An Optimization Decision Support Model for Sustainable Urban Regeneration Investments

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Abstract:- In order to support the decision-making process related to the reduction of land consumption into the urban regeneration interventions, the present research has the aim to define and propose a goal programming-based model that can be adopted for the negotiation phases of public and private subjects involved. In particular, the proposed model can provide for a range of feasible scenarios that, according to the specific purposes of the Public Administration, can be implemented in order to achieve the financial, environmental and social level of sustainability targets set by the Agenda 2030. In this way even the private entrepreneur can verify his personal convenience to participate in the investment. Furthermore, the possibility provided by the model to choose a different combination of urban parameters that define the convenience of interventions before their implementation, could reduce the increasingly significant problem of badly concluded interventions, interrupted because they lack an effective ex ante evaluation.

Key-Words: - urban investment, urban regeneration, land consumption, soil sealing, goal programming, decision support tool

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1 Introduction

The rapid development of urban systems has become one of the most faced challenges worldwide. Both academics and decision-makers agree on the need to manage uncontrolled urban expansion - the so-called sprawl - by promoting regeneration and enhancement processes [1]. However, to realize successful initiative it is necessary guaranteeing an improved environmental quality that, at the same time, offers a better livability without restriction on the economic development that is strictly correlated to the constantly evolving needs. It is therefore clear that environmental, social and economic issues are firmly dependent on each other and the variation of one of them born in the cities can have a positive or negative influence on the others [2-3]. This complex condition is also known as the “compact city paradox”, due to the conflicting situations which occur into urban dynamics and the difficulty that arises from managing all the specific interests of public and private subjects involved [4].

For these reasons, the concept of “sustainability” of the urban environment began to take shape and spread. It is a multidimensional concept in which the necessity to accomplish the simultaneous aggregation of different conflicting objectives in order to achieve an efficient and feasible solution requires the use of adequate decision support systems [5-7].

Depending on the final outputs provided by the different methods of assessment, determination and quantification of urban sustainability in relation to the reduction of land consumption, the existing approaches can be divided into three main categories: the first one relates to the cognitive analyzes that provide a framework with the criticalities or potentialities of the territory examined, such as reports or cartographic tools based on indicators and maps; the second one consists of operational tools defined to evaluate *ex ante* sustainability, also in the form of procedures that *step by step* guide the public and private subject in the analyzes; the third one, finally, contains all the tools that make it possible to quantify and determine specific aspects of sustainability (or all of them), both before and after the intervention, mainly adopting approaches based on systems of synthetic indicators and indices, multi-programming models objective, multi-criteria evaluation techniques [8-16].

Among others, the Goal Programming (GP) technique has been widely applied to address and manage the sustainable urban development decisions, due to its capacity to provide for compromise solutions that takes into account several typology of criteria and the possibility to aggregate often conflicting needs and interests of the subjects considered. Numerous studies have extended the principles of mathematical programming to address specific aspects of sustainability that occur in the urban dynamics. Morano et al. [17] provide for a GP linear model able to identify the most suitable compromise solution among the private entrepreneur and public administration goals by ensuring the environmental features of the regeneration of abandoned areas. Jayamaran et al. [18] study a weighted GP model applied to the key economic sectors of the United Arab Emirates to achieve Sustainable Development Goals (SDG) of the Agenda 2030. San Cristòbal [19] combines economic, energy, social and environmental issues into a GP model based on an environmental input-output linear programming in order to define the several goals that must be implemented to achieve sustainability.

As it can be seen, the scale of the analyses carried out in the reference literature varies from the local intervention to a more global vision. The main feature of an effective sustainable development strategy, indeed, is its ability to be scalable -with respect to the territorial context of application- and transversal according to the types of data analyzed and with a true methodology, so as to be able to guarantee its replicability by the decision-makers.

2 Aim

The present work is part of the framework outlined. The aim is to define a decision support model that, based on computational logic and principles of GP, can guide public and private subjects involved into urban regeneration investments in the identification of the most sustainable solutions. In particular, the model intends to address three levels of urban sustainability: the first one concerns the financial conveniences of the subject involved, in order to ensure the entire feasibility of the project; the second one regards the environmental degree related to the extent of urban green areas and the limited quantity of natural land take within the project; the third one considers the social aspects with respect to the public services that must be guaranteed to the local community.

The variables from which the most suitable solution derives are those that represent the core urban parameters of the negotiation phases between private and public subjects involved and, at the same time, the same variables determine the morphological structure of the urban regeneration project itself.

The model can be useful to support the public and private subjects involved into the complex decision-making phases of urban regeneration and enhancement processes aimed at improving the sustainability in the long term. Furthermore, it can help the local authorities to achieve the SDGs n.11 and 15 of Agenda 2030, which appear to be the furthest from the targets set by 2050.

The paper is structured as follows. Section 3 introduces the model by providing a description of the assumptions, the variables, the constraints, and the objective function defined in the proposed model. Section 4 outlines the model's strengths and weaknesses that future research insights might over-come.

3 Model

The problem to be addressed is analyzed through a linear programming model which applies the Simplex Algorithm through the Mathematica 9.0 software and with four different typologies of constraints, each one specifically defined to take into account the features of the urban regeneration process and the goals carried out by the two different subjects involved.

3.1 Assumptions

The considered subjects are schematized in a generic Public Administration (PA) and a private real estate entrepreneur (PE). Both for the PA and the PE, the financial balance sheets are obtained by considering the costs and the revenues of two different situations: in the first one, the PE realizes only the works related to the private share of the total land plot surface; in the second one, instead, the PE realize both the works on the private share and acquire and reclaim also the share of the total land plot surface to be freely transferred to the PA for public services. The financial conveniences assessment of both of them is carried out as follows: for the PA, they are determined by comparing the realization cost of the public works with the monetary amount of the resources and the buildings freely transferred by the PE for the public infrastructures; for the PE, by comparing the revenues generated by the sale of the properties allowed by the urban planning parameters, with the total financial resources that the PE will have to burden for constructing the private properties and the public ones at his expenses.

Three different intended uses and its occupied share of total realizable volumes are assumed. Among the cost items of the PE, its expected remuneration (normal profit) for the activities of production coordination and the risk investment is included. The taxes are not considered in the balance sheets because the aim is to achieve results that focus the attention on the urban initiative parameters, avoiding territory specific-related features that, however, could easily considered and added to the model in future development that pertain to a certain and well-know urban context. For both the balance sheets, the distribution over time of the financial items is not considered, in order to avoid that the uncertainty of the forecasts can affect the final outputs.

3.2 Variables

There are nine variables in the model, each one defined according to the general division of private and public shares of the total land plot surface on which the urban regeneration investment has to be realized. A brief description of each variable is following provided:

i. total land plot surface (S_{tot}) = the extent of the areas on which all the works decided for the investment have to be realized;
ii. Private surface (S_{pre}) = the share of the total land plot surface (S_{tot}) charged to the PE for the realization of the buildings, greenery and parking works;
iii. Private buildings surface (S_{prb}) = the share of the PE total land plot surface (S_{pre}) intended for the construction of the gross floor surface (GFS) allowed by the territorial building volume index (I_{bt}) for the area and planned for the residential (GFS_{res}), offices (GFS_{off}) and commercial (GFS_{com}) units;
iv. Green areas surface (S_{ga}) = the share of the PE total land plot surface (S_{pre}) where the private green areas will be;
v. Car parking surface (S_{cp}) = the share of the PE total land plot surface (S_{pre}) intended for the private car spaces;
vi. Public surface (S_{pub}) = the share of the total land plot surface (S_{tot}) where the PA will carry on the public works;
vii. Public infrastructure surface (S_{pui}) = the share of the public total land plot surface (S_{pub}) intended for the public services;
viii. Road surface (S_{pur}) = the share of the public total land plot surface (S_{pub}) where the public roads will be realized;
ix. Freely transferred surface (S_{tr}) = the share of the public total land plot surface (S_{pub}) that the PE will acquire, reclaim and freely transfer to the PA.

Essentially, I_{bt} and S_{tr} are the core variables on which the bargaining between the PA and the PE will take place. The other variables are useful to define the constraints of the initiative and to describe the morphological composition of the investment.

3.3 Constraints

The proposed model is structured into four different types of constraints described as follows and that can be schematized in the Table 1.

Table 1. Constraints of the model

Type of constraint	Constraint	Number
Physical	$S_{tot} = S_{prb} + S_{ga} + S_{cp} + S_{pui} + S_{pur}$	(1)
	$S_{pre} = S_{prb} + S_{ga} + S_{cp}$ $S_{pub} = S_{pui} + S_{pur}$	(2)
	$GFS_{tot} = I_{tb} \cdot S_{tot}$	(3)
	$GFS_{tot} = GFS_{res} + GFS_{off} + GFS_{com}$	(4)
	$GFS_{res} = \% \cdot GFS_{tot}$ $GFS_{off} = \% \cdot GFS_{tot}$ $GFS_{com} = \% \cdot GFS_{tot}$	(5)
	$S_{tr} \leq S_{pub}$	(6)
Project	$S_{prb} \leq R_c \cdot S_{tot}$	(7)
	$GFS_{tot} / S_{prb} \leq N_{f,max}$	(8)
	$S_{ga} \geq a \cdot S_{pre}$	(9)
	$S_{pur} = b \cdot S_{tot}$	(10)
Local urban	$S_{pui,res} = n_{inhab} \cdot 18 = (GFS_{res} / 25) \cdot 18$	(11)

planning	$S_{pui,off} = 0.8 \cdot GFS_{off}$ $S_{pui,com} = 0.8 \cdot GFS_{com}$	(12)
	$S_{pui} = S_{pui,res} + S_{pui,off} + S_{pui,com}$	(13)
	$S_{cp} = Vol_{tot} / 10 = (GFS_{tot} \cdot 3) / 10$	(14)
	Costs	
	$K_{lp} = k_{lp} \cdot (S_{pre} + S_{tr})$	(15)
	$K_{pt} = 0.15 \cdot K_{lp}$	(16)
	$K_{urb} = k_{urb} \cdot GFS_{tot}$	(17)
	$K_{rec} = k_{rec} \cdot (S_{pre} + S_{tr})$	(18)
	$K_{bc,res} = k_{cb,res} \cdot GFS_{res}$ $K_{bc,off} = k_{cb,off} \cdot GFS_{off}$ $K_{bc,com} = k_{cb,com} \cdot GFS_{com}$	(19)
	$K_{cp} = k_{cp} \cdot S_{cp}$ $K_{ga} = k_{ga} \cdot S_{ga}$	(20)
	$K_{ta} = 0.05 \cdot K_{bc}$	(21)
	$K_{man} = 0.04 \cdot K_{bc}$	(22)
	$K_{mar} = 0.02 \cdot R_{tot}$	(23)
	$K_{transf} = K_{bc} + K_{lp} + K_{pt} + K_{urb} + K_{ta} + K_{man} + K_{mar}$	(24)
	$K_{fc} = 0.06 \cdot K_{transf}$	(25)
	$K_{profit} = 0.20 \cdot R_{tot}$	(26)
	Revenues	
	$R_{res} = r_{res} \cdot GFS_{res}$ $R_{off} = r_{off} \cdot GFS_{off}$ $R_{com} = r_{com} \cdot GFS_{com}$ $R_{cp} = r_{cp} \cdot S_{cp}$	(27)
Financial for the PA	**Costs**	
	$K_{lp} + K_{rec} = (k_{lp} + k_{rec}) \cdot (S_{pub})$	(28)
	Revenues	
	$K_{urb} = k_{urb} \cdot GFS_{tot}$	(29)
	$K_{mis} = (k_{lp} + k_{rec}) \cdot S_{tr}$	(30)

The *physical constraints* (from n.1 to n.6 of Table 1) pertain to the articulation and subdivision of the total land plot into the share intended for the different land uses and works established. The *project constraints* (from n. 7 to n.10 of Table 1) refer to *i)* the general urban planning rules that must be applied according to the coverage ratio of the total property surface (R_c), *ii)* the maximum number of floors ($N_{f,max}$) achievable; *a* and *b* are two coefficients between 0 and 1, which determine the share respectively intended for green areas and public roads. For the *local urban planning constraints* (from n.11 to n.14 of Table 1) the infrastructure required for the number of inhabitants (n_{inhab}) is calculated for each intended use according to provisions of the Italian Ministerial Decree No. 1444/68; the extent of surface for the car parking spaces is set by total building volumes (Vol_{tot}), i.e. with reference to Italian Law No. 122/1989. Moreover, it is assumed that each floor of new buildings has an average height of 3 meters. The costs and revenues items that represent the PE and PA financial constraints are described in the following Table 2.

Table 2. Description of costs and revenues items considered for the PE and PA financial constraints.

Cost of land plot acquisition (K_{lp}) (Eq.15)	Determined by applying the unit market value (k_{lp}, €/m^2) to the extent of the building areas.
Property transfer expenses (K_{pt}) (Eq.16)	Calculated as 10% of the total purchase price of plot and including the registration and notary expenses.
Urbanization fees (K_{urb}) (Eq.17)	Quantified by applying the unit values (€/m^2) reported in the municipal tables according to the intended uses.

Reclamation cost (K_{rec}) (Eq.18)	Works to optimize soil surface are determined by multiplying the unit cost (k_{rec}, €/m^2) and the extent of surfaces.
Construction cost (K_{bc}) (Eq.19)	Parametric construction cost (k_{bc}, €/m^2) determined according to the different allowed intended uses.
Parking (K_{cp}) and green private spaces (K_{ga}) construction cost (Eq.20)	Parametric unit cost (k_{cp} and k_{ga}, €/m^2) based on similar works or the price list of relevant institutions.
Technical expenses (K_{ta}) (Eq.21)	The fees for technicians determined as a percentage of 5% of the sum of total construction costs.
General expenses (K_{man}) (Eq.22)	The management activities are calculated as a percentage of 4% of the sum of the total construction costs.
Commercialization fees (K_{mar}) (Eq.23)	Equal to 2% of the market value of the final buildings. They are intended for the marketing of them.
Financial fees (K_{fc}) (Eq.25)	Set equal to 6% of the total transformation cost (K_{transf}, Eq.24). They identify the interest on capital borrowed for the project.
Normal Profit (K_{profit}) (Eq.26)	The expected remuneration of the PE is set equal to 20% of the estimated revenues from the selling phase.
Transformation revenues (R) (Eq 27)	The revenues from the sale of the GFS of each intended use are obtained by multiplying the unit selling prices (€/m^2) and its extent of them.
Infrastructure contribution fees (Eq.28)	Unitary parametric values (€/m^2) fixed by the municipality.
Acquisition and reclamation of areas for the public works (Eq.29)	Estimated using unit price (k_{pl}) and unit reclamation cost (k_{rec}) found on the local market for the acquisition and reclamation of the areas intended for public works.
Opportunity costs of PA (K_{mis}, Eq.30)	They identify values of areas (S_{tr}) that PE is required to purchase, reclaim and freely transfer to PA by applying the unit selling price and reclamation cost of the local market.

3.4 Objective Function and Algorithm of the Model

In order to define the best range of solutions that can help PA and PE in identifying the combination of urban parameters on which the benefits of each of them depend, a complex objective function is proposed. It involves the maximization of the surface that the PE has to transfer to the PA for the public works (S_{tr}) and the extent of the green areas (S_{ga}) with the simultaneous minimization of land take surface (represented by the I_{bt}) of the urban project. The algorithm of the defined model is reported in Table 3.

Table 3. Algorithm of the model

Variables	I_{bt}, S_{prb}, S_{ga}, S_{tr}
Objective function	Max! ($w_{Str} \cdot S_{tr} + w_{Sga} \cdot S_{ga} - w_{Igt} \cdot I_{gt}$)
Type of constraints	Physical (see Table 1)
	Project (see Table 1)
	Urban Planning (see Table 1)
	Financial (see Table 1)

The importance of each variable of the objective function is taking into account by adding the weights (w_{Str}, w_{Sga}, w_{Igt}) that can vary from 0 to 2 in order to provide a range of different solutions that identify a set of feasible set of scenarios that can be chosen, according to the specific needs pursued by the PA.

4. Conclusions

The cities are considered as the place where the most significant dynamics occur, in terms of natural, social, and economic changes. However, the uncontrolled urban expansion is a phenomenon which has already affected a significant share of the existing ecosystem sphere. These contingences have raised up the necessity to adopt and implement adequate decision support tools, able to provide efficient management and feasible solutions, in order to achieve the sustainable development targets, set by the Agenda 2030 and the other existing directives.

Aim of the work has been to provide for a decision support model that public and private subjects involved in the decision-making process of urban regeneration and enhancement investments can use for identifying the most suitable compromise solution among financial, environmental, and social interests. In particular, the proposed model has the advantages *i)* to provide a series of easily understandable feasible scenarios, *ii)* to be flexible both in terms of constraints and objectives, *iii)* objectify and systematize the complex process of urban sustainability, *iv)* keep account of the different and conflicting intentions carried out by PA and PE.

Future insights of the present research could concern the application of the model to a real case study, also by integrating the “static” mathematical structure with the Cost-Revenues Analysis technique in order to take into account the effects of the time in the evaluation.

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