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Identification of technological and installation-related parameters for a multi-criteria approach to building retrofit

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Abstract

Building retrofit is a main concern to reach EU de-carbonisation goals of 2050. Façade retrofit plays a pivotal role in the reduction of energy consumption in buildings: several strategies are in fact available, both in terms of on-site systems and prefabricated elements. The research question arising regards therefore how to choose the best-suiting residential retrofit strategy between different technological systems.
In this sense, a current lack of diffusion of Decision Support Systems between can be underlined, as decisions mainly derive from previous experiences.
An optimizing strategy that could express the goals of the many actors involved in the building process is required. In order to consider the impact of different criteria on the choice, multi-criteria methodologies could be effective. Existing similar methods mostly focus uniquely on energy performance, or follow the categories of environment, economy and society. What is currently lacking in available tools regards production-linked and technological aspects, related to e.g. façade morphology, and building site features.
The aim of this paper is to identify relevant parameters related to installation and economy aspects, for a multi-criteria approach to be used in the choice of the most suitable building retrofit strategy. The methodological approach is therefore provided, and the choice of parameters, carried out by means of interview with actors of the building process, is explained. The criteria selection and the subsequent criteria weighting phase is to be carried out by means of interviews and surveys to the actors involved in the building process. The application on case-studies will offer the opportunity to assess the effectiveness of the method.

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Keywords: Building retrofit; decision-support systems; multi-criteria approach; residential buildings

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1. Introduction

Building retrofit is a current issue, as existing buildings are responsible for the 40% of total energy consumption, and the 36% of Europe's greenhouse gas emissions [1] [2].

European building stock, currently composed of different building typologies and morphologies, is outdated and inefficient, considering both private [3] and public sector [4]. Besides energy inefficiency, those buildings are often in need of renovation in terms of fire safety, indoor comfort, and exterior aesthetics [5].

European Union Directives stress the relevance of building retrofit as a strategy to overcome those issues, but also underline the urge of action as an occasion to stimulate local economy, by creating new jobs and revitalizing the market [6]. Existing building stock therefore represents a key aspect for EU energy efficiency targets.

The construction of new buildings can be carried out with high performances in terms of energy efficiency, and several case studies are available to help the design of sustainable buildings. At the same time, researches and support systems have been developed to support the improvement of energy performance of existing buildings.

1.1. European Union targets for building retrofit

The relevance of building retrofit for the European Union is underlined in first instance by the EU Directives regarding the theme. The EPBD (Energy Performance of Buildings Directive) 2002/91/EC, recast in 2010 [7], requires the Member States of European Union to set minimum energy performance requirements for new buildings, but also for the major renovation of building and for the replacement of retrofit of building elements, together with the establishment of national financial measures supporting the process [1], [8].

The EED (Energy Efficiency Directive) 2012/27/EU requires the Member States to undertake energy efficient renovations to at least 3% of public buildings, and to draw up National Energy Efficiency Actions Plans. These Plans include the national building renovation strategies, that include an overview of the national building stock, the main policies to support renovations and the expected energy savings resulting from renovations.

Renewable Energy Directive 2009/28/EU sets as a target the use of 20% of energy by renewable sources by 2020 for each Member State. A brief overview of EU targets in energy savings for 2020, 2030 and 2050 is provided in Table 1.

Table 1. European Union targets for 2020, 2030 and 2050.

	2020	2030	2050
GHG Emission reduction target*	20%	40%	80% (domestic reductions)
Renewable Energy Sources target	20%	27%	55%-64%-97% (depending on scenario)
Energy efficiency target**	20%	27%	Still not defined

The prior role of building retrofit in European Union agenda is testified also Many European research projects have been carried out regarding building retrofit with the engagement of several Countries. Those projects regarded different level of building process, from building components up to district renovation [9].

1.2. European building stock: an overview

As stated before, European building stock accounts for over 40% of final energy consumption in European Member States, and building retrofit clearly represents a main strategy to decrease this consumption. The most part of European building stock is represented by residential buildings. The technical potential of the EPBD application; calculated assuming that all existing buildings are retrofitted immediately, in terms of CO2 emissions reduction, is decisively greater for residential buildings, rather than non-residential [10].

In European Member States (considering EU-27), and Switzerland and Norway, the estimated amount of floor gross space occupied by dwellings amounts to 18.75 billion m^2, [11] mainly located in Germany, Italy and UK [12].

Residential building stock across European Member States presents some similarities, but a comparative analysis of different countries is difficult, due to the availability of heterogeneous data from the countries. Even considering similar climatic conditions, European Member States present different policies for building retrofit, and different building morphologies [13].

An attempt to properly classify residential building typologies, aiming at a facilitation of building renovations, has been carried out during EPISCOPE [14], and TABULA [15] projects.

TABULA research project divided existing buildings in different classes, depending on the age of the building and other parameters, and identified a representative building for each class. This was chosen as a case-study building, on which different retrofit strategies were applied (one standard and one advanced retrofit intervention), considering in their intervention both the envelope and the building services.

Several differences can be underlined in national residential building stocks; for instance, it is possible to notice as in Eastern European Countries the most frequent typology for housing is represented by panel buildings [13], whether in other Countries (that are the Netherlands, the United Kingdom and Ireland), the proportion of people living in flats is the highest [16].

Italian building stock is mainly composed of residential dwellings (86%), mainly consisting in multi-family buildings, that also represent the principal typology for new constructions [17].

86% of Italian residential buildings dates back before 1991: only the 25.8% of those has been reported by the inhabitants as in “Excellent” conditions [18].

Other sources indicate that 1.6% of buildings is in poor conditions and 28% in mediocre conditions [19].

64% of residential buildings has undergone interventions related to energy efficiency improvement; these interventions regarded mainly boiler installation or replacement (in 70% of the cases), and air-conditioner installation or replacement (in 33% of the cases). Few interventions regarded external envelope (less than 4%) [2].

1.3. Building retrofit scenarios: main barriers, experience

Besides the remarkable advantages and improvements that a building retrofit operation provides, some barriers are currently slowing down the diffusion of retrofit and renovation practices [20]. Those barriers can be related to several factors, as summarized in Table 2.

Table 2. Building retrofit barriers.

Barrier cluster	Barrier type	References	Country
Economic barriers	Lack of funding mechanisms	[21] [22]	Europe, UK
	Long or unsure payback period	[23] [24] [25]	Europe, Germany
	Confused granting mechanism	[26]	Italy
Political barriers	Lack of national or local policies	[26] [27]	Italy
	Lack of demonstration projects	[28]	Europe
Social barriers	Lack of consciousness regarding advantages of building retrofit	[29]	Germany
	Disturbance of inhabitants	[30] [31] [32]	Europe
	Lack of motivation of building owners	[33] [34]	Germany, Norway
	Property issues (multi-tenants' buildings)	[29] [35]	Germany, Sweden
Technical barriers	Lack of technologies	[21]	Europe
	Lack of professionals	[21]	Europe
	Logistic issues	[24]	Germany
	Difficulty to meet building regulations	[32] [36]	Europe, UK

Economic barriers mainly regard the lack of funding mechanisms or imprecise granting systems; political barriers are related to the lack of national, or regional policies on building retrofit. From a social point of view, a general lack of consciousness regarding the advantages of building retrofit can be underlined in several European Member States, together with property issues: a huge part of residential stock is composed of multi-tenant's buildings.

The management of inhabitants represents another relevant issue in social terms, and especially in case of residential building retrofit. Residential buildings are mainly inhabited, therefore during the retrofit operations it is necessary to look for a temporary accommodation.

Technical barriers include lack of technologies that are effective for building retrofit, and lack of professionals able to carry out a successful retrofit operation.

Besides political, economic, social and technical barriers, a striking issue regarding building retrofit concerns the lack of Decision Support Systems that could help in identifying the most suitable solution from the early stages of design.

These barriers could be interpreted as a reflection of the multiplicity of goals and actors involved in building retrofit, ranging from designers and consultants, to contractors and installers.

2. Problem statement and methodology

Building retrofit is a complex and thus multi-dimensional problem, as it involves multiple actors, with different and sometimes contrasting goals [37]

Considering the case of retrofit of a façade of a residential buildings, there are many factors to be taken into account, in terms of energy performance, users' comfort, and architectural aspects. For this reason, choosing the most suitable retrofit strategy is clearly an issue, related for instance to the building itself and its morphology, to the building site, to the requirements to be fulfilled, and to the clients' expectations [38] [39]. The lack of diffusion in common practice of Decision Support Systems for building retrofit suggests that there is still a gap to be filled in this context, in terms of flexibility and availability [40].

Consequently, those factors could be helpful in setting a methodology helping to choose the most suitable façade retrofit strategy to be used for dwellings.

Multi-criteria is an effective methodology for non-linear problems [41], as it allows to keep into account many different parameters, and to weight them, reflecting in an effective way the mutual importance of the criteria

Using a multi-criteria methodology from early stages of design could help in enhancing the effectiveness and reducing late variations. Current design procedures and existing tools in this context show limitations, connected to the great variety of parameters to be taken into account: for this reason, it may be not possible to obtain complete optimality of all aspects, but compromise solutions can be found [42].

Several experiences have been carried out choosing the bases of sustainability identified in ISO 15392 as criteria: social, economic, and environmental aspects [43].

Other tools have a cost-optimality approach, or cost-effectiveness, considering some parameters that characterize "optimality" [44]

Some other tools use Life Cycle Cost as a base for choosing the most suitable retrofit strategy [39].

All these examples, although valuable and effective, do not consider the installation-related issues [43], that have proven to be particularly relevant in case of building retrofit on façades. Since existing building stock morphology is wide and diverse, it is notably important to take into account the installation process, and the issues related.

2.1. Problem statement

The main focus of this paper is proposing a practical methodology for a multi-criteria based tool that can support the choice of the most suitable solution for external building retrofit, mainly focusing on residential buildings.

The aim of this paper is identifying technological parameters, and considering installation-linked issues, that play a relevant role in cost-evaluation and feasibility of any retrofit solution.

The proposed approach is a methodological one, therefore could be reapplied to different building typologies: further parameters could be added and integrated, and a certain flexibility could be provided.

Considering the complexity of any building process, the methodology should be applicable in early stage of design, proven to strongly influence final results [45].

2.2. Multi-criteria methodology

The proposed methodology follows a multi-criteria method, that unfolds through several steps, synthetized in Figure 1:

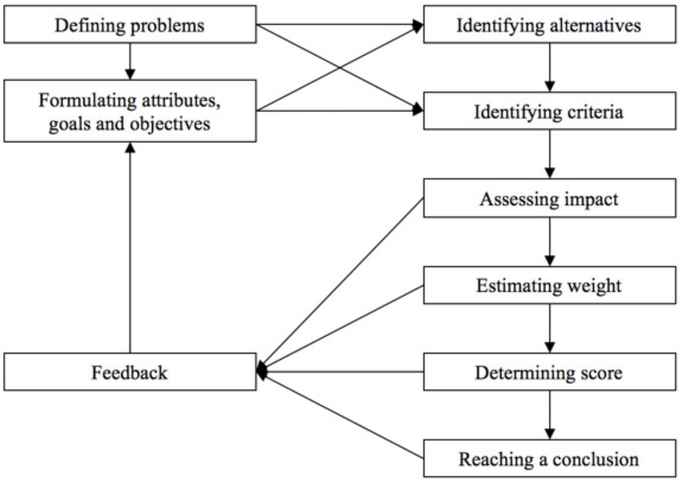

Fig. 1. Multi-criteria methodology scheme.

- problem definition and goal formulation
- identification of the criteria and parameters
- weights estimation
- score determination
- classification of solutions
- feedback

The problem can be defined as finding the most suitable retrofit solution, in technological terms, considering installation issues. Those issues are used as criteria, together with economic aspects, in order to evaluate different retrofit systems.

The approach is therefore developed in a first phase regarding the choice of the criteria and parameters, that are then validated together with actors involved in the process. Once the parameters are set, in terms of unity of measure and calculation procedure, a weighting phase is necessary to properly measure their mutual relevance [40].

Many different approaches are available to carry out the weighting phase; some are based on equal weights, and other are rank-order based. The most used approach in AEC issues is the Analytic Hierarchy Process (AHP), that allows to verify the mutual relevance of parameters by means of pairwise comparisons. AHP is a subjective approach, as the comparison phase is carried out by the decision maker himself, or engaging other actors of the process [40].

These operations should be carried out and applied to one or more case study buildings, in order to correctly develop the criteria, identifying lacking aspects or critical phases. The case studies additionaly induce an accurate validation of the methodology [41]

The score determination allows to create a classification of solutions, that helps in choosing the most suitable one, based on the building considered.

The focus has been kept on installation-related factors: environmental aspects, such as energy requirements have been considered as external boundaries: the aim of the work is not the optimization of energy performances, and those requirements precedes the choice of a retrofit strategy.

3. Parameters setting

The first phase of the chosen approach regards the choice of parameters. The parameters have been set with reference to a residential building, but the approach could be adapted also to other building typologies.

Table 3. Installation-related criteria

Parameter	Description	Comments
Transparency	Opaque/transparent ratio	Evaluate the glass portions over the opaque portions of the façade, considering windows, doors, etc. The number of openings is crucial to define the number, size and variability of cladding panels.
Geometry	Geometrical complexity	Evaluate the presence of non-flat parts on the façade to check the geometrical compatibility with different retrofit systems. Relevant especially if considering prefabricated panels that have fixed dimensions.
	Loggias or balconies presence	Relevant during installation phase, to verify scaffolding positioning, and to evaluate closing and consequent increase of floor area, and increase of market values.
Cladding and irregularities	Irregular areas ratio	Useful to evaluate the potential necessity of removal of cladding, that could cause an increase in costs and in time of installation of the retrofit system.
	Protruding thickness of the cladding	Evaluate the compatibility with different technological solutions (rigid or soft insulation), and with the presence of a sub-structure.
Structural properties and conservation	Structural typology	Relevant to verify the structural compatibility of retrofit systems, based on their weight and anchoring systems (e.g., presence of a substructure).
	State of conservation	Relevant to consider additional interventions on the façade or to identify technological defects of the façade.
Scaffolding	Available area to set scaffolding	Evaluate the possibility to properly set scaffolding on the façade, or the necessity to use other installation support systems (e.g. cranes, mobile scaffoldings)
	Available area for storage	Relevant to verify the building site management of components, especially in case of prefabricated elements that could require a large stocking area.
Accessibility	Distance from production site	Relevant to calculate transportation cost and delivery time, especially in case of prefabricated solutions or custom-tailored systems.
	Accessibility of building site	Useful to verify reachability of the building site and accessibility for trucks or lorries.
Installation	Users management	Relevant to evaluate users' discomfort due to building works, and potential re-collocation of inhabitants during the installation.
	Workers safety	Relevant to verify the safety level of the building site, related to the installation system. On-site accidents, even when not serious represent an increase in costs and times.

In order to properly identify relevant parameters that can influence the choice of the retrofit technology, a previous analysis of the residential typology has been carried out, and the main morphological elements have been identified and used as a base for the criteria formulation.

The parameters have been set based on a literature review, considering the building morphology, and by means of interviews and discussions together with the actors involved in a building retrofit operation. These interviews have been necessary not only to properly set the parameters, but also as a validation from different points of view during the building process.

The interviews were carried out singularly with building contractors, designers, and consultants, that have an expertise both in new construction and in building retrofit, and both in residential and in commercial buildings, in order to consider different boundary conditions.

3.1. Installation related parameters

Designing a building retrofit means having to cope with extremely different façade morphologies. Even if it is possible to take into account only one typology and limit the consideration to a restricted period of construction, the variability of façade elements is still very high. Decorative elements, frames, different claddings (both regular, i.e. plaster, and irregular, i.e. bricks, concrete, stone, wood), represent an important issue to consider when designing elements to be set on an existing façade.

The main problem linked to the existing façade is the unavoidable presence of irregularities, that can be partially absorbed by means of a substructure and soft insulation, especially in case of large modules

Balconies and loggias are usually thermal weak points, lacking of thermal break, and could represent an issue also during the installation phase.

Structural resistance and state of conservation have to be taken into account, in order to properly evaluate whether a retrofit intervention is viable.

Some of the provided parameters could act as boundaries to proposed solutions; for instance, considering structural resistance, it could be possible that no compatibility between the existing façade and the proposed retrofit system is reached, due to high weight of the system or weak bearing capacity of the wall.

3.2. Economic parameters

Considering economic parameters, it is possible to divide the criteria in four main categories, regarding initial investment, construction cost, use cost and dismission cost, as shown in Table 4.

4. Conclusion and further development

Residential buildings, that currently represent the most part of Italian and European building stock, are mainly out-of-date and in urge of retrofit.

Retrofit operations of building envelope are complex, due to the multiplicity of objectives involved: in several cases, the choice of technological system is based on previous experience, or general assumptions, without a strong scientific bases [46] For this reason, Decision-Support tools and approaches could represent a useful support in the choice of the most suitable retrofit system.

A multi criteria approach could represent a useful methodology to properly face this complexity, and could act as a base for the development of a practical tool.

Currently, a gap has been identified in terms of response to technological-based issues: those factors, besides being relevant or even essential, are mainly forgotten in many phases of a design process, and in most of the existing tools. Similarly, building morphology is seldom taken into account.

An early inclusion of those issues in a decisional process could help in guaranteeing an aware and well-founded choice, and a potential anticipation of possible technological problems.

The first step towards the development of this tool has been presented in this paper, as the choice of technological and economic parameters that play an essential role, based on structured interviews with actors of the process.

Table 4. Economic parameters

Parameter	Description	Comments
Initial investment	Design cost	Useful especially in case of prefabricated solutions, that could require an higher initial cost.
	Production cost	
Construction cost	Manpower cost	Depends on the installation system to be used, and on the retrofit system. Some solutions require specialized workers, increasing cost.
	Scaffolding and machines hiring cost	Depends on the retrofit system chosen.
	Transport cost	Depends on the features of the system, in terms of dimension, and on the building site distance from production or assembly site.
	Public soil occupation	Depending on where the building site is located, scaffolding occupation of public soil could require the payment of a fee.
Use cost	Maintenance cost	Some retrofit systems could require higher maintenance costs than others.
	Consumption reduction	Building retrofit provides a reduction of energy consumption during the life of the building.
Dismission cost	Cost of dismission	-

The next step, that has already been set, involves the application of the parameters to a case study, to verify their effectiveness and test the calculation method. A first case study has been identified in a residential building in Cinisello Balsamo (MI), that was used as demo building in Italy as part of the EASEE project, that interested several European partners from different Member States.

Other case study buildings will be chosen in order to verify the sensitivity of the methodology.

The tool aims at becoming a practical support in technological decisions, and has mainly been dedicated to residential buildings. Nonetheless, it could be possible to widen its applicability to other building typologies, by means of a review of the parameters.

Considering for instance prefabricated solutions, manufacturability related criteria represents an additional issue that should be included in the methodology.

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