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Life-Cycle Building Costs Based on Particle Swarm Optimization

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Abstract

One of the most current issues the society nowadays faces is the decrease of resources worldwide. In dealing with this subject, the trend to optimize resources emerged. Besides natural resources, the most important resources in the investors' and owners' point of view are the monetary resources. As a result, optimizing construction costs on the entire life cycle of a building is desired. In this paper we advance an innovative method that helps optimize all the costs with regard to constructing a building with the help of particle swarm optimization. Through particle swarm optimization costs will be optimized for every investment, whether a shell stage building, a turnkey stage building or a finish stage building.

Rezumat

Una dintre cele mai actuale probleme cu care societatea actuala se confrunta este scaderea numarului si a cantitatii de reseruse la nivel mondial. Din dorinta de a rezolva aceasta problema, a aparut tendinta de a optimiza resursele. Pe langa resursele natural, cele mai importante resurse din punctual de vedere al investitorului si al proprietarului sunt si resursele monetare. In concluzie, optimizarea costurilor unei constructii pe intregul ciclu de viata al acesteia este una dintre cele mai dorite aspecte in domeniu. Aceasta lucrare avanseaza o metoda inovativa ce ajuta la optimizarea costurilor in domeniul constructiilor cu ajutorul metodei optimizarii roiului de particule. Prin metoda optimizarii roiului de particule, se vor optimiza costurile pentru toate investitiile, fie ca este vorba despre cladiri la rosu, la gri sau la cheie.

Keywords: particle swarm optimization; life cycle building; building costs, sustainable building, intelligent building, inclusive building

1. Introduction

Ever since the beginning of men, the need to have a roof over one's head was considered a primordial need, a need that was paramount to accomplish. As technology and knowledge evolved, people started being interested in buildings that are able to satisfy any need one could have. In accomplishing these desires, men initiated constructing intelligent buildings, buildings that are

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intuitive in understanding their inhabitants' needs and desires and are adaptive to their requests. These buildings, along with sustainable buildings, rely on the evolvement of technology. Sustainable buildings started being of interest for the owners and the investors due to the increased tendency nowadays of protecting the environment. Sustainable buildings are buildings that use a small amount of resources and are capable of sustaining themselves by producing energy, recycling water. Taking into consideration the fact that every person has the right to a fair living, a new thought current emerged. This current is interested in constructing inclusive buildings, buildings that can be used by anyone at any time without being necessary to adapt them to every person in particular, every particular disability.

In our opinion, a merge between these three types of buildings would be the ideal building, the building of the future. Therefore, taking into account the characteristics of a sustainable, intelligent, inclusive building we have tried to identify every cost in every stage of life of a building. In order to accomplish this, we have to take into consideration that although every building is unique in its own way, they still have the same life stages. Knowing these stages enables professionals in the field to foresee all costs. These costs may vary and are dependent on different factors: the design details, the quality of the building, the climatic conditions, orientation of the building, the implication level of the owners and/or inhabitants with regard to the maintenance of the building etc.

2. Life Stages of a building

Professionals in the field have identified various classifications regarding the life stages on the entire life span of a building.

One of the most memorable classifications compares the life stages of a building with the life stages of a person as follows: prenatal (0-2 years), childhood (3-16 years), adolescence (17-29 years), maturity (30-49 years) and old age (over 50 years) [1]. In the prenatal stage the building is constructed and handed to the owners. As every material and appliance in the building is new, there is no need to spend money on repairs. In the childhood period there will be maintenance costs and small repairs may be necessary. Adolescence is a period in which the budget for renovations increases substantially. Maturity is the most expensive of the stages as there are both brand new equipment and old equipment that needs to be replaced entirely. Old age is similar to childhood as most of the equipment in the building are new.

BREEAM (Building Research Establishment Environmental Assessment Methodology) offered a general classification: the design and construction period and the post-construction period [2].

Another commonly used classification, the best known of them all is composed of 5 stages:

- Designing the building – the design of every element that comprises the building; most specialists [3],[4],[5] consider that this stage is not a distinct one and that it can be included in the construction phase, however, we believe this is an important stage as costs concern and decided it must be analyzed separately
- Selection, acquisition and transport of materials – selection of the materials used in constructing the building, purchasing the materials and transporting them to the building site
- Construction of the building – the actual assembling of the materials into a building
- Using the construction – installing the necessary equipment, living in the building, repairs, maintenance, replacements etc.
- End of life, reusing and recycling – this stage implies demolition, dispatch of waste, recycling of waste

Taking into consideration the life cycles of a product, in this case a building, it is a tremendous mistake, management wise, not to implement an integrated planning strategy when creating a product or equipment that is supposed to be beneficial both for the seller and for the buyer.

In the current competitive economy, the need to use money or other types of resources at an optimum level is undisputed. In the construction industry, as in any field, optimizing costs on the entire life span of a building is vital. In order to have an overall view of the necessary spending, one has to analyze costs on the entire life span of a building, not only at the construction stage. The best known tool to analyze costs at every stage of life of the building is called Life-cycle cost analysis (LCCA) [6]. The use of LCCA results in effectively differentiating initial costs, maintenance costs and operating costs of two similar in performance projects/buildings. The aim of LCCA [7] is to maximize profit: to further apart profit and costs.

LCCA, at management level, facilitates deciding whether to maximize or minimize initial costs at the expense of operational and maintenance costs. In other words, if one invests more in the initial phase, maintenance and operational costs will decrease and vice versa.

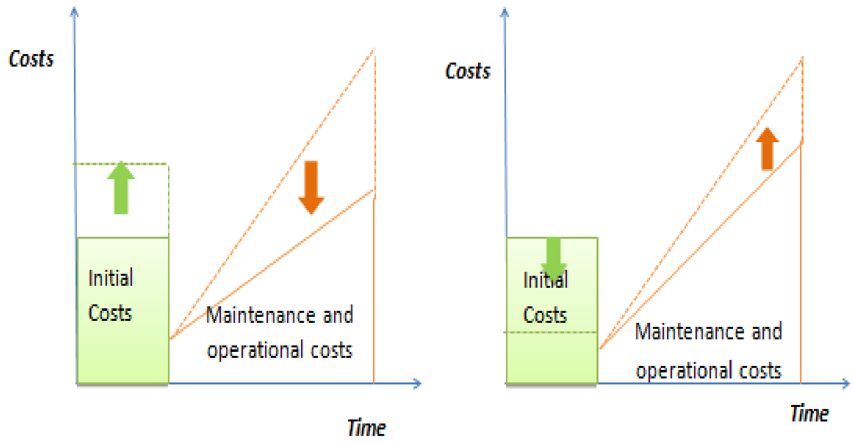

Figure 1. Initial costs vs. Maintenance and operational costs
(adapted from J. Niemann, S. Tichkiewitch, E. Westkamper, 2009)

3. Proposed model for structuring the costs

In order to exhaustively identify all the costs in all the life stages of a building we have divided them into two categories: costs from the investor's (builder or owner) point of view and costs from the beneficiary's (user of the building – owner or tenant) point of view.

A. Costs from the investor's point of view

An investor is concerned with costs regarding the following stages: 1. designing the building, 2. selection, acquisition and transport of materials, 3. constructing the building, 4. using the building and 5. end of life, reusing and recycling.

Designing the building implies, firstly, a geophysical study, that incorporates the study of all the specific geophysical, topometric and climatic conditions of the place the building will be built in/on. Afterwards, an architect will design the exterior of the building and its interior compartments. The planning certificate must be obtained. A specialized engineer will design the structural strength of a building while other engineers will design the execution details for cabling and pipelines with regard to electricity, plumbing, water, sewage, heating, security and surveillance, fire etc. Costs for designing the building are dependent on the architect and are calculated per square meter.

The selection, acquisition and transport of every necessary material from the stores to the construction site is a very difficult stage. At this stage we have to choose materials for the structural strength of the building, for its foundation, for the exterior and interior walls, for the insulation and finishes of these walls, for doors and windows, for the roof decking and covering, floors, pipelines and cabling for electricity, water, sewage, fire, security and surveillance, equipment that produces electricity from alternative sources, equipment that produces heat from alternative sources, equipment that recycles and reuses water etc. When selecting these materials we have to keep in mind every characteristic of every material as there are infinite possibilities to choose from when constructing a building. Costs are connected to the quality and performance of every material.

For starters, the structural strength of a building is composed of two structures: infrastructure and superstructure and include elements such as: columns, beams, floors, stairs, walls etc. The investor has to decide whether the structural strength will be: a reinforced concrete structure, a load-bearing masonry structure or a wood structure. When deciding what to choose one has to keep in mind that the reinforced concrete structure is the most expensive one and the most resistant, the wood structure is the least expensive, the most sustainable and with high insulation properties, while the a load-bearing masonry structure is simple to assemble, has good acoustic insulation, but bears a low number of floors.

The foundation of a building can be built of concrete, reinforced concrete or steel and must have hydro and thermal insulation.

Exterior and interior walls can be made out of: brick, autoclaved aerated concrete (AAC), wood etc. Nowadays, brick is the most expensive and has medium insulation qualities, AAC is the best at insulating and has a medium price, while wood is the cheapest and has good insulation qualities. Walls must be hydro, thermo and acoustic insulated. Between 25-40% of the total amount of heat in a building is lost through walls, so choosing the best material in building and insolation is a very important matter. The walls' finishes can be comprised of paint, emulsion paint, wood or crockery.

Doors and windows are important because they are responsible for 30-40% of the heat loss in a building. Doors and windows can be made of: wood, laminated wood, steel, PVC, aluminum, glass fiber or mixed. The most sustainable ones are the wood or the laminated wood ones. The best at insulating at the PVC windows and doors. The least expensive ones are the wood ones, PVC is in the medium price category, while laminated wood is the most expensive one.

When constructing the roof's framing one can use: wood, concrete or steel. Wood is the most sustainable and the cheapest, but is the least resistant. Concrete is the most expensive and the most resistant, while steel is average on both counts. For the roof's envelope one could choose from: metal shakes, shingles, and fiberglass shingles. Shingles is the easiest to mount, the lightest and the most sustainable of them all. The cheapest is metal shakes. The roof's envelope and the ceiling must be thermal insulated.

Flooring in a building can be: synthetic materials, wood, natural stone, artificial stone, freestone etc. Flooring made of wood and natural stone are the most expensive at acquisition and in maintenance, while artificial stone is the cheapest. Flooring must be thermo, hydro and sound insulated.

Pipelines and cables concerning electricity, heat, sewage system, water etc. are pretty standard usually and their prices are estimated in linear meters.

The equipment that produces electricity differs on the alternative production source: sun, wind, water, earth etc. There are numerous technologies, based on each of these sources, more or less productive. Some of the technologies supplement only 10% of the necessary electricity, while others are capable to self-sustain 100% of an entire building. Costs are dependent on the alternative source of production and on the degree of supplementation of energy.

The equipment that produces heat/cooling are dependent on and influenced by the incorporated technologies, taking into consideration the fact that the most effective of them are also the most expensive. Alternative sources for heating/cooling are: solar energy, fossil fuels, geothermal energy, wind energy, water energy etc. When choosing the source one has to take into consideration the potential of the area in which the building will reside. Some of the technologies are able to sustain 100% of the total consumption of a building.

The equipment used for recycling and reusing water have different technologies incorporated. Some of them harvest rainwater and collect it in order to be used for irrigation. Other technologies collect waste water and transform it into water used in irrigation or for toilet flushing. Specialists in the field estimate that 50-80% of the waste water can be recycled and reused. Costs for these equipment vary technology and performance wise.

When considering the costs for transporting materials and equipment from the store to the construction site we have to mention most of the stores transport the sold merchandise without any additional cost. Also, if there is to be a cost, it will be determined taking into consideration the distance in kilometers and the weight in kilograms.

Nowadays, when constructing the building, the company/team in charge with its execution does not make an offer for every particular labor needed to be accomplished. Instead, they make an offer depending on the degree of finished executed, namely, an offer will be made for a “shell stage building”, a “turnkey stage building” or a “finished stage building”. A shell stage building has the following stages completed: structural strength, foundation, interior and exterior walls, roof framing and envelope. Its price is calculated by square meter. The turnkey stage building, has, besides the one stated above, the following: thermo and hydro insulation, doors and windows, finishes for the interior and exterior walls (excluding paint), wood and freestone flooring, crockery. The costs of the labor are calculated per square meter. A finished stage building includes all the necessary finishes, sanitary appliances, radiators, lighting appliances, some of the furniture (bathroom and kitchen). The costs of the labor are calculated per square meter. Over time it can be observed that a finished stage building is more expensive than a turnkey stage building by 45% and a turnkey stage building is more expensive than a shell stage building by 15%.

From the investor’s point of view costs regarding the using of the construction comprise of the entire furniture that is needed in order to use the building for its intended purposes, yearly taxes to the local authorities, yearly damage insurance, repairs and replacements needed during the building’s life cycle.

When considering the end of life of a building, reusing and recycling we have to take into consideration different costs. Firstly, there will be costs with the consumption of energy while demolition. Furthermore, some machinery and equipment will be necessary to rent in order to knock down the building. Afterwards, the waste produced during demolition must be transported to sites or centers that recycle it. This last step implies transport costs. Some of the waste can be used at a future construction site, in which case transport costs are evidently implied. All transport costs will be calculated per kilometer.

B. Costs from the beneficiary’s point of view

The only costs a beneficiary has to take care of are the costs regarding the use of the construction. From the beneficiary’s point of view the most stable and fix of the expenses are rent costs. Rent costs materialize themselves in a fixed sum per month and it is calculated usually at the market price taking into consideration location, the quality and the performance of the building.

Energy costs vary in buildings as the consumption of energy is dependent on the activities performed inside. If equipment that produce electricity from alternative sources was incorporated into the building, energy costs will reduce proportionally to the amount of energy produced by these technologies.

Heating/cooling costs will appear in the form of thermic energy if the building is linked to a centralized heating system. Otherwise, costs will appear as energy costs and marsh gas costs. If technologies that produce thermal energy from alternative sources, the consumption will decrease proportionally to the performance of these technologies.

Fresh water and sewage costs can be decreased by implementing technologies that either recycle and reuse sewage water or collect and reuse pluvial water, or both. Some of these technologies can result in saving of 80-90% with respect to fresh water consumption.

Security and surveillance costs vary on whether the building is an intelligent one, meaning whether it has an intelligent surveillance system incorporated. If this system exists, one person that will monitor the surveillance cameras will be enough per shift. If there is no such system, the building will need a certain number of guardians per shift per square meters.

The tenant/beneficiary also has to take care of some minor repairs during their stay in the building. Some of these repairs include: changing light bulbs, repairing walls' coating, repairing or replacing degraded floors, windows and doors, locks etc.

4. Particle Swarm Optimisation

Particle Swarm Optimization [8], [9] is a stochastic optimization technique based on a population of individuals and inspired by the birds' behavior. In Particle Swarm Optimization individuals (particles) are moving through a designed space in order to seek and to follow the best individual. A "swarm" of particles is composed of individuals who have a specific a position in space exploration and a movement speed. These individuals memorize the position where they obtained the best results. Also, each individual receives information related to the best individual in the swarm. Depending on this information, they change velocity and position of each individual, thus realizing the search space exploration. As in the case of the initial population of the genetic algorithm, the randomly generated population will be updated along with each iteration executed.

If we consider a N-dimensional searching space, the position vector of each particle (x_i^k) is updated by the following formula. The process is also presented in Figure 2.

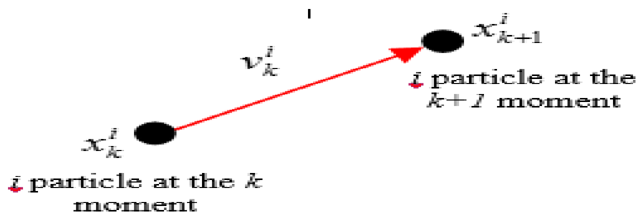

Figure 2. Particle position updating process

$$x_{k+1}^i = x_k^i + v_{k+1}^i \tag{1}$$

Where,
x_{k+1}^{i} - new particle i position
x_{k+1}^{i} - current particle i position
v_{k+1}^{i} - new particle i velocity

The new particle velocity is given by:

$$v_{k+1}^{i} = \omega * v_{k}^{i} + c_1 * r_1^k * (pbest_i - x_k^i) + c_2 * r_2^k * (gbest_i - x_k^i) \quad (2)$$

where:

ω	Inertia weight
c1, c2	Acceleration constants. c1+c2 must be between 0 and 4
r1, r2	Random acceleration between [0, 1]
$pbest_i$	Best position of the particle i founded so far
$gbest_i$	Best global position of the entire swarm at i moment

5. Fundamenting the core concept in order to estimate costs

In order to fundament a software program we decided to take into account the three stages that represent the finish degree of the building: shell stage building, turnkey stage building and finish stage building. After analyzing these initial stages, we have studied the following ones: using the construction and demolition, reuse and recycle of the building.

In order to better analyze these stages we have elaborated tables that emphasize the level of every investment cost and every exploitation cost for each year in the building's life. We have considered that the life a building resides between 0-49 years. As investments we have considered both the initial investment in year 0 of life and all the repairs and replacements in the following 49 years. As exploitation costs we have taken into consideration all the costs/reduction of costs with respect to every incorporated technology in these 50 years. Costs over the mentioned 50 years will be actualized through a constant, similar to the net present value. The estimated initial costs and exploitation costs, on a period of 50 years, for a shell stage building, can be observed in Table 1.

Table 1. Initial costs and exploitation costs on the entire life span of a shell stage building

	y 0	**y 1**	**y m**	**y 30**	**y 31**	**y n**	**y 49**
R.01. Building design							
R.01.1. Geotechnical study – unit: lei/total	600	0	…	0	0	…	0
Exploitation costs R.01.1.	0	0	…	0	0	…	0
R.01.2. Architectural project – unit: lei/m²	34	0	…	34	0	…	0
Exploitation costs R.01.2.	0	0	…	0	0	…	0
R.01.3. Interior design project – unit: lei/ m²	40	0	…	40	0	…	0
Exploitation costs R.01.3.	0	0	…	0	0	…	0
R.01.4. Structural strength	10	0	…	0	0	…	0

project – unit: lei/ m²							
Exploitation costs R.01.4.	0	0	…	0	0	…	0
R.01.5. Installations'' project – unit: lei/ m²	3.5	0	…	0	0	…	0
Exploitation costs R.01.5.	0	0	…	0	0	…	0
R.01.6. Construction permits – unit: lei/ m²	3	0	…	0	0	…	0
Exploitation costs R.01.6.	0	0	…	0	0	…	0
R.01.7. Exterior design project – unit: lei/ m²	15	0	…	0	0	…	0
Exploitation costs R.01.7.	0	0	…	0	0	…	0
R.02. Site management							
R.02.1. Site management - unit: %/entire project	2.5	0	…	0	0	…	0
Exploitation costs R.02.1.	0	0	…	0	0	…	0
R.03. Excavation							
R.03.1. Excavation - unit: lei/m³	25	0	…	0	0	…	0
Exploitation costs R.03.1	1	0	…	0	0	…	0
R.04. Structural strength - unit: lei/m³							
R.04.1. Reinforced concrete structural strength	480	0	…	0	0	…	0
Exploitation costs R.04.1.	2	0	…	0	0	…	0
R.04.2. Bearing masonry structural strength	280	0	…	0	0	…	0
Exploitation costs R.04.2.	2	0	…	0	0	…	0
R.04.3. Wood structural strength	850	0	…	0	0	…	0
Exploitation costs R.04.3.	2	0	…	0	0	…	0
…	…	…	…	…	…	…	…
R.09. Workmanship							
R.09.1. Workmanship - unit: %/entire project	25	0	…	0	0	…	0
Exploitation costs R.09.1.	0	0	…	0	0	…	0

The algorithm at the basis of the software program bound to estimate all the costs is the swarm particles optimization algorithm that can be observed below.

```
For each particle
{
    Initialize particle
}
Do until maximum iterations or minimum error criteria
{
    For each particle
    {
        Calculate Data fitness value according to (1)
        If the fitness value is better than pBest
        {
            Set pBest = current fitness value
        }
        If pBest is better than gBest
        {
            Set gBest = pBest
        }
    }

    For each particle
    {
        Calculate particle Velocity according to (2)
        Use gBest and velocity to update particle Data
    }
}
```

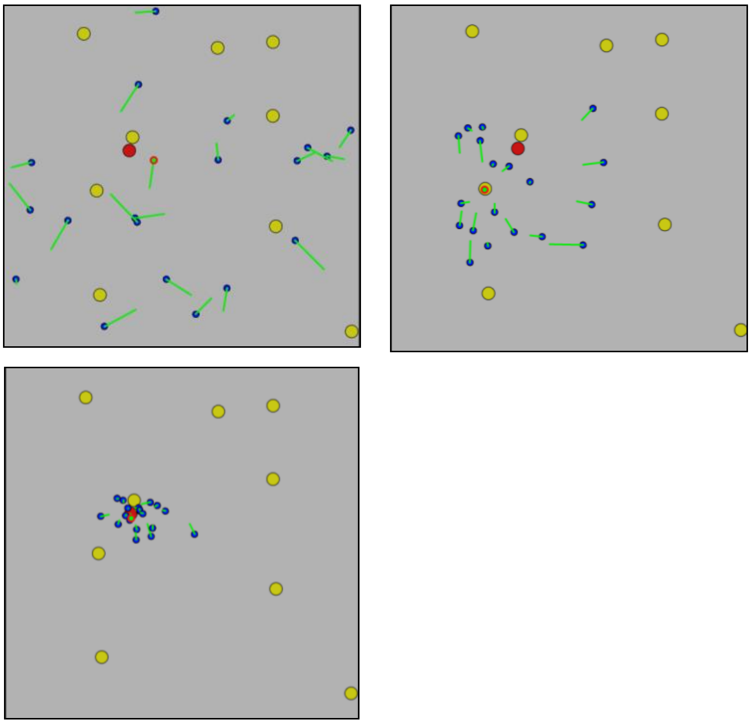

Figure 3. Swarm particle optimization on a building's life cycle

In the first picture one can observe the initial and exploitation costs that have been excerpted from the table that featured all the costs of a shell stage building on its entire life span. The second picture iterates the particles' movement, right in the middle of their movement. Furthermore, the last picture presents the end of the optimization.

6. Conclusions

The figure that exemplifies the swarm particle optimization on a building's life cycle has only been

tested on a shell stage building. In the future we plan to disseminate all the costs involved in all the three stages of a building: shell stage building, turnkey stage building and finish stage building
This analysis/experiment will help us plan and handle in validating our algorithm, to furthermore, later on, include all the costs with regard to all the stages of a building on its entire life span.
We are confident in the fact that our work is the ground key in developing a future application that will better the lives of investors, owners and tenants alike, having in mind that costs are one of the most important factors when developing a building.

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