Selection and control of green roof materials based on sponge city perspective

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Abstract. This article starts from clarifying the connotation relationship between sponge city construction and green roof, and analyzes the construction plan and the best material selection under the influence of sponge city construction. Then introduces and compares the construction of the green roof under the sponge city background and the materials that can be used at the structural level, the evaluation index system of material selection based on DEA, five kinds of materials of input/output ratio of SBS modified asphalt waterproof coiled material is 0.477, TPO thermoplastic polyolefin waterproofing material is 0.255, PVC waterproof coiled material is 0.335, EPDM waterproofing material is 0.292, and spraying polyurea waterproof coating is 0.245. Comparison and analysis to choose spraying polyurea waterproof coating as the green roof material is more reasonable. This will provide a basis for the design of green roof materials in the context of a sponge city.

1. Introduction
The heat island effect and urban flooding caused by global warming are one of the most serious challenges facing mankind in the 21 century. And the construction of green roof in sponge city is an effective measure to realize low carbon and water storage under the situation of low resource utilization rate, land shortage and high land price [1,2]. How to reduce the roof load, the green roof waterproof and impervious has strict requirements, so the choice of green roof materials is crucial [3]. The design of planting roof in developed countries has been standardized and systematized [4]. As the country with the earliest origin of roof greening in the world, Germany's famous Weida planting roof system is composed of ten basic structural levels [5]. Its root-resistant waterproof material resists the puncture and destruction of plants by using the chemical and physical properties of the material itself, Commonly used waterproof materials are composite copper-based asphalt-resistant puncture waterproofing membrane (VEDAFLOR ws-1) and OCB plastic root-puncture waterproof material (VEDAPLANMF) [6]. American and Japanese planting roofing technology and materials are mostly borrowed from Germany. Asphalt is the main waterproof layer material in the United States. In recent years, a new ecological technology -- liveroof system emerged. Japan's planting roof structure waterproof system mainly includes asphalt waterproofing, membrane defense, urethane waterproofing + FRP, and about 40 species of sedum plants are widely used for planting roofing [7]. New Japanese planting roofing technology -- Hydroculture system is widely used [8]. In China, through qualitative construction and DEA model research and analysis of the properties of several root-resistant penetration coil materials, the polyurea waterproof coating with excellent physical properties was selected and applied [9]. Meanwhile, efforts were also made to study the compound waterproof system
of compound planting roof [10]. However, the previous research only qualitatively considered the waterproof effect and time limit, without considering the economic effect. Therefore, a qualitative and quantitative comprehensive study on structural hierarchy differences and economic parameters is urgently needed to select the best green roof materials under the background of sponge city.

2. Selection of green roof materials under sponge city -- DEA method

Sponge city has good "elasticity" in adapting to environmental changes and coping with natural disasters, and pays attention to recycling. In the construction of sponge city, green roof can effectively regulate runoff, play a role in energy conservation and emission reduction, and achieve a good landscape effect [11,13], which puts forward higher requirements for green roof construction, material selection and methods in integrating low-impact development technology.

Data Envelopment Analysis (DEA), an efficiency evaluation method, has become a common and important Analysis tool and research method in the field of decision Analysis and evaluation technology [14]. DEA method is a method to comprehensively judge the rationality and effectiveness of input/output of n decision making units of an economic system that can input a certain number of production factors and produce a certain number of products through a series of decisions. It doesn't need to set the weights of input index and output index in advance, avoid the objectivity of determination of index weight coefficient in the average sense, and do not need dimensionless processing in evaluation (As shown in figure 1).

![Figure 1. work flow chart of DEA model](image)

2.1. Comprehensive evaluation system of root-resistant waterproof materials for green roof

In order to effectively evaluate and select root-resistant waterproof materials for green roofs, a comprehensive evaluation index system can be established from the aspects of technology, economy, environmental impact, etc. The first layer is the target layer, and the second layer is the specific factors for selection (as shown in figure 2).
Figure 2. Comprehensive Evaluation Index system of Roof-resistant Waterproof Material for Green Roof

2.2. DEA evaluation model selection and establishment

C²R model is the most classical model of DEA method. DEA counter cross evaluation method can be used to obtain effective evaluation value for materials under reasonable returns of scale. However, when there are few kinds of targets, it can avoid the problem that traditional DEA model cannot distinguish the good from the bad to some extent.

With the root-resistant waterproof material of green roof as the decision-making unit, there are n kinds of root-resistant waterproof materials, each of which has s types of input X and m types of output Y, defined

\[ E_{ii} = \frac{\mathbf{u}^T \mathbf{y}_i}{\mathbf{v}^T \mathbf{x}_i} = \sum_{t=1}^{m} \frac{u_t y_{t i}}{v_t x_{t i}}, \quad i = 1, 2, 3, \ldots, n \]

\[ x_i = (x_{1i}, x_{2i}, \ldots, x_{mi}) \quad y_i = (y_{1i}, y_{2i}, \ldots, y_{si}) \]

Where: \( x_{t i} \) - input output of the i-th material to the t-th type input
\( y_{t i} \) - output output of the l-th material to the t-th type input
\( v_t \) - weight coefficient of type t input

| Decision unit | 1   | 2   | ... | N   | weights |
|---------------|-----|-----|-----|-----|---------|
| input         |     |     |     |     |         |
| 1             | \( x_{11} \) | \( x_{12} \) | ... | \( x_{1n} \) | \( v_1 \) |
| 2             | \( x_{21} \) | \( x_{22} \) | ... | \( x_{2n} \) | \( v_2 \) |
| ...           |     |     |     |     |         |
| m             | \( x_{m1} \) | \( x_{m2} \) | ... | \( x_{mn} \) | \( v_m \) |
| output        |     |     |     |     |         |
| 1             | \( y_{11} \) | \( y_{12} \) | ... | \( y_{1n} \) | \( u_1 \) |
| 2             | \( y_{21} \) | \( y_{22} \) | ... | \( y_{2n} \) | \( u_2 \) |
| ...           |     |     |     |     |         |
| N             |     |     |     |     |         |

Note: the greater the value of in general \( E_{ii} \), show that the more DMU with relatively few input to obtain relatively large output.
Now evaluate the efficiency of the i-th green roof root-piercing waterproof material (DMUi, 1 ≤ i ≤ n), with u and v as weight vectors and the efficiency index of all green roof root-piercing waterproof materials as constraint, the following model is constructed:

\[
\begin{align*}
\text{max } & \frac{u^T y}{v^T x_i} \\
\text{st.} & \frac{u^T y}{v^T x_i} \leq 1 \\
v^T = (v_1, v_2, \ldots, v_m)^T, \quad v > 0 \\
u^T = (u_1, u_2, \ldots, u_s)^T, \quad u > 0 \\
x_i = (x_{1i}, x_{2i}, \ldots, x_{mi}) \\
y_i = (y_{1i}, y_{2i}, \ldots, y_{si})
\end{align*}
\]

According to c-c transformation, assuming \( s = 1 / v^T x_i \), \( \omega = sv \), \( \mu = su \), Convert the above model into

\[
\begin{align*}
\text{max } & \mu^T y_i = E_{ii} \\
\text{st.} & \omega^T x_i > \mu^T y_i \\
\omega^T x_i = 1, \quad \omega \geq 0, \quad \mu^T \geq 0
\end{align*}
\]

Let the optimal solution of the latter linear programming be \( \mu^* \) and \( \omega^* \), The optimal value \( E_{ii} = \mu^T y_i \) is the efficiency evaluation index of DMUi in cross evaluation method called decision making units DMUi self value. In the traditional DEA method evaluation, if \( E_{ii} = 1 \), DMUi is effective, indicating that the internal operation efficiency of DMUi is high and the relative maximum output is obtained with the most appropriate input. If the \( E_{ii} < 1 \), DMUi as invalid, suggesting that DMUi under the existing technical level, the investment of input is too much and too little output, waste of resources.

Finally, the modle of counter cross evaluation is established, assuming \( i \in (1, 2, 3, \ldots, n) \), \( k \in (1, 2, \ldots, n) \), solve the following linear programming problem

\[
\begin{align*}
\text{min } & \mu^T y_k \\
\text{st.} & \mu^T y_i \leq \omega^T x_i \\
\mu^T y_i = E_{ii} \omega^T x_i \\
\omega^T x_k = 1 \\
1 \leq i \leq n, \quad \mu \geq 0, \quad \omega \geq 0
\end{align*}
\]

The optimum value of \( \mu^* \) and \( \omega^* \) was obtained, and the cross evaluation value was calculated

\[
E_{ik} = \frac{\mu^T y_k}{\omega^T x_k} = \mu^* y_k
\]

By the above formulas come out again of the value of the cross evaluation matrix E

\[
E = \begin{bmatrix}
E_{11} & E_{12} & \cdots & E_{1n} \\
\vdots & \ddots & \vdots \\
E_{n1} & E_{n2} & \cdots & E_{nn}
\end{bmatrix}
\]

The main diagonal element \( E_{ii} \) of the matrix serves as the self-evaluation value of DMUi, and the other elements are the cross-evaluation value, The i-th line besides the diagonal elements to represent DMUi value for other DMU, the smaller the value of DMUi the better.

Divided element matrix to calculate arithmetic average, the final index of DMUi as evaluation decision unit.

\[
e_i = \frac{1}{n} \sum_{k=1}^{n} E_{ik}
\]

The larger the calculated mean \( e_i \), is, the better DMUj is.
3. Green roof material selection and cost control analysis

3.1. Structural analysis of green roof

The green roof is a multi-layer overall structure. The general green roof is constructed from top to bottom in order: vegetation layer, matrix layer, filter layer, drainage (storage) water layer, root-piercing waterproof layer, and then the basic structural layer of building roof [15,16]. Due to the different development needs of different cities, their structures are different, and in the specific green roof construction projects, the structure should be constructed according to the type of green roof in accordance with "the technical specifications of planting roof engineering" (JGJ155-2013) and make appropriate adjustment at the level. In this paper, we discuss the sponge under the background of urban green roofs, when the design on the basis of the "delay" and "net", at the same time satisfy the sponge under the condition of construction and roof load requirements, the accumulation of rainwater and the reuse technology into consideration.

In any green roof system design, water impermeability is an important goal, and the root-piercing waterproof layer can not only prevent leakage, but also protect the roof components of the building, which is an extremely important structural layer in roof design. Green roof has a good water retention capacity, but if there is no timely drainage, the roof load will be enhanced, so the drainage layer should be set to improve the ventilation state of the matrix, quickly discharge excess water, effectively relieve the instantaneous pressure, and design an aquifer that can store suitable water and keep the planting medium moist for plant growth. The green roof, regardless of the drainage method, should be equipped with a filter layer to prevent the small particles and nutrients in the planting soil from running away with the water and blocking the pipes. Plant growth requires adequate nutrients, and the stroma not only provides nutrients and water, thermal properties and water retention, but also provides space for plant root growth. As the aesthetic layer of green roof, the vegetation layer is an important symbol of green roof environmental products. It can not only absorb solar energy to reduce heat island effect, improve air quality, improve urban ecological environment and beautify urban landscape by absorbing carbon dioxide through photosynthesis, but also regulate rainwater runoff through retention and evaporation to increase the energy-saving effect of the building itself. In view of the above design factors, the following detailed description of the green roof structure is designed.

![Figure 3. the structure of green roof](image)

3.2. Analysis of structural materials of green roof planting system

3.2.1. Root resistant waterproof layer. Root penetration refers to the overlap of roof and waterproof layer, joints and corners of plant root damage, invasion of waterproof layer. And the key of green housetop construction lies in its waterproof prevent leakage stand or fall, need to apply appropriate waterproof material adequately so safeguard roofing service life. Root-piercing waterproof material not only has the function of ordinary waterproof material, but also has the functions of mildew resistance, puncture resistance and preventing plant roots from penetrating, and can promote the smooth growth of roofing plants.
Specified in the "regulations of technology of planting roof engineering" green roof waterproof level need to meet I level requirements, and set up at least two of the waterproof layer [17]. So far, the materials participating in root penetration experiments in China can be classified into modified asphalt, plastics, synthetic rubber and coatings according to their components. In this paper, the performance of these eight materials is briefly summarized and analyzed by referring to the specifications and literatures, as shown in table 2.

Table 2. Comprehensive Analysis of Properties of Waterproof Materials

| Material classes       | Name of coil            | Dead load Durability | Durable puncture(thickness) | Extens ion | Heat resistance | Cost performance | Construction                        |
|------------------------|-------------------------|----------------------|----------------------------|------------|-----------------|------------------|-------------------------------------|
| Modified asphalt       | Elastomer (SBS) modified asphalt waterproof coil | 0.05 KN•m⁻² | Over 15 years | ≥4 mm | ≥40% | 90~10 0 ℃ | 75-80 yuan•m⁻² | Difficult to grasp the degree of hot melt |
|                        | Polyvinyl chloride (PVC) waterproof coil         | 0.10 KN•m⁻² | 25 years | ≥1.2 mm | ≥200% | 85 ℃ | 75-80 yuan•m⁻² | Cold adhesive, construction process of dry gel time is difficult to control |
|                        | EPDM waterproof coil                       | 0.10 KN•m⁻² | 50 years | ≥1.2 mm | ≥450% | 80 ℃ | 75-80 yuan•m⁻² | Poor adhesion, difficult joints, node processing is more difficult |
|                        | Thermoplastic polyolefin (TPO) waterproof coil | 0.10 KN•m⁻² | 30 years | ≥1.2 mm | ≥450% | 120 ℃ | 95-105 yuan•m⁻² | Wet roof can be constructed, exposed without protective layer |
|                        | Spray polyurea waterproof coating            | 0.015-0.2 KN•m⁻² | 25 years | ≥2 mm | ≥450% | 160 ℃ | 30-40 yuan•kg⁻¹ | Affected by the pressure deviation is big, the construction process of continuous stirring |

Roof material usually structure deformation, dry shrinkage, unreasonable design and construction quality under the factors such as cracks, resulting in leakage, and polyurea coatings can well solve this problem. First of all, polyurea material up to 16 Mpa tensile strength effectively restrain cracks, secondly polyurea material is more than 450% of elongation make polyurea coatings in the roof cracking can still keep complete [18].

3.2.2. Drainage (storage) water layer. The goal layer is in the green roof system for best balance in the air and water, which can effectively reduce the roof runoff to the natural water cycle process. Drainage material type and the shape of the mainly depends on the choice of green roof systems, weather conditions and component, south drainage, heavy water in northern China, "The technical specification of planting roof engineering"points out that drainage (storage) water layer materials should have the properties of ventilation, drainage, water storage, high compressive strength, good durability and light quality, and recommends five drainage (storage) water layer materials  [19](table 3).
Table 3. technical index of drainage material

| Number | Material                      | Technical indicators                              |
|--------|-------------------------------|--------------------------------------------------|
| P1     | Concave and convex type water plate | Maximum strength at 20% compression ≥150kpa   |
|        |                               | longitudinal flow ≥10cm³·s⁻¹                      |
|        |                               | compressive strength ≥50kN·m²                     |
| P2     | Mesh interwoven drain plate    | Surface porosity ≥95%                            |
|        |                               | Flow capacity ≥380cm³·s⁻¹                       |
| P3     | Graded gravel                 | Particle size should be 10mm-25mm, laying thickness ≥100mm |
| P4     | The pebble                    | Particle size should be 25mm-40mm, laying thickness ≥100mm |
| P5     | Ceramsite                     | Particle size should be 10mm-25mm, laying thickness ≥100mm |

With the progress of technology, and in the garden greening project appeared a new type of environmental protection material -- glass light stone, the material light porous, high hardness, good compression resistance, in addition to a good drainage, its water absorption is also very good. Selection of various parameters of water layer materials for drainage (storage) (table 4).

Table 4. Comparison of plastic drainage (storage) material parameter

| Performance Class | Dry weight(3cm thick, kg·m⁻²) | Longitudinal flow(cm³·s⁻¹) | 3cm Storage capacity(L·m⁻²) | Compressive strength 0.7mm thickness(kpa) | Durable life | Porosity | Cost(yuan·m⁻²) | Tear resistanc e |
|------------------|-------------------------------|----------------------------|-----------------------------|-------------------------------------------|--------------|----------|----------------|----------------|
| PVC drain        | 0.314                         | ≥25                        | 4.75                        | ≥300                                      | 25 years     | About 50% | 45-50                  | ≥100N            |
| drainage plate   | 1.36                          | ≥5.6                       | 3.24                        | ≥150                                      | 50 years     | About 70% | 50-55                   | ≥100N            |

Table 5. comparison of loose particle drainage(storage)material properties

| Performance class | Dry density(kg·L⁻¹) | Saturated wet weight(kg·L⁻¹) | Storage capacity(kg·L⁻¹) | Compressive strength(Mpa) | Porosity (%) | Durable life | Actively absorb water | Cost(yuan·m⁻³) |
|-------------------|---------------------|------------------------------|--------------------------|---------------------------|--------------|--------------|-----------------------|----------------|
| Ceramsite gravel  | 0.366               | 0.439                        | 0.073                    | 10                        | 55-75        | short        | no                    | 300~350         |
| Glass pumice      | 1.484               | 1.499                        | 0.015                    | 20                        | 20-35        | long         | no                    | 150~220         |
|                   | 0.224               | 0.342                        | 0.118                    | 0.9-1.5                    | 50-95        | long         | yes                   | 650~700         |

By comparison, it is found that the weight of PVC drainage board is lighter than HDPE drainage board, and the water storage capacity is about 1.47 times of HDPE, and also occupies advantages in terms of price and compression performance. Compared with other materials, pumice glass has active water absorption capacity, and its water storage capacity is stronger than the other two kinds of loose granular materials. Its large porosity enables it to retain water and fertilizer, and its mass is light. However, the manufacturing process of pumice glass in China is not perfect, so it is not superior in cost performance.

Table 6. comparison of water storage performance of drainage(storage)material

| Reservoir performance       | Gravel | Ceramsite | Glass pumice | PVC drain | HDPE drain |
|-----------------------------|--------|-----------|--------------|-----------|-----------|
| Weight ratio(Water weight/Material dry weight) | 0.01   | 0.20      | 0.06         | 15.13     | 2.38      |
| Volume ratio (Water storage volume/material's volume) | 0.02   | 0.04      | 0.12         | 0.16      | 0.11      |
Firstly, comparative analysis of five kinds of material based on the 3 cm thick, found that the storage capacity is with preferential treatment to the carrier, is PVC board > glass light stone > HDPE plate > ceramsite > gravel, only when the thickness of the ceramsite is 5 cm to reach the level of the HDPE plate, 7 cm more than the PVC board, therefore ceramsite is more suitable for intensive green roof. And the glass light stone can reach the level of PVC board when 4cm, it has better air permeability than PVC board, and PVC board in the simple green roof when the wind load resistance is not strong, so the development prospect of glass light stone is very broad. Although gravel quality is heavier, draw materials easily, price is cheap, intensity is big, suffer environmental influence to be small, the application of dense green roofs cannot be ignored. Secondly, row (storage) layer material also affects the stromal layer, soil moisture and soil microbial biomass in the physical properties of different drainage material itself is lead to changes in soil microbial biomass and microbial functional diversity of the main reasons. And the quantity of soil microorganism is related to the water quality of roof runoff and the growth of vegetation, so storage and drainage plate is not necessarily the best choice of green roof, but use porous material, can make green roof has better biological adaptability and environmental coordination.

3.2.3. Filter layer. The filter layer is a structural layer that filters out the water in the fluid mud, but does not cause the loss of soil and nutrients in the soil, avoids the fluid mud and debris entering the drainage layer and causing blockage, and is located under the matrix layer above the drainage (storage) water layer. The selection of filtration layer material should have longer water permeability, a certain pore diameter and the ability to resist corrosion and root penetration.

Table 7. advantages and disadvantages of filter layer

| Class                          | Advantages                                                                 | Disadvantages                        | Engineering case                      |
|-------------------------------|-----------------------------------------------------------------------------|-------------------------------------|---------------------------------------|
| Organic materials:            | Easy to draw materials, environmental protection, light quality, low price, and can maintain a relatively long water permeability | Perishable, filter unstable          | Kaiser empire center                  |
| straw, coconut shell, organic waste, etc |                                                                               |                                     |                                       |
| Burlap, plastic woven bag    | The quality is light and the price is low                                   | Perishable, unstable filtration performance | The rooftop garden of the Oakland museum, Peking University stomatology hospital, Beijing lun hotel |
| Non-woven fabric:            | Good corrosion resistance, easy construction, excellent root penetration      | Water seepage does not last long     |                                       |
| glass fiber, polypropylene, polyester, polyamide, etc |                                                                               |                                     |                                       |

3.2.4. The substrate layer. Substrate layer is the "soil" plants, plants rely on it provides nutrients and moisture to grow, reasonable choice of substrate layer material for plant growth and ecological benefits of green roofs perform has extremely important significance. Unlike the ground soil, green roof structure will be restricted by roof load, and in the roof structure composed of all levels, wet density condition of dry density of 1.2-1.5 times [20], it occupies the main bulk density, it determines the weight of the green roof is violated security principle. So green roof substrate material choice is restricted by many aspects.
Table 8. Basic index requirements for properties of commonly used planting soils

| Planting soil type | Saturated water density (kg·m⁻³) | Organic matter content (%) | Total porosity (%) | Effective moisture (%) | Drainage rate | PH | Total nitrogen (g·kg⁻¹) | Total phosphorus (g·kg⁻¹) | Total potassium (g·kg⁻¹) | Salt (%) |
|--------------------|-------------------------------|----------------------------|-------------------|-----------------------|---------------|----|------------------------|--------------------------|--------------------------|---------|
| Rural soil         | 1500~1800                     | ≥5                         | 45~50             | 20~25                 | ≥42           | 6.5~8.2 | -                      | -                        | -                       | <0.3    |
| Improved soil      | 750~1300                      | 20~30                      | 65~70             | 30~35                 | ≥58           | -    | 7.0~8.5                | >1                       | >0.6                    | >17     |<0.12   |
| Inorganic soil     | 450~650                       | ≤2                         | 80~90             | 40~45                 | ≥20           | 0    | -                      | 1                        | 0.6                     | 17      |0.12    |

Table 9. Comparative analysis table of three kinds of planting soils

| Planting soil type | Introduction | Merit | Defect | Engineering case |
|--------------------|--------------|-------|--------|------------------|
| Rural soil         | The most primitive planting matrix material | Easy materials, low prices, adequate nutrients | Poor stability, unstable porosity, wet bulk density, easy shrinkage | Wedge-shaped square in zhongguancun, Beijing, the roof garden of Rockefeller center |
| Improved soil      | Natural soil, drainage materials, lightweight aggregate and fertilizer are mixed in proportion | Small load, good water retention, good ventilation, good water permeability | Poor stability, easy loss of organic matter, soil volume change | Roof garden of Beijing huaye international center, Beijing Great Wall hotel |
| Ultralight medium  | Such as peat soil, coal slag, perlite, vermiculite, sawdust, pumice | Material light, water retention and drainage, good air permeability, nutrition controllable | Poor stability, the price is more expensive, need to carry out surface reinforcement treatment | Yindu building, Qinhuangdao |

3.2.5. Vegetation layer. Vegetation layer is the core hierarchy of green roof to bring ecological, social and economic benefits into play. Selecting plants should be comprehensive load, growing conditions and actual environment and the plant itself form, color, texture, growth rate and the function of the roof greening and so on various factors taken into account, the general intensive roof garden shrubs and small trees often planted with grass and commonly used vegetation planting have paved the mianzhu grass, purple back cotton bamboo grass, big flower purslane, loose leaf peony, such as floor mianzhu grass and Buddha grass is currently the most ideal plant selection [21].

3.3. Cost accounting

When using green roof root-piercing waterproof materials for construction, a variety of applicable materials need to be evaluated not only for performance but also for economic evaluation. The so-called "waterproof construction depends on material selection". Therefore, this paper chooses a motor vehicle garage in a residential area in qingbaijiang district of Chengdu with an example. The
roof of the garage is the roof of people, and there are winter jasmine, heather and lawn planted above, and the walkway is available for owners' leisure and entertainment. Select the above procedures recommended to evaluate five kinds of materials: SBS elastomer modified asphalt waterproofing materials, PVC waterproofing materials, TPO thermoplastic waterproofing materials, EPDM waterproofing materials, spraying polyurea waterproof coating. The comprehensive unit price is based on the comprehensive unit price of Sichuan province's roof garden base treatment item in 2018 and the construction procedures of different materials applied in 2015 "Sichuan province construction engineering quantity bill valuation quota". The amount is estimated according to different lap joints and construction treatment details.

Table 10. Material consumption and Comprehensive Unit Price Table of Green Roof of garage in a residential area of Qingbai river

| Name of the material | Roof area(㎡) | Design life | Production unit price(yuan•m²) | Comprehensive unit price(yuan•m²) | Dosage | Total price(yuan) | Total price of person, machine and other materials(yuan) |
|----------------------|-------------|-------------|------------------------------|-----------------------------------|--------|-------------------|---------------------------------|
| SBS                  | 300         | 15          | 58                           | 119.37                            | 330 m² | 19140             | 20252.1                         |
| TPO                  | 300         | 30          | 100                          | 159.49                            | 320 m² | 32000             | 19036.8                         |
| PVC                  | 300         | 20          | 76                           | 131.16                            | 315 m² | 23940             | 17375.4                         |
| EPDM                 | 300         | 30          | 80                           | 135.38                            | 340 m² | 27200             | 18829.2                         |
| Spray polyurea       | 300         | 20          | 33.33 yuan•kg⁻¹              | 95.67                             | 410 kg | 13665.3           | 18726.75                        |

By the table 10(AC_pro), estimate the corresponding production cost, construction cost (AC_con) and maintenance costs (AC_mai).

Formula (where I is 10%):

$$A_{C_{pro}} = TP \times \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$A_{C_{con}} = (\text{cost of labor} + \text{Other materials} + \text{Mechanical fee}) \times \frac{i(1+i)^n}{(1+i)^n - 1}$$
$AC_{\text{mai}} = \left[\text{Daily maintenance} \times (P/A,i,n) + \text{Overhaul cost}\right] \times \frac{i(1+i)^n}{(1+i)^n-1}$

① SBS modified asphalt waterproof coil

$AC_{\text{pro}} = 19140 \times \frac{i(1+i)^n}{(1+i)^n-1} = 2516.408 \text{ yuan}$

$AC_{\text{con}} = (\text{cost of labor} + \text{Other materials} + \text{Mechanical fee}) \times \frac{i(1+i)^n}{(1+i)^n-1} = 2662.62 \text{ yuan}$

$AC_{\text{mai}} = \left[\text{Daily maintenance} \times (P/A,i,n) + \text{Overhaul cost}\right] \times \frac{i(1+i)^n}{(1+i)^n-1} = 1976.33 \text{ yuan}$

The economic input data of the five materials are shown in Table 11.

| Material                          | $AC_{\text{pro}}$ | $AC_{\text{con}}$ | $AC_{\text{mai}}$ |
|-----------------------------------|-------------------|-------------------|-------------------|
| SBS                               | 2516.41           | 2662.62           | 1976.33           |
| TPO                               | 33941.50          | 2019.41           | 1725.87           |
| PVC                               | 2811.98           | 2040.90           | 2194.35           |
| EPDM                              | 2885.35           | 1997.38           | 2156.98           |
| Spray polyurea waterproof coating | 1605.12           | 2199.64           | 2073.21           |

Then according to the relevant literature search and consultation of some decoration work designers, material managers and some staff, the technical performance and environmental performance were rated (full score of 5 points).

| Material                          | Input          | Output                  |
|-----------------------------------|----------------|-------------------------|
|                                  | $AC_{\text{pro}}$ | $AC_{\text{pro}}$ | $AC_{\text{mai}}$ | Resistance root | Durability | Heat resistance | Ductility | Cycling situation | Low carbon protection |
| SBS                               | 2.52           | 2.66                    | 1.98               | 2              | 2          | 3              | 1         | 2               | 4           | 1             |
| TPO                               | 3.39           | 2.01                    | 1.73               | 4              | 5          | 3              | 5         | 4               | 2           | 5             |
| PVC                               | 2.81           | 2.04                    | 2.19               | 3              | 3          | 2              | 3         | 4               | 4           | 2             |
| EPDM                              | 2.85           | 1.99                    | 2.16               | 3              | 5          | 4              | 4         | 3               | 2           | 3             |
| Spray polyurea waterproof coating | 1.61           | 2.20                    | 2.07               | 3              | 3          | 5              | 5         | 1               | 4           | 3             |

Then based on the DEA evaluation model of cross formula of index in assessment of five kinds of material model, using MATLAB software to calculate, get a cross efficiency evaluation matrix evaluation results, self value is as follows:
According to the above evaluation, self value spray polyurea waterproof thermoplastic polyolefin < TPO waterproofing < EPDM EPDM waterproofing materials < PVC waterproofing < the SBS modified asphalt waterproof coiled material. All shown in the results, spraying polyurea waterproof material minimum the self evaluation, explain that the input is small but the output value is high, which is the most suitable material.

4. Discussion and Conclusion

4.1. Structural design of green roof

Cong Zhang [5] found that the typical structure of planting roofing in some western developed countries was basically the same, which was roughly the structure layer -- blocking root layer -- drainage layer -- filtering layer -- vegetation layer, with only partial hierarchy order difference. However, the structure layer of planting roofing in sponge cities in China was most similar to that in Japan, which was almost consistent with the research results of Lijuan Huang. This may be related to the type of planting roof. The United States is mostly fine type plant roof, while Germany and Japan are mainly extensive type planting roof. This also indicates that when designing the urban green roof structure, it is necessary to select the most suitable structure based on the difference in the development needs of different cities and the existing technology. The root layer is an indispensable layer of green roof, directly affect the service life of the green roof and construction safety. At the same time, due to the climate in our country, when designing the planting roof structure, it can be considered to increase the insulation layer with the function of separating indoor water vapor from the cracks of the prefabricated plate to the insulation layer, and reduce the engineering repair. Almost all western developed countries has its plants roofing system, our country also should strengthen the research of new materials and new technology, strive for an early research issue of planting roof system with Chinese characteristics.

4.2. Selection of green roof materials

On the micro level, the optimal materials for the important structural layers of planting roofing (root-resistant puncture waterproof layer, etc.) were analyzed. Although spraying materials have relatively high comprehensive construction costs, their excellent durability and physical and chemical properties can significantly reduce the high maintenance costs in the later stage and achieve considerable comprehensive benefits, which is almost consistent with the research results of Huanzhi Hou [22]. Moreover, Xuelian He after consulting relevant literatures found that the tensile strength of spraying polyureas can also effectively prevent the cracking of the roof. The porous material of PVC drainage plate is considered to be the best drainage layer material, which is also similar to the research results of Wei Yu etc. [18]. The reason lies in its good economic benefits and physical properties, and the compressive strength is as high as 300KPa compared with the previous year. As a substrate layer on the roof of the soil, is not entirely adopt the original sense of the soil, it may with high wet bulk density will increase the roof load effects are concerned, is developing in the direction of the light, thin layer, water, it will also promote the research of the new matrix materials. In the imitation of Germany planting roof vegetation layer, abandoned the original meaning of the plant, such as cloverleaf grass, lopegrass, etc. In the selection of green roof vegetation in the future, more abundant vegetation rolling technology should be explored to absorb harmful substances in the air and improve the ornamental value of green roof.

Based on DEA method, this paper established a comprehensive evaluation analysis, quantitatively selected the five waterproof materials qualitatively analyzed by Yonghua Dong [9], and obtained the results basically consistent with the qualitative analysis, spraying polyurea waterproof material is the best root-piercing waterproof material, its self-evaluation value is 0.245, which may be related to its good material properties and advanced technology. Although the construction cost and maintenance cost of spraying once are higher than those of the other four types of materials, but one-time molding and overall seamlessness, its excellent heat resistance and ductility make the material have a long service life, and the spraying technology avoids the defects of traditional waterproof materials and
processes and has high technical performance and environmental protection performance, at the same
time, it will greatly improve the waterproof function and become a high-tech that is worthy of
development and promotion in waterproof engineering. The conclusion also provides material
selection for actual green construction and is beneficial to the development of green roof. The research
and analysis in this paper deepened the profound significance of green roof building in sponge city for
alleviating urban heat island effect and flood disaster, provided the conception and theoretical basis for
builders to design the green roof structure level of sponge city and the selection of corresponding
material level, and provided the research direction for the development of green building materials in
the future, which could realize the effect of 1+1 > 2 by combining polyurea spraying material with
other materials.

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