a considerable improvement in their quality of life.

## 3. Roof typologies

The housing of Tuxtla Gutiérrez contain a wide variety of buildings with different typologies of roofs or rooftops (Figure 1). In the city, more than 75% of the housing are built with reinforced concrete roof (INEGI, 2010) and in most developed cities, roofs represent approximately 40-50% of the impermeable urban surface (Stovin et al., 2012).





**Figure 1.** City of Tuxtla Gutiérrez, roof diversity. Source: Photo by Chiapas Paralelo

The reinforced concrete (RC) roof design is not complex. Moreover, its easy empirical construction and the amount of stony materials available close to the city offer a relatively low cost compared with other slab systems, which make it economically viable for the user, combined with the performance they add to the building and the good construction process (Ramírez et al., 2011). These characteristics make the system attractive for self-build projects in irregular communities (Novas-Cabrera, 2010); (Argüello-Méndez et al., 2012).

## 4. Method

When rooftops are used as green roofs, they assume two challenges: the axial load increase, which demands greater inertia (depth) to prevent deflections and cracking; and a durability-based design that reduces the risk of corrosion in the steel. Therefore, a comparative study consisting in a detailed review of the information was undertaken, based on the analysis results between the existing relationship between RC slabs and the installation of a green roof, with the requirement of maintaining the integrity of the member per se and of the green roof system. The analysis included a review of the observance of slab deformations, considering the adequate inertia to prevent cracks caused by deformation and, therefore, the corrosion of the reinforcing steel; considering the necessary steel amount, spacing, depth, and sheathing. Under these conditions, the research is complemented by a physical onsite inspection of the members, thereby identifying their damage and the construction pathologies produced around the housing of Tuxtla Gutiérrez, based on the methodology proposed by (Sánchez-Trujillo et al., 2019).

The data collection format for structural assessment issued by the Mexican National Civil Protection System and National Center for Prevention of Disasters (CENAPRED, 2011) was used for collecting the information. However, a further paragraph was attached thereto, in order to increase the number of characteristics for the housing roof typology, both in mezzanines and rooftops. A random evaluation of 173 housing belonging to 36 different residential ensembles, including residential developments, apartments, duplex and condominiums, was carried out in different cardinal quadrants of the city. This allowed attending the various prototypes of social interest housing used throughout the city's evolution (González-Herrera et al., 2010); (González et al., 2012); (Silva et al., 2015).

## 5. Results

### 5.1 structural design

An analysis carried out by (Sánchez-Trujillo et al., 2017) proposed unit panels for the largest spans and most unfavorable supports, in more than 30 social interest housing projects built in Tuxtla Gutiérrez from 2005 to 2015. The criteria used were the Technical Standards for the Design and Construction of Reinforced Concrete Structures of the Federal District Building Code (NTC-DC-RCDF, 2004), and the Environmental Standard for the Federal District (NADF-013-RNAT-2007, 2008). According to this analysis, minimum required steel amount and adequate diameters were obtained, under the pertinent weight of both dynamic and static loads, considering the weight of the extensive green roof in each case. The standards were updated after the earthquake of September 19, 2017 in Mexico City; however, the results do not differ when using the new standards (NTC-DC-RCDF-2017, 2017), because no changes were introduced in the corresponding paragraphs related to the NTC-2004.

The results of the analyzed models show that the panel dimensions and proposed load determine the member's depth; the larger the dimensions, the greater the depth, as well as the steel amount. In the favorable case of this study, where borders are continuous and monolithic, it is necessary to reinforce the steel in two layers or beds for panels measuring  $5.00 \times 5.00 \text{ m}^2$  and  $6.00 \times 6.00 \text{ m}^2$ . The standard specifies that with depth over 15 cm, the reinforcements must comply with these requirements and, regarding the unfavorable case, whose borders are discontinuous and non-monolithic, this reinforcement is repeated for the same panels and even for the panel of  $4.00 \times 4.00 \text{ m}^2$  (Figure 2).

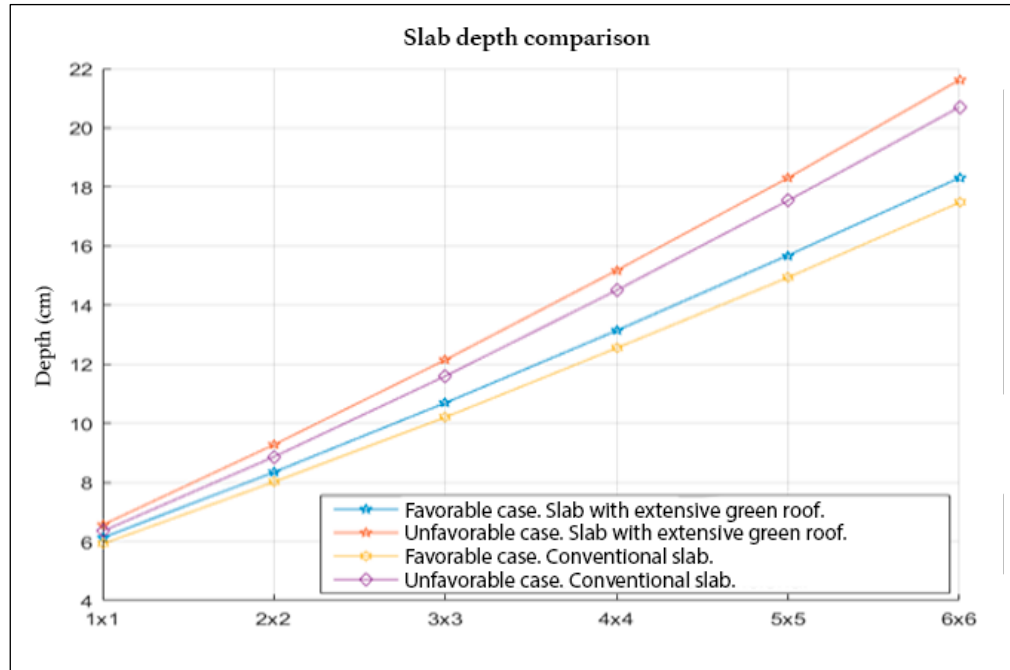


Figure 2. Slab depth for each case. Source: Self-prepared

In relation to social interest housing with reinforcements of 20-cm spacing, the latter is acceptable in favorable cases, both in conventional slabs and slabs with extensive urban greening. Meanwhile, for unfavorable cases, with panels of  $5.00 \times 5.00 \text{ m}^2$  and over, the spacing does not comply with the reinforcements made (Figure 3). (Figure 4) shows the behavior when making the calculations for reviewing the spacing between reinforcing steel bars subject to shrinkage stress, according to (NTC-DC-RCDF 2017) (Eq. 6.7.1, page 442).

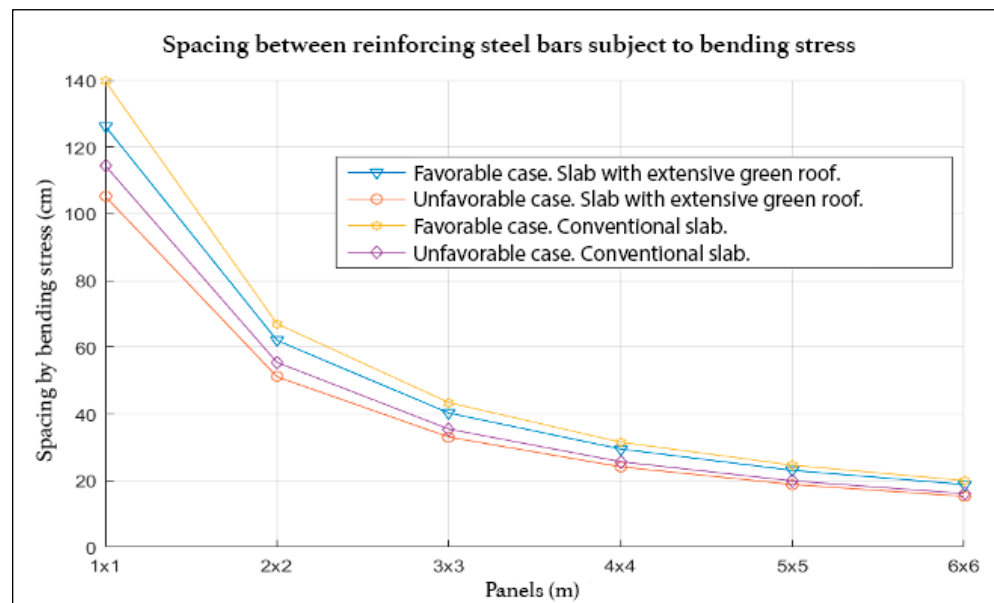


Figure 3. Spacing between reinforcing bars subject to bending stress for each case. Source: Self-prepared



For the structural analysis carried out in this research, grade 40 corrugated steel bar with 3/8" diameter (N° 3) was used, since it is the most common size used in the construction process of social interest and average housing. This aspect should be considered in the analysis, because, sometimes, electro-welded mesh with no additional reinforcement are used instead of steel reinforcing bars.

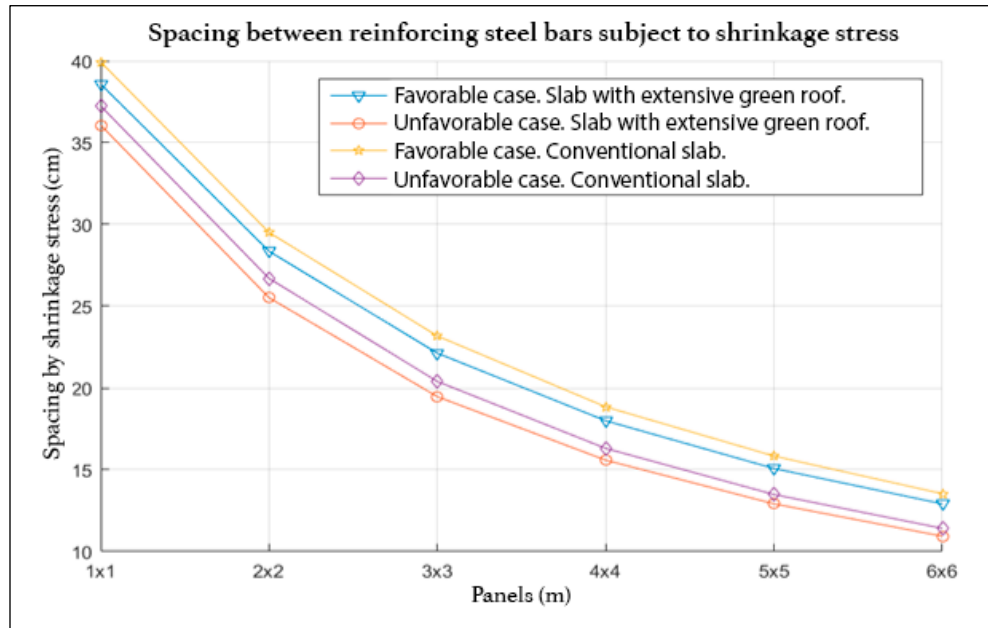
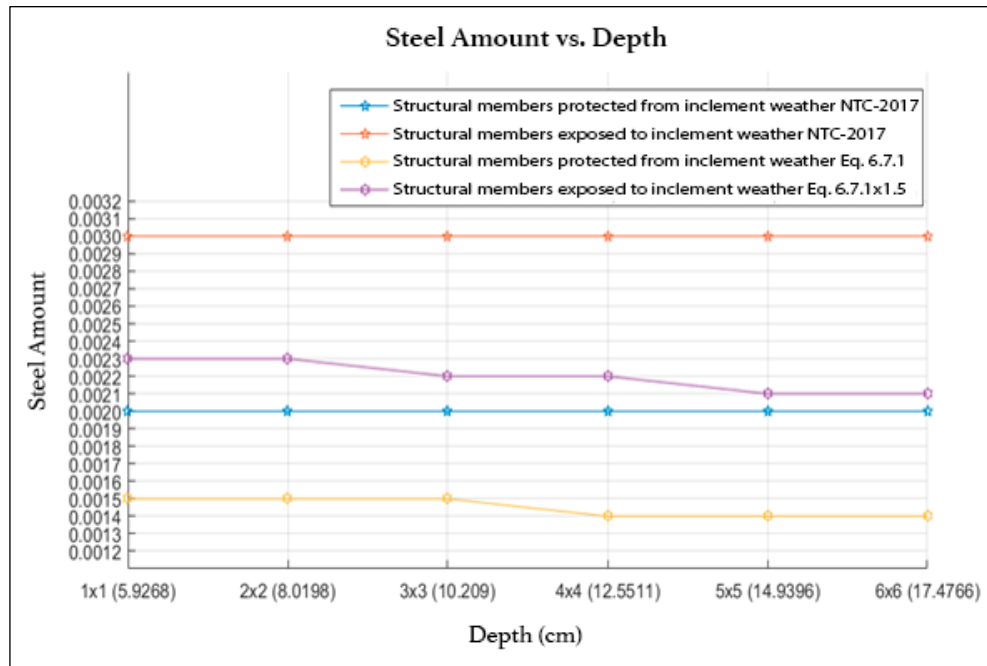


Figure 4. Spacing between reinforcing steel bars subject to shrinkage stress in each case.  
 Source: Self-prepared

## 5.2 Corrosion effect

An analysis carried out by (Sánchez-Trujillo et al., 2018a) graphically shows the steel amounts required by the (NTC-DC-RCDF standard 2004) in order to control cracking due to volumetric changes. Next, the (NTC-DC-RCDF standard 2017) was revised, where no changes were evidenced in the paragraphs consulted for that analysis. In this study, the design of different panels under shrinkage criteria was used, thus defining panels with dimensions of 1.00 x 1.00 m<sup>2</sup>, 2.00 x 2.00 m<sup>2</sup>, and so on, up to the panel of 6.00 x 6.00 m<sup>2</sup>, considering that, from a critical perspective, it is the biggest viable panel used in social interest housing. Accordingly, the depth for each panel is presented below. It should be highlighted that the design applies for the most favorable case, concerning panels with all continuous and monolithic borders, with the aim of minimizing the uncertainty and obtaining more conservative parameters (Figure 5).



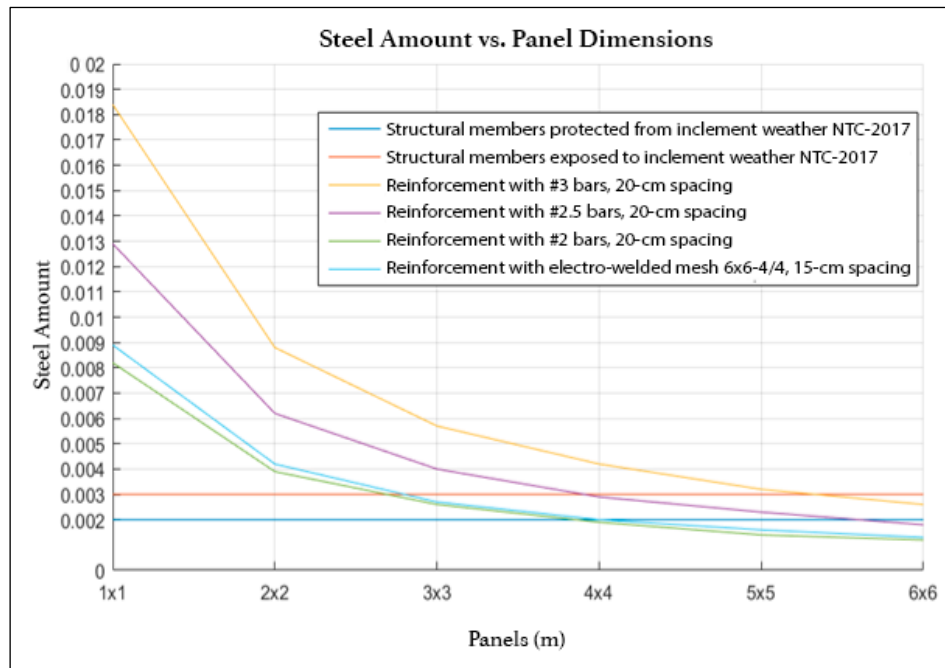
**Figure 5.** Comparison of steel amount vs. depth, according to section 6.7 of NTC-DC-RCDF (2017).  
Source: Self-prepared

(Figure 5) shows the behavior of the different steel amounts required by the (NTC-DC-RCDF 2017), under the condition of section 6.7 (Eq. 6.7.1, page 442). The standard specifies that “Given its simplicity, it is possible to provide minimum reinforcement with an amount equal to 0.002 in structural members protected from inclement weather, and 0.003 in those exposed to them, or which are in contact with the ground”. According to the depth of studied members, these amounts are generally insufficient to meet the minimum durability requirements of RC members when using the proposed equation, which implies durability issues and undesirable appearance in RC slabs (Rodríguez and Padilla, 2006); (Moreno et al., 2004), limiting the service life due to the corrosion effects of the reinforcing steel.

(Figure 6) compares the steel amounts by making the analogy between using reinforcing steel #3, #2.5 and #2, and electro-welded mesh of 6x6-4/4, commonly used for reinforcing steel in rooftop RC slabs. Under these conditions, a 20-cm spacing between reinforcing steel bars, and a 15-cm spacing in the electro-welded mesh is used, which is the spacing that is sold in the market.

The chart in (Figure 6) shows how the amount decreases as the panel dimension increases, because as the member dimensions grow, it is subjected to higher stresses. There is also an analogy comparing the reduction of the cross section area of the steel diameters used in the construction of these structures. If bars #3 are used, the amount is accepted for panels up to 5.00 x 5.00 m<sup>2</sup>. However, if electro-welded mesh is used, the amount decreases from the panel of 3.00 x 3.00 m<sup>2</sup> upwards, which is below the requirements of 0.003 specified in the (NTC-DC-RCDF, 2017) for members exposed to inclement weather.





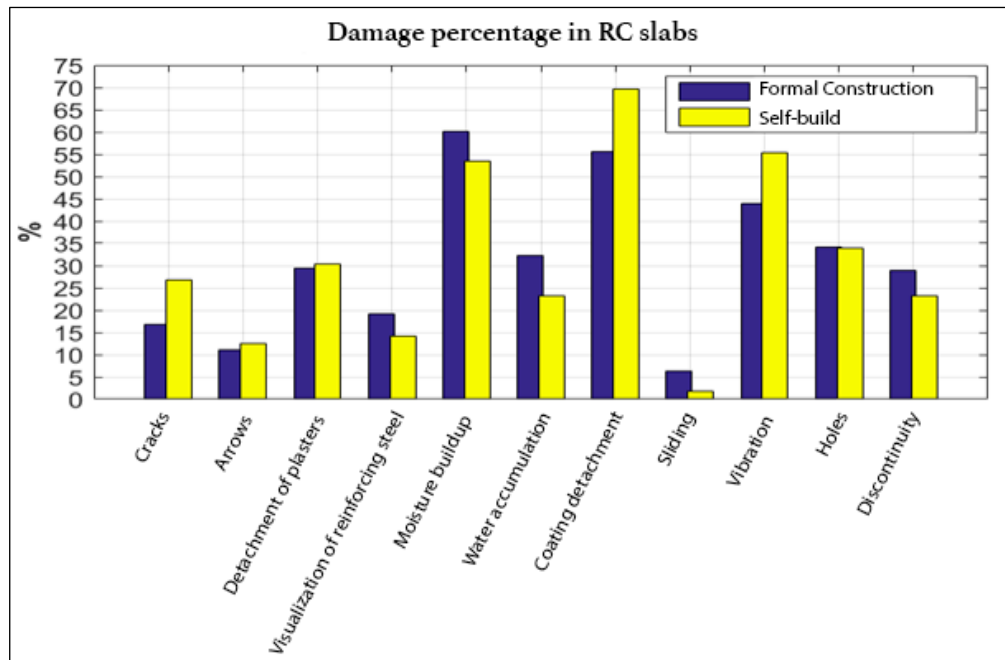
**Figure 6.** Comparison of steel amount vs. panel dimensions, in relation to the cross-sectional area of the reinforcing steel.  
Source: Self-prepared

It is important to highlight that these parameters refer to the loss of the reinforcing steel cross section due to the corrosion effects. When the steel loses cross-sectional area, the ratio no longer complies with (NTC-DC-RCDF 2017). However, when using steel bars with smaller diameters, and corrosion is produced, the structures tend to present a brittle failure because the cross-section loss does not have a margin to counteract the extra stresses caused by this material loss, thus enabling a sudden collapse (Zhang and Li, 2018). The new Standards for the Seismic Rehabilitation of Damaged Concrete Buildings indicates that "If corroded bars have lost more than 25% of the cross section, they should be replaced or else supplementary and correctly anchored bars should be installed". Therefore, a thorough inspection of existing structures designed with other regulations is necessary.

### 5.3 Physical evaluation of the supporting structure

Reinforced concrete slabs are defined as rigid plates, where the structural capacity of the member is based on its supporting function, depth and steel amount. In the city of Tuxtla Gutiérrez, not all the structures have these characteristics, and the construction process suffers pathologies (González-Herrera et al., 2008); (Sánchez-Trujillo et al., 2019). Consequently, most of the time, the members are highly vulnerable to damage (Simavorian et al., 2017) and it is difficult to reasonably evaluate their behavior in the face of any local damage in these members, since generally there is no project documentation available, due to the lack of knowledge and the unawareness of the homeowners themselves (Velázquez-Leyer, 2015).

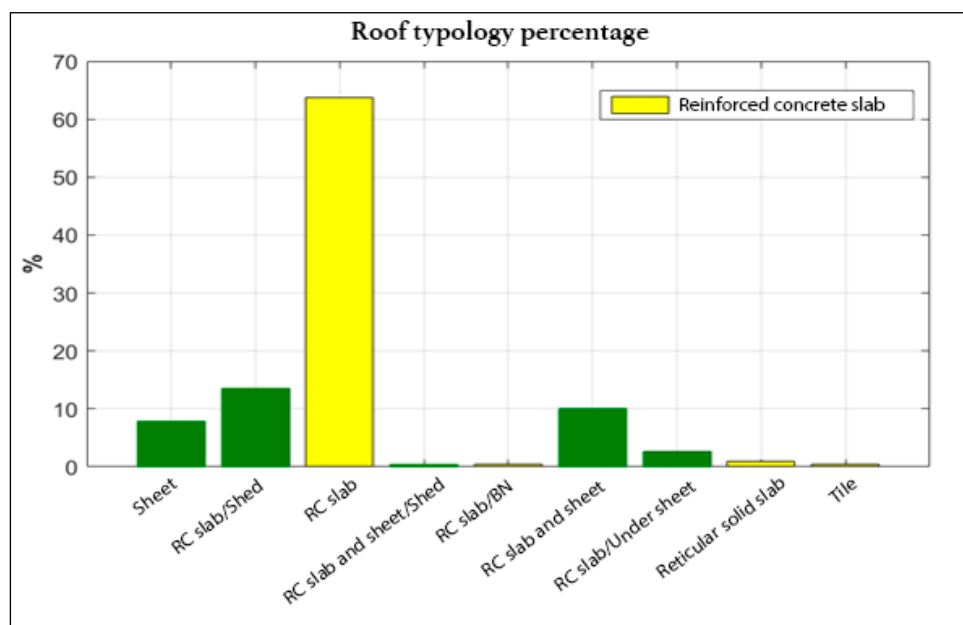
(Figure 7) shows the damages in these members, in a study carried out in the city of Tuxtla Gutiérrez, on 226 housing, considering formal construction and self-build processes (Sánchez-Trujillo et al., 2019).



**Figure 7.** Damage in RC slabs in the city of Tuxtla Gutiérrez, Chiapas.  
 Source: Self-prepared

As shown in (Figure 7), the most significant damages are found in self-build processes, due to the lack of maintenance of the structure before or after each rainy season. On the other hand, formally built structures show more deficiencies in relation to water accumulation, because no adequate designs and construction processes are envisaged (Chew Lin et al., 2004); (Ahzahr et al., 2011); (Ramírez de Alba et al., 2011); (Guajardo, 2017); (Solar and Río, 2015).

Among the studied housing, 92% evidenced a 10-cm depth in buildings with RC slabs, thereby finding that garage areas or business premises had panels larger than 5.00 x 5.00 m<sup>2</sup> and 6.00 x 6.00 m<sup>2</sup> panels with intermediate joists in some cases. Furthermore, in the city of Tuxtla Gutiérrez, rooftops are built with RC slabs in 63.8% of the evaluated housing (Figure 8).



**Figure 8.** Roof typology in 226 evaluated housing. Source: Self-prepared



## 6. Result analysis and discussion

Reinforced concrete slabs are not designed according to durability parameters, thereby defining the design of these members under shrinkage and not flexural standards. It is important to highlight that durability problems have affected different types of structures. Once they are damaged, they are no longer functional nor efficient and they are unable to comply with their estimated service life. This entails costs and economical losses for the homeowner or investor, either due to repairs in the affected areas, the replacement of deteriorated members, or operational costs attributable to renovations or periodical maintenances (Chew Lin et al., 2004); (Hernández-Castañeda and Mendoza-Escobedo, 2005); (Ramírez de Alba et al., 2011). Consequently, the design also lacks spare capacity, as mentioned by (Munby, 2005), where she identified a reduction in the snow load design for roofs in Ontario, Canada from 1.95 to 1.07 kN/m<sup>2</sup>. This leaves 0.88 kN/m<sup>2</sup> for the installation of the green roof.

There is uncertainty in the housing built with electro-welded mesh, due to corrosion in the cross section, which is minimal from the beginning. The main problems associated to corrosion is that the reinforcing steel reduces its mechanical strength, and the corrosion buildup applies stresses that the deformation of the concrete plastic limit cannot bear. This reduces the bonding capacity and anchorage between concrete and steel, which directly affects the service capacity and maximal strength of structural members (Cabrera, 1996); (Lee et al., 2002); (Chang, 2003); (Castorena-González et al., 2010); (Rodríguez-Reyna et al., 2012); (Mosquera-Rey, 2015). Consequently, the reinforcing steel corrosion is one of the main deterioration sources in RC structures (Cano-Barrita et al., 2006); (Moreno et al., 2004).

(Sánchez-Trujillo et al., 2018) found reinforcements with electro-welded mesh of 6x6-4/4 in housing where, due to the homeowners' unawareness, gravitational overloads are applied in subsequent floors. When analyzing the buildings onsite in the studied region, it was possible to identify that the emphasis is not put on structural safety, but on "dignified and decent housing" in terms of having larger spaces.

The social interest housing and average housing built with formal construction (in residential developments or complexes), show damages associated to moisture buildup, such as filtration and leaks in rainy seasons. In their research, (Delgado-Hernández and Romero-Ancira, 2013) also mention that "the people are not satisfied with the roofs, because leaks are usual during the rainy seasons". Therefore, implementing green roofs on these structures is quite a challenge (Vijayaraghavan, 2016); (Shafique et al., 2018).

Moreover, the fieldwork allowed identifying microfissures on bathroom roofs, commonly used as water storing areas, which are caused by episodic overloads on the member. The filling and emptying of the containers vary over time, thus presenting structural fatigue due to mass changes that deteriorate the structure, given these gravitational loads borne by the member (Spathelf and Vogel, 2018).

These fissures appear when a section is subjected to axial compressive stress, which acts on the gravity center of this area. In fact, these load demands do not occur spontaneously, since it would require an extremely high precision of the load centering mechanisms. The usual form of fatigue is produced by very fine cracking (0.05 to 0.15 mm), parallel to the direction of the member, as mentioned in (Toirac-Corral, 2004) and (Halvorsen et al., 1993).

No evidence was found of a significant increase in the RC slab construction in relation to the facts reported by (González-Herrera et al., 2010), who report 72.90% of concrete slab buildings; while (Argüello-Méndez et al., 2012) report 79% of RC structures. Nevertheless, a consistent change is evidenced in the use of laminate roofing to protect these RC members that present leaks and puddles. A further requirement is to use the rooftop as a service or recreation area, as well as reducing the temperature gradient inside the housing (Sánchez-Trujillo et al., 2019).

The present study seeks to delineate the housing within a sustainable housing concept, without compromising the structural design nor the quality of the building. The analysis of the current housing scenario emphasizes the need to develop integral building techniques that guarantee structural safety and sustainable urban development. In order to be able to implement a sustainable housing plan, several obstacles have to be overcome, including, among others, turning around the trend of historical housing construction, promoting the environmental benefits and quality of life derived from adopting ecofriendly building techniques, establishing detailed building specifications for new materials and construction systems, and integrating the country's real estate developers, so that they can build bearing these aspects in mind (Carrillo and Alcocer, 2012); (Welsh-Huggins and Liel, 2017).

## 7. Conclusion

Panels larger than 3.00 x 3.00 m<sup>2</sup> (most common panels in evaluated housing) subject to shrinkage stress do not comply with the depths and steel amounts of the slabs studied in Tuxtla Gutiérrez, Chiapas, under conventional loading on a rooftop system. In order to meet the green roof structural demand in the studied area, panels should have smaller dimensions or else search for other structural reinforcing alternatives for larger panels, as mentioned by



(Stovin et al., 2007); (Cox, 2008); (Castleton et al., 2010); (Alkhrdaji, 2012); (Cascone et al., 2018), in different studies.

The city's current slabs do not comply with the parameters specified for a critical weight of 140 kg/m<sup>2</sup> in extensive green roofs, according to the standard (NADF-013-RNAT-2007, 2008), under the durability criteria of the member. However, it is possible to work on lighter substrates to allow a faster drainage, and obtain a ratio between substrate weight and slab parameters (Cascone et al., 2018).

It should be mentioned that these structures are currently built as if they were recipes. Generally, the depth, the reinforcing steel spacing and the steel diameter are ruled by repetitive aspects during the construction of these members, which are, in most cases, empirically imposed by the owners themselves or the construction foreman and workers of the region.

Nowadays, RC slabs have come to define the economic aspects of the users and the lack of rigor of the authorities who fail to enforce the compliance with the city building code. Therefore, as the research on these members is further emphasized, an endless number of events are seen, which are not only defined by a good design and construction process, but from the understanding of the local regulations of each region in the country. The latter do not rely on sufficient studies to evaluate adequate parameters for each region. This study in particular contributes with knowledge on RC slab systems in Tuxtla Gutiérrez, considering its potential use as a green roof reinforcing structure.

## 8. References

- Ahzahar, Nadira; Karim, Nurulzatushima Abdul; Hassan, Sabaria. H.; Eman, J. (2011). A Study of Contribution Factors to Building Failures and Defects in Construction Industry. *Procedia Engineering*, 20, 249-255. <https://doi.org/10.1016/j.proeng.2011.11.162>
- Alkhrdaji, Tarek. (2012). Structural Roof Strengthening to Support New Green Roofs. *Concrete Repair Bulletin*, (5).
- Argüello-Méndez, Teresa; Argüelles-León, Beatriz; Badillo-González, Rosa Mar (2012). Características físicas de la vivienda popular en la periferia urbana de Tuxtla Gutiérrez, Chiapas, México. *Quehacer Científico en Chiapas* 1(14): 4-13.
- Cabrera, Joseph G. (1996). Deterioration of concrete due to reinforcement steel corrosion. *Cement and Concrete Composites*, 18 (1), 47-59. [https://doi.org/10.1016/0958-9465\(95\)00043-7](https://doi.org/10.1016/0958-9465(95)00043-7)
- Cano-Barrita, Felipe de Jesús; Balcom, B. J.; Bremner, Theodore W. (2006). Imaginología por resonancia magnética y la determinación de cloruro y sodio en mortero de cemento Portland. *Ingeniería, Investigación y Tecnología*, 8 (3), 147-155. <http://dx.doi.org/10.22201/fi.25940732e.2007.08n3.013>
- Carrillo, Julián; Alcocer, Sergio M. (2012). Revisión de criterios de sostenibilidad en muros de concreto para viviendas sismorresistentes. *Ingeniería, Investigación y Tecnología*, 13(4). <http://dx.doi.org/10.22201/fi.25940732e.2012.13n4.047>
- Cascone, Stefano; Catania, Federico; Gagliano, Antonio; Sciuto, Gaetano. (2018). A comprehensive study on green roof performance for retrofitting existing buildings. *Building and Environment*, 136, 227-239. <https://doi.org/10.1016/j.buildenv.2018.03.052>
- Castleton, Holly Faye.; Stovin, Virginia; Beck, Stephen B. M.; Davison, J. B. (2010). Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings*, 42(10), 1582-1591. <https://doi.org/10.1016/j.enbuild.2010.05.004>
- Castorena-González, José Humberto; Almeraya-Calderón, Facundo; Almaral-Sánchez, Jorge Luis; Gaona-Tiburcio, Citlalli.; Martínez-Villafañe, A. (2010). Análisis con elemento finito de los esfuerzos expansivos por corrosión en las estructuras de concreto reforzado. *Ingeniería, Investigación y Tecnología*, 12(1), 1-7. <http://dx.doi.org/10.22201/fi.25940732e.2011.12n1.001>
- CENAPRED. (2011) Manual del formato breve de captura de datos para la evaluación estructural. México: CENAPRED.
- Cerón-Palma, Ileana; Sanyé-Mengual, Esther; Oliver-Solà, Jordi; Montero, Juan-Ignacio; Ponce-Caballero, Carmen; Rieradevall, Joan. (2013). Towards a green sustainable strategy for social neighbourhoods in Latin America: Case from social housing in Merida, Yucatan, Mexico. *Habitat International*, 38, 47-56. <https://doi.org/10.1016/j.habitatint.2012.09.008>
- Chang, Jiangliang J. (2003). Bond degradation due to the desalination process. *Construction and Building Materials*, 17(4), 281-287. [https://doi.org/10.1016/S0950-0618\(02\)00113-7](https://doi.org/10.1016/S0950-0618(02)00113-7)
- Chew Lin, Michael Yit; Tan, San; Kang, Kyu Ho. (2004). Building Maintainability—Review of State of the Art. *Journal of Architectural Engineering*, 10 (3), 80-87. [https://doi.org/10.1061/\(ASCE\)1076-0431\(2004\)10:3\(80\)](https://doi.org/10.1061/(ASCE)1076-0431(2004)10:3(80))
- Chiapas paralelo (2019). Las 10 colonias más violentas en Tuxtla Gutiérrez: Julio 2019. México, Chiapas 2019.
- Cortés, Carolina Forero.; Castillo Devia, Carlos Alonso. (2011). Mejora de las condiciones de habitabilidad y del cambio climático a partir de ecotechos extensivos. Estudio de caso: barrio La Isla, Altos de Cazucá, Soacha, Cundinamarca. *Cuadernos de Vivienda y Urbanismo*, 4(8). Recuperado a partir de <http://revistas.javeriana.edu.co/index.php/cvyu/article/view/5578>
- Cox, William D. (2008). 1099 New York Avenue Washington, D.C. (Construction Management).
- Delgado-Hernández, David Joaquín; Romero-Ancira, Liliana (2013). Satisfacción de las necesidades del cliente en el sector vivienda: el caso del Valle de Toluca. *Ingeniería, Investigación y Tecnología*, 14 (4), 499-509. [https://doi.org/10.1016/S1405-7743\(13\)72261-3](https://doi.org/10.1016/S1405-7743(13)72261-3)
- Flores-Asin, Juan Emiliano; Martínez, Claudia Fernanda; Cantón, María Alicia; Correa, Erica Norma. (2016). Desempeño térmico de cubiertas vegetadas en ciudades de zonas áridas. *Hábitat Sustentable*, b6 n2, 6-15.
- González-Herrera, Raúl; Borraz-Santiago, María A.; Sánchez-Hernández, Pedro Alberto; De la Cruz De la Cruz, Yoana; Aguilar-Carboney, Jorge Alfredo; Ruiz-Sibaja, Alejandro. (2010). Construcción Histórica de la Vulnerabilidad Sísmica en Tuxtla Gutiérrez, Chiapas. XVII Congreso Nacional de Ingeniería Estructural, León, Guanajuato, 3-6 de noviembre de 2010.
- González-Herrera, Raúl; Aguilar-Carboney, Jorge Alfredo; Gómez-Soberón, Consuelo. (2008). Patologías constructivas de viviendas en Chiapas. *LACANDONÍA revista de Ciencias de la Universidad de Ciencias y Artes de Chiapas*, año 2, número 2, págs. 73-86.
- González, Raúl; Mora, Juan Carlos; Aguirre, J. (2012). Microzonificación Sísmica de Tuxtla Gutiérrez, Chiapas, Informe técnico de Protección Civil del Estado de Chiapas. Recuperado a partir de [https://proteccioncivil.tuxtla.gob.mx/admin/archivos/Sistema\\_Municipal\\_de\\_Proteccion\\_Civil/documentos/f5c6b1d0\\_07082016\\_1404.pdf](https://proteccioncivil.tuxtla.gob.mx/admin/archivos/Sistema_Municipal_de_Proteccion_Civil/documentos/f5c6b1d0_07082016_1404.pdf)



ENGLISH VERSION.....

- Guajardo, A. (2017).** Análisis tipológico de bloques lineales de vivienda social: España 1950-1983. El caso de Andalucía occidental. *Informes de la Construcción*, 69(545), 185. doi: <http://dx.doi.org/10.3989/ic.16.055>
- Halvorsen, Grant T; Poston, Randall W.; Barlow, Peter; Fowler, David W; Pashina, Keith A; Barth, Florian; Bishara, Alfred G. (1993).** Causas, Evaluación y Reparación de Fisuras en Estructuras de Hormigón. Informado por el Comité ACI 224, 24.
- Hernández-Castañeda, Oscar; Mendoza-Escobedo, Carlos Javier (2005).** Durabilidad e infraestructura: retos e impacto socioeconómico. *Ingeniería, Investigación y Tecnología*, 7 (1), 57-70. <http://dx.doi.org/10.22201/ii.25940732e.2006.07n1.005>
- ICIPLAM (2012).** Instituto Ciudadano de Planeación Municipal. Tuxtla 2030 La agenda estratégica de nuestra ciudad. Recuperado a partir de: <https://tuxtla.gob.mx/iciplam/descargas/Tuxtla2030.pdf>
- INEGI (2010).** Instituto Nacional de Estadística, Geografía e Informática. México en cifras: Información nacional, por entidad federativa y municipios.
- Lee, Han.-Seung; Noguchi, Takafumi; Tomosawa, Fuminori. (2002).** Evaluation of the bond properties between concrete and reinforcement as a function of the degree of reinforcement corrosion. *Cement and Concrete Research*, 32(8), 1313-1318. [https://doi.org/10.1016/S0008-8846\(02\)00783-4](https://doi.org/10.1016/S0008-8846(02)00783-4)
- Moreno, Eric I.; Domínguez Lara, Gerardo. G; Cob Sarabia, Enrique J.; Duarte Gómez, Francisco. (2004).** Efecto de la relación agua/cemento en la velocidad de carbonatación del concreto utilizando una cámara de aceleración. *Ingeniería*, 8(2).
- Mosquera-Rey, Emilio R. (2015).** Revisión de la validez del coeficiente de seguridad, propuesto por EHE-08, para la estimación de la vida útil de cálculo en estructuras de edificación sometidas a la acción de cloruros. *Informes de la Construcción*, 67 (538), 082. <http://dx.doi.org/10.3989/ic.13.127>
- Munby, Beatrice. (2005).** Feasibility Study for the Retrofitting of Green Roofs. (Master in: Civil and Structural Engineeringaster). University of Sheffield, Sheffield.
- NADF-013-RNAT-2007. (2008).** Norma ambiental para el Distrito Federal. Gaceta oficial del Distrito Federal, México.
- Normas para la Rehabilitación Sísmica de Edificios de Concreto Dañados por el Sismo del 19 de septiembre de 2017. (2017).** Gaceta Oficial de la Ciudad de México.
- Novas-Cabrera, Joel Alexander. (2010).** Sistemas constructivos prefabricados aplicables a la construcción de edificaciones en países en desarrollo (Maestría). Universidad Politécnica de Madrid, Madrid, España.
- NTC-DC-RCDF (2017).** Normas técnicas complementarias para diseño y construcción de estructuras de concreto del Reglamento del Distrito Federal. Gaceta oficial del Distrito Federal. México.
- NTC-DC-RCDF (2004).** Normas técnicas complementarias para diseño y construcción de estructuras de concreto del Reglamento del Distrito Federal. Gaceta oficial del Distrito Federal. México.
- Ramírez de Alba, H.; De León, D.; Valdez, M. E. A. (2011).** Estudio del comportamiento estructural de losas macizas de concreto reforzado para vivienda. *Concreto y cemento. Investigación y desarrollo*, 3 (1), 2-13. Consultado en línea en: <http://www.imcyc.com/ccid/pdf/JUL-DIC-ART-1.pdf>
- Rodríguez, Mario; Padilla, Daniel. (2006).** Recomendaciones para el Control de Agrietamientos en Losas de Concreto Reforzado. XV Congreso Nacional de Ingeniería Estructural.
- Rodríguez-Reyna, Sandra Luz; Miranda-Vidales, Juana María; Espericueta-González, Dora Erika; Gaona-Tiburcio, Citlalli. (2012).** Resultados de una EEC variando los grados de Corrosión y el tiempo de aplicación de la técnica. *Ingeniería, Investigación y Tecnología*, 13(4), 425-431. <http://dx.doi.org/10.22201/ii.25940732e.2012.13n4.041>
- Sánchez-Trujillo, Víctor Manuel; González-Herrera, Raúl; Castañeda-Nolasco, Gabriel; García-Lara, Carlos; Aguilar-Carboney, Jorge. (2018).** Análisis de los efectos de corrosión en losas de concreto armado. En: Martínez-Salinas, R.I. & González-Herrera, R. (Coordinadores), *La Ingeniería Ambiental y Química ante los problemas ambientales en el sureste mexicano II*. Capítulo 19, págs. 267 a 283. ISBN 978-607-8410-81-1, Universidad de Ciencias y Artes de Chiapas, Colección Jaguar, Tuxtla Gutiérrez, Chiapas, México.
- Sánchez-Trujillo, Víctor Manuel; González-Herrera, Raúl; Castañeda-Nolasco, Gabriel; García-Lara, Carlos; Aguilar-Carboney, Jorge. (2019).** Characterization of pathologies in housing structures. A case study in the city of Tuxtla Gutiérrez, Chiapas, Mexico. *Journal of Building Engineering*, 22, 539-548. <https://doi.org/10.1016/j.job.2019.01.014>
- Sánchez-Trujillo, Víctor Manuel; González-Herrera, Raúl; Castañeda-Nolasco, Gabriel; García-Lara, Carlos; Aguilar-Carboney, Jorge. (2017).** Análisis de esfuerzos inducidos a estructuras de losas en viviendas de interés social con techos verdes. Congreso Universidad, Salud y Ambiente La Responsabilidad Social de las IES, Universidad Autónoma de Chiapas.
- Silva, Moisés; García, Antonio; Hernando, Ana. (2015).** Crecimiento de la mancha urbana en la Zona Metropolitana de Tuxtla Gutiérrez (Chiapas, México), 7.
- Simavorian, David; de Brito, Jorge; Castro, Luís; Azenha, Miguel. (2017).** Analysis of the effect of shoring on the behaviour of reinforced concrete slabs. *Construction and Building Materials*, 143, 473-489. <https://doi.org/10.1016/j.conbuildmat.2017.03.096>
- Shafique, Muhammad; Kim, Reeho; Rafiq, Muhammad. (2018).** Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, 90, 757-773. <https://doi.org/10.1016/j.rser.2018.04.006>
- Solar, Patricia. D.; Río, M. D. (2015).** Metodología para seleccionar oportunidades de mejora continua en promociones de viviendas. *Informes de la Construcción*, 67(538), 073. <http://dx.doi.org/10.3989/ic.13.142>
- Spathelf, Christian A.; Vogel, Thomas. (2018).** Fatigue performance of orthogonally reinforced concrete slabs: Experimental investigation. *Engineering Structures*, 168, 69-81. <https://doi.org/10.1016/j.engstruct.2018.04.058>
- Stovin, Virginia; Dunnett, Nigel; Hallam, Adrian. (2007).** Green Roofs – getting sustainable drainage off the ground (p. 8). 6th international conference of sustainable techniques and strategies in urban water management.
- Stovin, Virginia; Vesuviano, Gianni; Kasmin, Hartini (2012).** The hydrological performance of a green roof test bed under UK climatic conditions. *Journal of Hydrology*, 414-415, 148-161. <https://doi.org/10.1016/j.jhydrol.2011.10.022>
- Toirac-Corral, José. (2004).** Patología de la construcción. Grietas y fisuras en obras de hormigón. Origen y prevención. *Ciencia y Sociedad*, 29(1), 72-114.
- Velázquez-Leyer, Ricardo. (2015).** The Development of Housing in Mexico: A Welfare Regime Approach. *Social Policy and Society*, 14(04), 523-539. <https://doi.org/10.1017/S1474746414000591>
- Vijayaraghavan, K. (2016).** Green roofs: A critical review on the role of components, benefits, limitations and trends. *Renewable and Sustainable Energy Reviews*, 57, 740-752. <https://doi.org/10.1016/j.rser.2015.12.119>



ENGLISH VERSION.....

- Welsh-Huggins, Sarah. J.; Liel, Abbie. B. (2017).** A life-cycle framework for integrating green building and hazard-resistant design: examining the seismic impacts of buildings with green roofs. *Structure and Infrastructure Engineering*, 13(1), 19-33. <https://doi.org/10.1080/15732479.2016.1198396>
- Zhang, Jing-Zhou; Li, Guo-Qiang. (2018).** Collapse resistance of steel beam-concrete slab composite substructures subjected to middle column loss. *Journal of Constructional Steel Research*, 145, 471-488. <https://doi.org/10.1016/j.jcsr.2018.03.002>
- Zielinski, Seweryn; Collante García, Mario Alberto; Paternina Vega, Juan Carlos (2012).** Techos verdes: ¿una herramienta viable para la gestión ambiental en el sector hotelero del rodadero, Santa Marta? *Gestión y Ambiente*, 15(1), 91-104.

