ECONOMIC STUDY OF GREEN ROOFS AS A SUSTAINABLE CONSTRUCTION SYSTEM

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Abstract: *Green roofs respond to a need of today's society to orient its development towards sustainability. Architecture and urban planning, as builders of the modern city, play a crucial role in the search for a balance between social, environmental and economic growth. Green roofs imply recognized benefits in all three fields, but a study of the economic viability of these solutions is necessary, especially in the field of rehabilitation with tighter budgets. Through a cost-benefit analysis throughout its useful life, it is intended to avoid that the initial construction cost of a green roof, or any sustainable construction, could discourage users, helping them to understand its global dimension from an economic point of view.*

Keywords: *Green roof, Sustainability, Energy saving, Construction cost.*

1. INTRODUCTION

Sustainability is currently presented as the engine of the changes that must take place in our society. It is understood as such the balance between three main axes that define and determine the development of the contemporary world: social, environmental and economic (Think.org Inc.). The wide disparities that have occurred in recent decades in the social field, at the mercy of an irregular economic development in the different strata of the population, have led to an unsustainable current situation. To this we must add that, in the constant clash between the social and the economic, the environmental axis has become rather their battlefield, completely forgetting about its necessary care. The balance has been diminished, the three axes do not have the same importance or the same visibility.

Organizations such as the United Nations determined in 2015 a series of goals to be achieved, encompassed in the 17 Sustainable Development Goals (SDGs) (United Nations). This seeks to achieve greater equality and ensure stable and balanced prosperity between society, the environment and the economy. Considering that more than half of the world's population lives in cities (according to Lesjak et al (2020) 55% of the population, a value that rises to 74% when considering only Europe), and this number is expected to keep increasing in the next decade, it must be taken into account that cities have become a nucleus of inequality and social, environmental and economic pathology, although, also for this reason, they are presented as neuralgic spaces in the sustainable career. Architecture, urban planning and construction, as designers of the urban

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context, must join in this necessary search for growth that does not harm communities socially and economically, but especially the environment in which they are located. In the SDGs, cities are dedicated to a particular objective (Goal 11: Sustainable cities and communities) that seeks to achieve inclusive, safe, resilient and sustainable settlements. Architecture, in its new path of green and sustainable architecture, is in charge of materializing this new space of balance.

2. SUSTAINABLE CONSTRUCTION

Green roofs, as one of the booming tools of sustainable architecture, are capable of achieving a series of benefits included in the social, environmental and economic axes. From the social point of view, the renaturation of cities will improve, according to the degree of development of an inclusive network of green spaces with equitable access, the feeling of collectivity (Huang et al, 2015), urban and natural education (Walters & Midden, 2018) and people's health (Peen et al, 2010) (Pastor & Villacañas, 2014).

In the environmental field, these vegetable coating systems allow to improve air quality by capturing dust particles and pollutants (Penonić, 2016); reduce and improve the quality of rainwater runoff, minimizing flood risks (Berndtsson, 2010); reduce the urban heat island effect (UHI) by humidifying and reducing the temperature of the air near the roof (Mentens, 2006) (Correa, 2001); increase acoustic absorption by reducing environmental noise (Meulen, 2019); and increase biodiversity by rebuilding natural spaces eliminated during urbanization (Walters & Midden, 2018).

From an economic point of view, the use of green roofs presents a series of benefits throughout its useful life, such as increasing the value of the building and the surroundings (Jim & Chen, 2006), but also its benefits should be considered due to the reduction of energy consumption for air conditioning (cooling and heating) (Mohammadi & Sobouti, 2016). Its improvement in the insulation of the thermal envelope (facades and roofs) of the building makes it possible to reduce internal temperature variations. The energy saving will be more remarkable if the green roof is installed in a building with poor thermal characteristics of the envelope (rehabilitation) than if it is installed in a new building, whose envelope must comply with current thermal regulations, already very restrictive. If the vegetal coating is installed on a roof with a thermal transmittance value (U) of 0.51 W/m^2K (knowing that the U is the inverse of the resistance that an element opposes to the passage of heat, this value indicates good insulation and thermal resistance) the reduction in the annual consumption of cooling energy was only 0.6%, while in a roof without any previous insulation, this same vegetal covering could produce an annual cooling energy saving of 10.5% (Wong et al, 2003).

3. CONSTRUCTION COST ANALYSIS

Therefore, it is necessary to determine how much the construction cost of the green roofs will be, so that, combined with an analysis of costs and benefits throughout the useful life of a building (between 50 and 100 years), the viability of the construction project of this sustainable system can be determined with greater perspective. It should be noted that to maximize the energy benefits of this solution, using it in rehabilitation of buildings with little or no insulation in the envelope, the cost of construction must be considered even more carefully, since, especially in small or medium-sized renovation projects, the execution budgets are usually highly conditioned.

The study of the cost of construction of the roofs is carried out based on their multilayer structure, since the construction section is made up of different elements with specific functions, the cost of which can be studied separately. The combination of each of the layers responds to the good execution and the needs of each type of roof, also defining a specific construction cost. For the study conducted, nine models have been taken: M1 with a gravel finish (traditional roof existing in buildings susceptible to rehabilitation) and M2-M9 different types of green roofs. The multilayer composition will allow us to study the variation in construction cost not only between a green roof and a traditional roof with a gravel finish, but also between vegetable roofs, assessing the influence of some of the layers depending on the choice of materials or the thickness.

The standard construction section of a green roof is made up of the following layers over the structure, considering an inverted system in which the thermal insulation is placed over the waterproof sheet: slope formation, regulation mortar, waterproof sheet, anti-roots sheet, thermal insulator, drainage layer, filter sheet, substrate and vegetation. The choice of the inverted system is due to an increase in the durability of the waterproof sheet since being located under the thermal insulator it is subjected to lower thermal stress (Liu, 2003), thus also reducing the costs associated with repairs and replacements throughout the life of the roof (Meulen, 2019).

The M2-M9 models, which respond to green roofs, are determined with all the layers mentioned previously, studying the difference in the use of different materials in the drainage layer and the different substrate thicknesses, and the consequent size of vegetation they can support. According to the thickness of the substrate, the green roofs are divided into extensive, with substrate thicknesses between 8 and 15 cm, although in hot climates and with little rainfall, as is the case of the Mediterranean climate, it is recommended that the minimum thickness be 10 cm; semi-intensive, with thicknesses between 15 and 30 cm (Ajuntament de Barcelona, 2015); and intensive, with a substrate between 30 and 100 cm, although thicknesses of 60 cm are usually used (Cruz, 2017). The vegetation that can be used in intensive roofs is larger, considering the use of shrub, even trees and palms. The models studied are the following:

- M1. Gravel finish roof with 8 cm thick insulation.
- M2. Extensive green roof (10 cm thick substrate) with drainage layer of nodular panels and 4.5 cm thick insulation.
- M3. Thin semi-intensive green roof (20 cm thick substrate) with drainage layer of nodular panels and 3 cm thick insulation.
- M4. Depth semi-intensive green roof (30 cm thick substrate) with drainage layer of nodular panels and 3 cm thick insulation.
- M5. Intensive green roof (60 cm thick substrate) with drainage layer of nodular panels and 3 cm thick insulation.
- M6. Extensive green roof (10 cm thick substrate) with drainage layer of granular materials and 5 cm thick insulation.
- M7. Thin semi-intensive green roof (20 cm thick substrate) with drainage layer of granular materials and 3 cm thick insulation.
- M8. Depth semi-intensive green roof (30 cm thick substrate) with drainage layer of granular materials and 3 cm thick insulation.
- M9. Intensive green roof (60 cm thick substrate) with drainage layer of granular materials and 3 cm thick insulation.

Once the different layers have been chosen, a detailed study of the construction cost of each layer has been carried out, including labor and materials. Responding to its multilayer operation, the overall cost of the roof depends on the construction solution used. The detailed costs of two roofs with different materials as drainage layer are detailed below (Figure 1, Figure 2) and the total costs of the nine models studied (Figure 3).

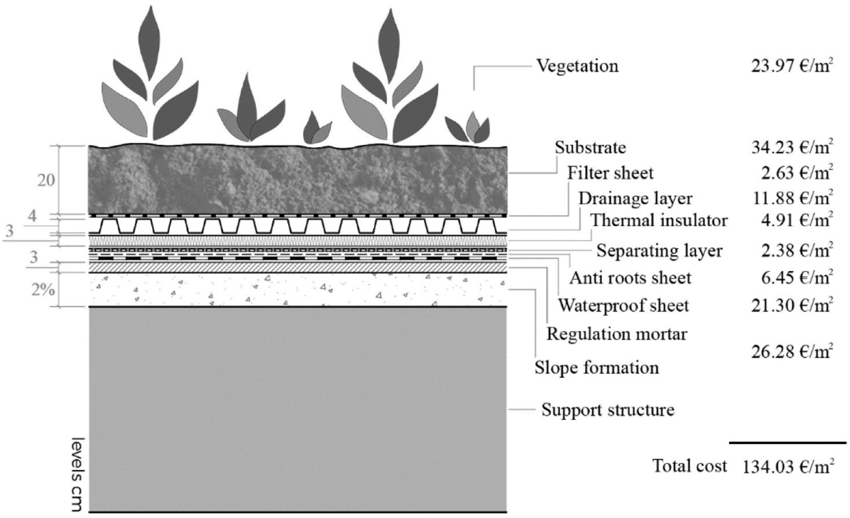

Figure 1. Indicative detailed cost M3

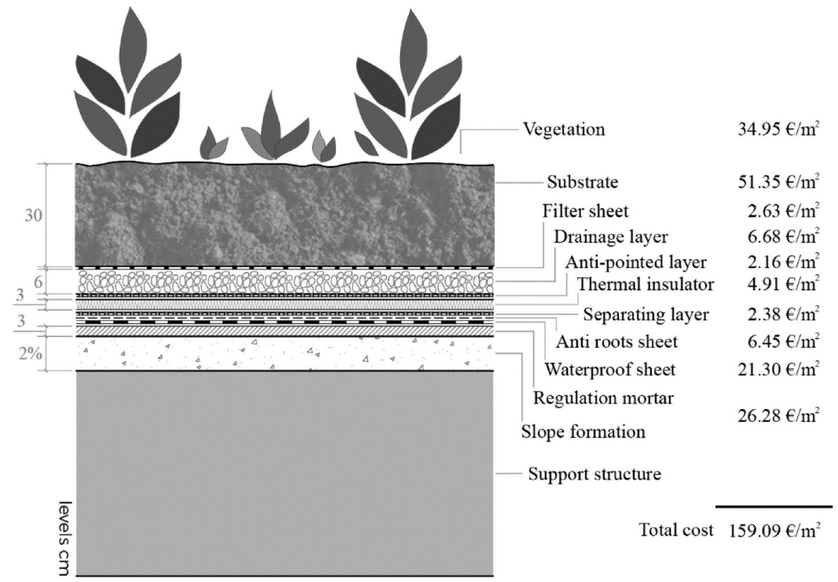

Figure 2. Indicative detailed cost M8

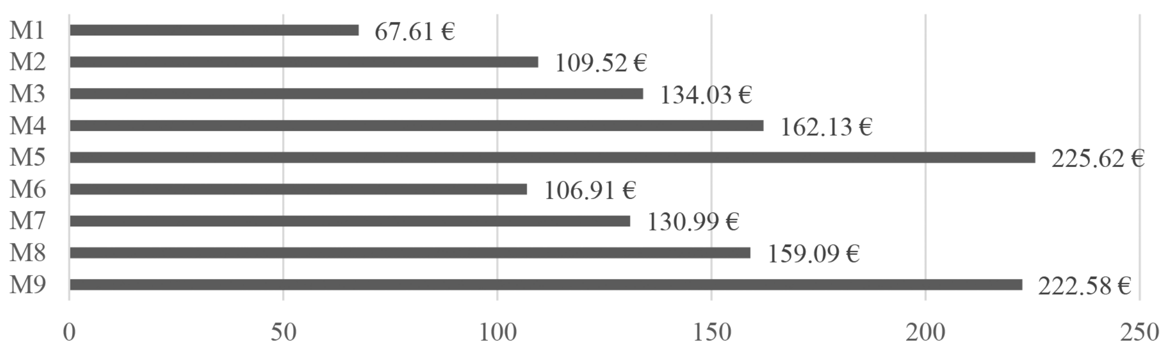

Figure 3. Indicative cost of the models studied

4. CONCLUSION

From the data presented above, first of all, we are going to focus on the influence of the different layers of an extensive green roof (M2) on the final construction cost (Figure 4). If we consider a total cost in which only the particular layers of a green solution are valued (from bottom to top: waterproof sheet, anti-roots sheet, drainage layer, filter sheet, substrate and vegetation), the construction cost of the group is 75.08 €. Substrate, drainage layer and filter sheet account for 38% of the total construction cost, 37% depends on the waterproof and anti-roots sheet and 25% is related to the vegetation. This agrees with the conclusions of Townshend (2017) in which, for a roof with a 10 cm thick substrate, the greatest influence on the final construction cost was the substrate and the draining layer. In his case of it, the influence of the substrate, the drainage layer and the fertilizer was 48%, 31% referring to the waterproof and anti-roots sheet, 16% to the vegetation and 5% to irrigation. Considering the absence of irrigation and fertilizer in the M2 model, and the use of an EPDM waterproof sheet, which is more expensive than the PVC used in the case of Townshend, the variations in the percentages can be justified. Even so, the high percentage that the substrate represents makes it possible to reflect on the possibility of considerably reducing construction costs by using a substrate that can take advantage of construction waste as an inorganic component (for example, broken bricks).

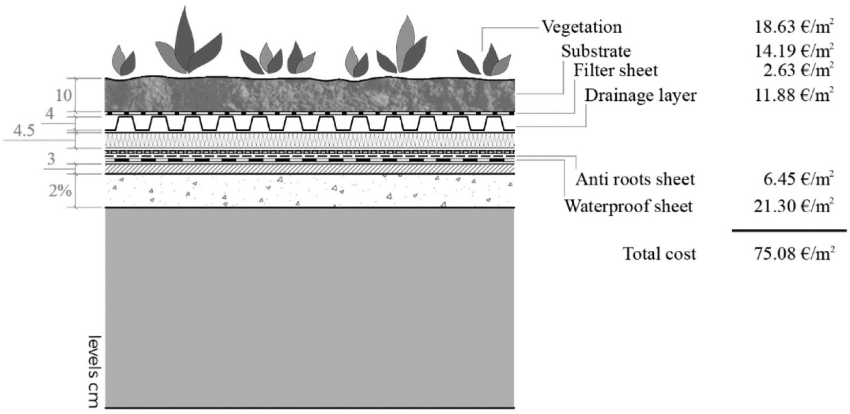

Figure 4. Indicative detailed cost of M2 with only representative layers

Making a comparison between the different models (Figure 3) it can be seen that the choice of an extensive green roof (M2 and M6) supposes a construction cost less than double (approximately 60%) compared to a traditional roof with a finish gravel (M1). On the other hand, the use of a solution with greater thicknesses (M5 and M9) represents an increase of approximately 230% in the cost of the traditional roof. Due to the fact that all the roofs have been calculated to comply with the thermal requirements of current Spanish regulations, we see that large thickness of substrate, or higher construction costs, are not necessary to achieve comfortable conditions inside, greater energy efficiency of the building and an improvement in the sustainability of the solution.

It should be noted that the construction cost of a green roof is relevant, but the entire useful life of the roof must be considered, with its associated costs and benefits. Peri et al (2012), after their studies, concluded that throughout the useful life of a green roof, construction costs only represented 36.1% of the total, with 59.3% maintenance costs and 4.6% disposal costs. Since the cost of construction does not represent the main percentage of the total cost of the roof over the entire life cycle, the cost-benefit final balance of a green roof can be considerably close to the values of a traditional roof. According to Carter and Keeler (2008), considering a useful life of

60 years, the green roof is only 10-14% more expensive than a traditional roof. But it should be noted that in the future case that the cost of energy increases, the prevention of floods becomes a priority of public policies or the cost of construction of the green roofs will decrease, only by 20%, due to a higher standardization or development of techniques related to green roofs, then these sustainable systems would become more economically attractive. But it must be taken into account that in these evaluations the social benefits or all the environmental benefits are not considered, so it can be concluded that although the cost of construction of an extensive green roof is 60% higher than in a traditional roof, the properties of any sustainable construction are capable of generating environmental and social benefits that are not currently accounted for in cost-benefit studies throughout their useful life, and that is capable of reversing the initial cons.

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