Decision-making methods applied to regenerative process of existing buildings

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Highlights

The retrofitting projects of existing buildings are based on current regulations and using the energy audit methodology. This methodology allows to analyse the building and to identify solutions for energy saving. These solutions can really be considered sustainable or will only consider the costs and energy savings? If do we want to consider more aspects (energy, economic, social, comfort, environmental ...) would we be able to identify the optimal solution?

Abstract

The path traced in construction sector leads to an increased attention to building heritage and its refurbishment into “nearly zero-energy buildings”. The regeneration process of an existing building is complex and requires the designer to use the distinctive features of the building and of the site where is built in order to achieve the objectives. One of the most important moments of this process is the choice of the interventions. The objective of this research is to identify a replicable decision-making method to support the designer in identifying the optimum solution through the Operations Research.

Keywords

Regeneration of existing buildings, Optimization, Decision-making methods

1. INTRODUCTION

The idea of refurbishing buildings, districts and cities as we know it nowadays, has become part of our lives since the beginning of the twenty-first century, when the sustainable development needs have almost overlapped to the global and European goals to achieve “nearly zero-energy buildings”. These needs have been translated into European Directives, Standard and national or local laws with strictly requirements to achieve a high level of energy efficiency. The attention was focused mainly to the existing buildings, especially residential ones as they represent the 75% of the building heritage. About the 45% of these buildings were built before the 60’s and another large part, about 38%, were built in the period between 1961 and 1990. These was the periods of the construction boom when our territories have been built very quickly at the expense of the quality, are also years in which the attention to the issue

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of energy efficiency in building codes were limited or non-existent (Figure 1) [1].

The requests submitted by the European Commission created a virtuous process leading industry expert to think about the existing refurbishment process and to integrate it with the sustainable development. Europe has already including in her goal this concept in particular to transform our territory by 2050 into Sustainable Europe.

From these two concepts comes the sustainable development. It might seem like a repetition but this concept embodies the ambitious idea of finding sustainable solutions for the planet, not only focusing on energy issue.

This research fits into this scenario with the aim of identifying a systematic and replicable methodology for the sustainable renovation of existing buildings, with particular attention to the choice of sustainable solutions using the decision-making theory.

2. STATE OF THE ART

The energy audit is the most used tool to analyse the existing buildings and to identify opportunities for energy savings [2]. This methodology has been developed over time with “in situ” experience since the 70s in the United States and then was introduced at European level by Directive 2006/32 / EC and implemented in Italy by D. Lgs n. 115/2008.

In this law, the energy audit is defined as a systematic procedure to obtain adequate knowledge of the energy consumption profile of a building or group of buildings, of an activity and/or industry or public or private service. This process allow to identify and quantify energy savings opportunities in terms

Figure 1. Age categorisation of housing stock in Europe.
cost-benefit and report on results [3]. As can be seen in the same definition of the energy audits, it does not consider the whole concept of sustainable development. The building analysis is only from the point of view of the energy profile, this method aims to identify solutions considering only the cost balance and benefits from the economical point of view. In energy audit, laws there are not specific instruments or indications to designers in order to support them choosing solutions and there are not identified the parameters that should be considered in making this decision. This whole series of “lacks” is understandable because the applicable solutions can be very numerous. No list would be exhaustive, considering the market for the products and technologies is different, depending on the geographical location, and it is also constantly evolving, thanks to search for new performing products.

Another limitation that comes out in giving specific advices is that each building is a unique product placed in a specific site, as it can have peculiarities not always replicable and generalizable to different boundary conditions. Therefore, the designer must use his sensitivity and preparation to identify the characteristics that can be exploited to identify retrofitting solutions.

The designer normally evaluates all the parameters and possible techniques/materials that can be used for the regenerative project and choices the solutions to be implemented with simple calculations, or based on their own experience, trying to optimize the performance and taking into account the demands and the goals set by the client. Anyway if we extend the concept of energy regeneration to the sustainable regeneration, also we increase the parameters that must be considered, therefore, be more difficult to identify the optimal technical solution without the aid of a method that can filter and highlight the hypothesis that satisfies the most of its objectives. In this context, it may be used Operations Research, commonly referred to with the acronym OR, also known as Decision Theory or Science of Management, which is specifically intended to provide valuable support to the decision maker in the decision process.

The origins of Operations Research can be found in the sixteenth century, when the pioneers of this discipline began to use a scientific approach to the management of organizations [4]. The real birth of this science, however, is set in the years before the Second World War and in the military sector: the OR was used to decide how to allocate limited resources to the various military operations. The General British Staff’s first and then the US ones, required the commitment of scientists, that using a scientific approach, found the solution to this problem in the context of military operations, from here born the name (military) operations research [5]. The activity of these groups
was called Operational Research in the UK and later *Operations Research* in the United States. These studies on the optimal management of anti-submarine operations and the transfer of the convoys were winning secret weapon in the battle of the North Atlantic, as defined by the physical Ellis Johnson, the US military office director of Operations Research (Figure 2).

This approach was very successful and was employed in the following years in other sectors to address the problems generated by the post-war industrial boom and the increase complexity and specialities. The first applications took place in the oil industry because only big companies could afford this type of study. In the 60s, it was used in the services and public administration sector.

The first associations of Operations Research were founded in these years and they are still in existence: in Great Britain in 1948 born the “OR Society” (www.theorsociety.com), in 1952 in USA born “ORS – Operations Research Society of America” now called “INFORMS – Institute For Operations Research and Management Science” (www.informs.org) and in 1961 born the Italian “AIRO – Associazione Italiana Ricerca Operativa” (www.airo.org).

There is no single codified and globally accepted definition of Operations Research since each association wrote its definition. So in this paper it is shown only the English one because it highlights the fundamental aspect of this discipline is to help the decision-maker in the complex problems of the real world, even if this research can become abstract and divorced from reality.

“Operational Research is the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials, and money in industry, business, government, and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies, or controls. The purpose is to help management determine its policy and actions scientifically”” [6] [7].

Operations Research has got a rapid spread and growth for two main factors: the first is the encouragement that was given to scientists who participated in the research groups during the war and that determined the progress of the OR techniques; the second is the computer revolution, which could provide the resources to perform calculations of this magnitude. This second factor was decisive because it allowed since 1980, with the increase of the potential of personal computers, to make accessible the OR to a growing number of people.

Nowadays the operations research can have multiple software, including also some free, and is used and appreciated in many sectors. Some examples are
reported to present the different of applications, but a more comprehensive list of real cases can be found on the INFORMS website [8]:

- **finance:** choice of investments, determining the price of financial derivatives...
- **industry:** production-planning, distribution of the workforce, inventory management, location and size of the plants, shifts rotation...
- **telecommunications:** network design, determination of network capacities...
- **public Administration:** water resources planning, performance evaluation of schools or hospitals...
- **transport:** optimization of the rail network, vehicles journey...
- **construction:** optimal shape, structural design, construction site management...

The operational research is not born for the construction industry but having regard to its potential has also been introduced in this area, as already anticipated. For example, for the following purposes: to determine the optimal shape as a function of one or more parameters such as free solar gain; designing the optimal structure depending on the wind or the stress caused by an earthquake; manage the construction site or the whole project by optimizing the sequence of the various activities to minimize time; ... .

Could be list other applications, but what is important is that this discipline can also be used for sustainable regeneration of the building heritage in order to optimize the designer’s choices, taking into account not only the energy and economic parameters, but also of all those required for the process it can be truly defined sustainable.
3. METHODOLOGY

The presented research aims to identify a systematic and replicable methodology for the sustainable renovation of existing buildings, with particular attention at the choice of sustainable solutions using the decision theory.

The proposed methodology for the sustainable retrofitting process is the result not only of a theoretical study, but also has been verified through the application of real cases with which it was possible to evaluate that it might become a valid and replicable “guide”, whatever the size and the type of the building. Among the various projects that have been used for testing the methodology, we want to quote the project funded by the European Commission under the Seventh Framework Programme called “R2CITIES “R2CITIES – Residential Renovation towards nearly zero energy CITIES”.

The proposed methodology takes into account several aspects: constructive/innovative, managerial, economic, environmental, integration between all stakeholders, user involvement, methods to support decisions... All these issues of the complex procedure for retrofitting are declined in four key aspects: management of the entire design process, from the audit to verifications of results; technical aspect in order to develop the process, from data collection to final test; verification of sustainable indicators and digitalization of the entire process through the use of Building Information Modelling (BIM) [9] [10]. These four aspects cross the entire project from diagnosis phase to the execution and the evaluation of the results obtained (Figure 3).

The research was then focused on a specific “moment” of the entire process because it is considered one of the crucial steps for the success of the project: the choice of one or more sustainable solutions.

In this research of the best technical solution must fulfill several tasks:

- Identify the project objectives based on customer requests and the results obtained from the analysis of the building. Possible targets may be summarized in the three pillars of sustainable development: environmental, social and economic. Some examples are reducing energy consumption, elimination of situations of discomfort...
- Evaluate the characteristics of the building and boundary conditions that can be used to achieve targets. The aspects to be assessed are many and we can enclose them in three categories: environmental (such as climate, the morphology of the site, the local characteristics), typological (the shape and orientation) and detail (materials, construction and technical elements constructive) [11].
- Identify a set of solutions that optimize aspects previously identified allow
to reach the goals set. In this case, we speak of a set of solutions and not of a single, because thanks to the variety of products that are available on the market is possible to achieve the same goals with similar solutions. Finally identify the solution that most closely to the ideal solution, and made a ranking of all the alternatives identified.
As can be seen from this explanation it is a complex process, but if you consider
a few variables, a designer, in his daily work, is accustomed and able to
solve it. However, if we expand the problem and increase the variables, it
is necessary the help of a scientific approach as the Operations Research
allowing the identification of the best solution [12].

Taking a practical example, if we set targets to reduce energy consumption
and minimize costs is possible to find more solutions that meet these two
goals: for example, the insulation of the roof, substitution of the regulatory
system, the replacement of windows... Of each hypothesis will be found
similar solutions to the varying some parameters, for example in the insulation
case is possible to choose different insulating material as a function of the
performance and the costs. Then is necessary to find which of these solutions
is closest to the ideal solution, which in this case is to reduce to zero the
energy consumption without spending anything. It is clear that there are two
problems: the first is to identify a whole range of solutions that modify the
initial condition towards the targets, while the other is to find which among all
these solutions allows getting closer to the goals. The different between these
two issues is not so clear and it can be a reiterative process to find the best
solution. In the Operations Research these two different problem are defined
as Multi Objective Decision Making (MODM) and Multi Attribute Decision
Making (MADM) [13] [14].

Before you can go into the details of the two methodologies, it is necessary to
examine some of the terminology typically used in this discipline and define
the precise meaning.

The alternative, already widely mentioned with the term of solutions, are the
decisions which the decision maker has available.

The attribute indicates a characteristic or quality of the alternatives, for
example in the case of an insulating material may be price, conductivity,
density...

When it is pointed out the direction that an attribute makes more attractive an
alternative, it becomes criterion.

The criterion is divided into objective, that indicates the purpose that you
want to achieve as much as possible, and goal, or even defined target, you
want to achieve.

Finally, the constraints are the conditions that must be respect.

The difficult to distinguish between attribute and criterion is just the same
that is found in distinguishing the multi-objective problems by multi-attribute
ones.

When there are one or more objectives is necessary, the multi-objective

che devono essere valutati sono
multipli e possiamo raccordarli
in tre categorie: ambientali (come il clima, la morfologia del sito, le
caratteristiche locali), tipologici (la forma e l’orientamento) e di
dettaglio (materiali, elementi
costruttivi e tecniche costruttive)

• Individuare un insieme di soluzioni
che ottimizzano gli aspetti
precedentemente individuati,
permettono di raggiungere gli
obiettivi fissati. In questo caso
parliamo di un insieme di soluzioni,
e non di una singola, poiché
grazie alla varietà dei prodotti
che sono disponibili sul mercato
e alla molteplicità degli aspetti
che possono essere considerati è
possibile ottenere soluzioni simili
per gli stessi obiettivi.

• Identificare infine la soluzione che
maggiormente si avvicina a quella
ideale, realizzando una classifica
tutte le alternative individuate.

Come si evince da questa spiegazione
è un procedimento complesso, ma se si
considerano pochi variabili e tecnico,
nella sua quotidianità lavorativa, è
abituato e capace a risolverlo. Volendo
invece ampliare il problema e aumentare le
variabili, occorre un approccio scientifico come la Ricerca
Operativa che permetta di individuarne
la soluzione [12].

Facendo un esempio pratico, se
poniamo gli obiettivi di ridurre il
consumo energetico e di minimizzare i
costi si potranno trovare più soluzioni
che soddisfino le due richieste: ad
esempio l’isolamento della copertura,
la modifica del sistema di regolazione,
la sostituzione dei serramenti,... Di
ciascuna ipotesi si potranno trovare
soluzioni simili al variare di alcuni
parametri, ad esempio nel caso
dell’isolamento potrà variare la scelta
del materiale isolante in funzione
delle prestazioni e dei relativi costi.
Successivamente occorre trovare
qual è quella soluzione che
maggiormente si avvicina alla soluzione
ideale, che in questo caso è ridurre a zero il
consumo di energia senza spendere nulla.

E’ chiaro che esistono due problemi: il
primo è quello di individuare tutta quella
gamma di soluzioni che modificano la
condizione iniziale verso gli obiettivi
posti, mentre l’altro è quello trovare quale tra tutte queste soluzioni
permette di avvicinarsi di più agli obiettivi.
La distinzione tra i due problemi non è così
netta poiché può essere un processo
reiterativo nel quale si cerca di trovare
la soluzione sempre più prossima a
quella ideale.

Nell’ambito della ricerca operativa
questi due differenti problemi sono
definiti come problemi multi obiettivo
o Multi Objective Decision Making
(MODM) e problemi multi attributo o
Multi Attribute Decision Making
(MADM) [13] [14].

Prima di poter scendere nei dettagli
delle due metodologie occorre
soffermarsi su alcune terminologie
tipicamente usate in questa disciplina
ed definire il significato preciso.

Le alternative, già ampiamente
menzione con il termine di soluzioni,
sono le decisioni che il decisore ha a
disposizione.

L’attributo indica una caratteristica o
qualità delle alternative, ad esempio nel
caso di un materiale isolante potrebbero
essere il prezzo, la conducibilità, la
densità,...

Quando si precisa la direzione che
un attributo rende un’alternativa più
attraente, esso si trasforma in criterio.
decision-making methods to obtain several alternatives that allow achieving the goal, but without knowing if exist and what it is the ideal solution.

In Figure 4, the dots represent the solutions of the problem, set two criteria that define the plane on which lie the alternatives. If we need to solve a problem with three criteria, we would not find solutions on the plane C1, C2, but in a space defined by C1, C2, C3.

The multi-attribute decision-making methods are used to identify the optimal decision between a finite numbers of alternatives. A problem of this type can be represented in a matrix form [m, n] in which the An columns represent the attributes and dm lines represent alternatives (Figure 5).

There are several methods to find the optimal solution to multi-attribute problems, scaling criteria and identifying the exact location of the ideal solution and to evaluate the distance from it of each alternative.

In this paper we present the example of the resolution with the Technique for Ordiner of Preference by Similarity to Ideal Solution (TOPSIS) (Figure 4).
This method sorts the alternatives considering the distance from the ideal solution, which is artificial and utopian, and at the same time trying to maintain much distance as possible to the other artificial solution, the anti-ideal. The ideal solution is created by taking the highest value for each criterion while the anti-ideal is constructed by taking smaller values. Then the distances of each alternative are evaluate realizing a ranking of the decisions from the closer to the ideal solution up to farther. The best solution in the example shown in Figure 6 is the C and the worse is the E. The objective of this research as already mentioned is to identify a method that allows in case of sustainable regeneration project to use the MODM and MADM methods to define with greater objectivity the best solution. Thus, sets one or more goals you want to find a vector of solutions with the variation of predetermined aspects; then we are going to find a method to sort this vector, through the evaluation of each solution with a series of attributes that can be summarized in six aspects. Examples of attributes for each aspect:

- Energy: final energy consumption, energy saving, degree of compliance with national standards, ...
- Cost: cost of the intervention, incentives, cost of maintenance, ...
- Comfort: visual comfort, indoor air quality, well-being index PMV, ...
- Environmental: CO2 emissions, life cycle analysis, ...
- Social: degree of user satisfaction, degree of liveability, ...
- Urbanistic: change of public spaces, impact on urban transport, ...

Each attribute has to be brought back to a numeric format so if you have a qualitative indication is need to be transformed by assigning a score to a predetermined scale. In addition to each attribute, it can be given greater or lesser importance, depending on the goals of the project, by a weight vector, which is the exact transposition of the targets set.

Figure 6. Graphic resolution of a problem with multi-attribute method (TOPSIS).
4. CONCLUSIONS

The research about sustainable retrofitting process has made it possible to verify the presented methodology and make it a valuable tool to be used in different cases, from single buildings to entire districts.

The specific research on the decision-making phase of optimal solutions is still in development. For now it allow to identify the presented stages of decision making in the case of a refurbishment project and the attributes that can be used to evaluate a set of solutions. Also highlighted the validity of the application of Operations Research to problems of this type and the short diffusion due mainly to the necessity of a mathematical, statistical and specific software knowledge. A second actual limit, that also could be an ambitious idea for the future of this work, is the identification of a system that can correlate, not only all the software necessary to complete this process, but also the same with new generation tools such as the Building Information Modelling (BIM).

5. REFERENCES

[1] Europe’s buildings under the microscope, Buildings Performance Institute Europe (BPIE); 2011.