DECISION-MAKING PROCESS TO SELECT ENERGY-EFFICIENT RENOVATION ALTERNATIVES FOR RESIDENTIAL BUILDINGS: TWO CASE STUDIES

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In the EU, buildings consume 40% of the final energy and are responsible for one-third of the CO_2 emissions. Since new buildings account just for 1% of the stock, the largest opportunity to implement energy efficiency comes from the renovation of existing buildings. However, renovation projects address particularities that make the selection of suitable options a complex process. Developing tools to support this process requires to get a better understanding of who participates, what criteria stakeholders consider, how they assess alternatives, and what methods they implement. Therefore, this paper studies how the decision-making process was performed in two residential case studies: An apartment building in Spain, and a set of dwellings in The Netherlands. The main goal is to identify stakeholders, objectives, criteria, alternatives assessment methods, and the sequence of the decision-making process. Findings are contrasted with concepts presented in the related literature. Results show that not only energy-related activities are considered in the decision-making process, but also additional renovation tasks that are performed simultaneously. Social criteria play an important role in the process. Moreover, renovation deals with stakeholders' interactions related not only to the landlord/tenant dilemma, which may impact the process and final solution.

Keywords: building renovation, decision-making, energy efficiency, sustainability

INTRODUCTION

Buildings account for 40% of the EU's energy consumption, 36% of its CO_2 emissions and 55% of its electricity consumption. The rate at which new buildings either replace the old stock or expand the total stock, is about 1% a year (Artola *et al.,* 2016). This implies that the renovation of existing buildings is key for achieving sustainability at the urban level. According to Artola *et al. (*2016), renovation rates should increase from 1% to almost 3% to accomplish the energy-saving targets of the 2030 Agenda. In this context, building owners, investors and other stakeholders need proper support and tools to choose suitable renovation options. A renovation alternative may include a single measure such as façade insulation, or packages of measures such as window replacement, façade and roof insulation, and mechanical ventilation units. While stakeholders, alternatives design, and other aspects in new construction are well established, renovation encounters specific conditions that may impact the way the final solution is selected. Ferreira *et al. (*2013) show that most of the decision-making tools have been developed for new buildings and renovation, just a few of them focus only on renovation projects. While decisions in new buildings

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involve only a few stakeholders such as designers, architects and investors, one of the particular elements in renovation projects is the involvement of tenants and building managers (Jensen and Maslesa, 2015). These additional stakeholders may define different criteria to choose the final renovation solution. Moreover, existing conditions of the building may call for objectives and renovation options that cover not only building energy performance and comfort issues but structural, accessibility and other aspects.

A closer study of the decision-making process in real renovation cases may contribute to understanding who participates, what procedures the stakeholders follow, what criteria they consider, how they assess alternatives, and which decision-making methods they implement to choose the solution. Therefore, the main goal of this paper is to study how the decision-making process is conducted in real residential renovation projects. To this end, two real cases are studied to map common practices, identify stakeholders, objectives and criteria, and methods to assess the renovation options. A sequence chart of the decision-making process is developed for one of the cases. These elements are contrasted with the related literature to identify gaps that may be covered by decision-making tools addressing renovation projects. This analysis may support the development of decision-making tools aligned with common practices of stakeholders, the information they have access to, and strategies that allow considering their preferences. The paper is structured as follows: First, the background and motivation are presented. Second, the methodology to capture and analyse the data is summarised. Third, the two case studies and results are introduced. Finally, the discussion and conclusions are synthesized. In this paper, *renovation* will be used as a general term comprising improvements in the form of refurbishing or retrofitting.

Background and Research Motivation

The steps often considered in decision-making processes can be described as defining the problem and objectives, identifying criteria and alternatives, criteria weighting, aggregation of weights and alternatives performance, and final decision (Majumder, 2015). All this process is carried out by the stakeholders involved in the decision-making process. In renovation projects, there are multiple stakeholders with different interests, but except for the landlord/tenant dilemma, these interests are not contradictory (Jensen and Maslesa, 2015). However, decision-making tools should enable the active participation of the different stakeholders since their preferences are relevant along the process. In countries such as Denmark, the law demands that tenants vote to approve the renovation project, while in Spain the regulation asks the owners to vote on the project. Nevertheless, most of the decision-making tools presented in the related literature are based on literature reviews, researchers' suggestions or certification schemes and do not include directly practitioners, users, investors and other stakeholders in their development.

According to a review conducted by Nielsen *et al. (*2016), most of the tools developed for decision-making in renovation focus only on specific aspects such as performing simulations or criteria weighting, but elements such as goal setting and the integration of weights and alternatives are considered in fewer studies. One of the main steps in the decision-making process is to define the objectives, they are the starting point to identify criteria and characteristics of alternatives. In the literature, a few tools as the proposed by Jensen and Maslesa (2015) rely explicitly on the discussion of objectives with stakeholders, other tools include choosing goals but do not mention how to do it

(Nielsen *et al.,* 2016). According to Jafari and Valentin (2018), reducing Life-cycle cost is the most frequent objective in decision-making tools for optimal building renovation, other objectives comprise reducing energy consumption, increasing energy savings, reducing CO_2 emissions, and increasing thermal comfort. Once the objectives are established, alternatives to accomplish them should be identified. Pombo *et al. (*2015) conducted a review of renovation measures applied to different kind of houses, showing that envelope insulation, windows replacement and air sealing are the most common strategies. Other measures comprise the renovation of heating, cooling, and lighting systems. A renovation alternative may include one single measure or a package of measures. Evaluating the multiple possible combinations of these elements considering materials, dimensions, configurations and other parameters may represent thousands of options. The high number of alternatives and multiple variations of each one makes the analysis and decision-making process for renovation very complicated (Jafari and Valentin, 2017).

To assess how alternatives fulfil the objectives, it is necessary to define a set of criteria which quantify directly how the alternatives perform on the objectives. These criteria may be quantitative or qualitative. Kylili *et al. (*2016) identified eight generic categories to classify criteria for renovations, including conventional categories such as environmental and economic, and other groups such as technological, time, and disputes. However, most of the studies follow the traditional triple bottom line integrating environmental, economic and social criteria (Taillandier *et al.,* 2016; Kamari *et al.,* 2017; Li and Froese, 2017; Jafari and Valentin, 2018). Criteria considered on those tools comprise energy efficiency improvement, investment cost, acoustic, thermal and visual comfort, and among others. Pombo *et al. (*2015) show that economic and environmental criteria are included in most of the studies, while social aspects are barely considered. Other studies such as (Dodd *et al.,* 2017) follow environmental and life-cycle cost principles, including global warming potential, construction and demolition waste or materials, and cost.

After defining the criteria, approaches such as the Analytic Hierarchy Process (AHP) assign weights to them to capture the stakeholders' preferences. The selection of the weighting method and the weights themselves have repercussions on the final rank of alternatives. Weighting methods can be subjective, objective or a combination of them. In subjective methods, criteria weights are derived from the stakeholders' judgment, while in objective methods, the weights are obtained from mathematical models (Zardari *et al.,* 2015). According to Nielsen *et al. (*2016), AHP is the most used weighting method in decision-making tools for renovation. Other approaches include Direct raking, SMART, and Entropy method. After defining weights, they and alternatives performance are integrated to obtain the final ranking. Integration approaches include methods such as Additive Aggregation, AHP and ELECTRE. Dirutigliano *et al. (*2018) use the PROMETHEE method to rank different renovation alternatives, while Taillandier *et al. (*2016) incorporate ELECTRE III to their tool.

The fragmentation of the process, the large number of proposed criteria and the small number of studies regarding the stakeholders' interactions may reflect the complexity of the decision-making process in renovations. Some studies have focused on understanding it better, Gohardani *et al. (*2013) examined the decision-making process to identify the drivers of energy renovations, analysing three case studies through semi-structured interviews and questionnaires. Kim *et al. (*2019) analysed a renovation project at an education institution, using semi-structured interviews and general data to study the factors considered when making a decision. As the best of

our knowledge, such a study has not been conducted in the residential field. Therefore, it is required to understand better how the decision-making process is conducted in practical residential renovations to explore aspects that have not been studied in detail, map common practices, identify stakeholders' perspectives, and identify gaps between theoretical and practical approaches.

RESEARCH APPROACH

The research approach focuses on studying how the decision-making process to select renovation alternatives for residential buildings is executed in practice. The main goal is two-fold: 1) To identify key aspects including objectives, stakeholders, alternatives and criteria, and process; 2) To contrast the findings with concepts from the related literature to identify gaps and elements that should be addressed by decision-making tools in this field. To this end, we analyse two real case studies: A twelve multi-family apartment building in Spain, and a 79-unit dwelling, in a district in The Netherlands.

We collect general information from the two cases and conducted semi-structured interviews with the project's supervisor from the case in Spain and an architect, who monitored the case in The Netherlands. The former has experience in renovating different types of buildings, while the latter leads a firm in the renovation industry. A sample of the questions that guided the interviews is shown in Table 1. They were developed based on a grand tour approach and the queries presented by Gohardani *et al. (*2013) and Kim *et al. (*2019). The main goal is to address objectives, stakeholders, alternatives, criteria, weighting and integration methods, restrictions and tools. The interviews lasted around 60 minutes and were conducted in January and March 2020.

Transcripts of the interviews were coded and analysed individually using a deductive approach, the concept-driven content analysis was assisted by the qualitative data analysis tool ATLAS.ti. The initial categories correspond to objectives, stakeholders, alternatives, criteria, tools and methods, and restrictions. The codes gathered in each category are used to identify the main elements of the decision-making process, then we present a descriptive narrative. Finally, we contrast these elements with some of the concepts presented in the related literature.

Table 1: Interview questions

Topic	Question
General	- Could you make a brief description of the renovation project?
Objectives	- Could you describe the expectations you had from the renovation project?
Stakeholders	- Which stakeholders did you work with to select the final alternative? Were there any other stakeholder that should have been included? - Could you describe the process to select the alternative that will be implemented?
Alternatives	- Could you describe the renovation alternative that will be implemented?
Criteria	- Could you list the criteria that were used to assess these alternatives? - Which criteria were important for you? which were important for other stakeholders?
Tools and methods	- Could you describe the process to select the solution that will be implemented? - What kind of tool did you use to assess the alternatives and rank them? - Are you familiarized with decision-making tools or methods such as AHP?
Restrictions	- What kind of external restrictions (e.g. fire regulation, contract requirements, construction licenses) did you encounter during the decision-making process?

RESULTS

Table 2 summarizes the main aspects of the decision-making process extracted through the coding process of the interviews. The following sections analyse these aspects in detail, italicized texts correspond to quotes from the interviewees.

Table 2: Main aspects of the decision-making process in the two case studies

	Spain	The Netherlands
Main objectives	To reduce CO_2 emissions and dependency from fossil fuels. To improve quality of life.	To improve energy performance. To improve comfort.
Main stakeholders	Owners, supervisor, design architect. Tenants had voice but not vote.	Owner, contractor, energy consultants, architects.
Decision-maker	Owners, at least 60% agreement.	Single owner.
Alternatives	Initially by combining insulation for façade options and windows types. Then, other aspects such as the refurbishment of terraces and internal pipelines were added.	Prefabricated façade, five scenarios considering different materials, windows sizes, insulation thickness and image.
Criteria	Main: Minimum technical requirements, investment cost and aesthetics. Secondary: comfort, operational energy cost, safety.	Main: Energy performance, energy savings, investment, comfort. Secondary: durability, endurance, and aesthetics.
Weighting and integration methods	No specific methods.	No specific methods.
Restrictions	Requirements imposed by funding entities, external renovations going on, fire regulation, conflicts between owners.	Façade building limits, regulation on the quality of prefabricated façade.

Case Studies and Objectives

The first case study is a building with twelve apartments and two commercial units, it *is a typical case in Spain. It was constructed in 1950 and does not have any insulation on the façade nor the roof, and the energy performance is low. The local government and a European project are executing also a renovation at the neighbourhood level, which is out of the scope of this analysis. However, it is important to mention that these institutions provided funds for the building renovation and defined the connection to the district heating and insulation of the envelope as mandatory tasks. The public society representing the government would like to improve the quality of life of people. This goal is integrated with the aim of the general project: to reduce the CO_2 emissions and reduce the dependency from fossil fuels.*

The second case study is a 79-unit dwelling, in The Netherlands. The dwellings were built in 1975 and are owned by a social housing corporation and occupied by tenants. According to the local regulation, the energy label was G, the houses were old, they had moist issues and low comfort level. The renovation was conducted in the context of a European project that looked for the implementation of innovative renovation elements. The interviewee mentioned that the social housing company was really ambitious with the project and wanted to renovate almost to zero energy. They also aimed at very comfortable new dwellings and building wise.

Alternatives

In the Spanish case, different options for the thickness, materials and technologies for the façade insulation were analysed including ETICS or just a ventilated cavity air façade… with mineral wool and with polystyrene. *In a similar fashion, for the windows,* two alternatives, aluminium with thermal bridge cut and *PVC were analysed. Once the owners were engaged with the main renovation tasks, additional activities such as the replacement of terraces and internal pipelines were included in the options as a result of a building inspection that must be performed according to the Spanish regulation. The final solution includes the insulation of the envelope, roof and a ventilated façade, second external windows, the insulation of the first-ground floor slab, terraces, pipelines and boiler replacement, and heating exchanger installation.*

In the Dutch case, the renovation alternatives focused on insulation for the façade, the stakeholders wanted to install fully prefabricated façade elements over the existing one. To study different alternatives, they *used scenario thinking, they composed*

different kinds of solutions, made a full scenario and look which were going to be the consequences. In total, five scenarios were evaluated varying the insulation, PV panels installation, windows size to increase the area of the closed façade, windows frames materials and closure. Since the roofs were renovated three years ago, they were not considered. The final renovation solution comprises the insulation of the full façade, installing a prefabricated façade over the existing one. This new façade includes the windows and doors. Moreover, the ground floor and the foundation were also insulated, and a new ventilation box was installed to improve the indoor air quality.

Stakeholders and Criteria

The main stakeholders in the Spanish case were the owners, the project's supervisor, and an external designer. The owners selected the final solution *in terms of technical solution, they also had to consider the cost which is really important, and they had to consider also the final appearance of the building.* It was not possible to implement the best solution in terms of technical aspects due to the cost, the designers *considered also to install a heat recovery system for the ventilation… the best technical solution is that one to avoid condensation problems… but at the end it was not affordable for the community*. Moreover, social aspects such as comfort were implicitly considered in the alternatives, *the comfort inside is considered in the whole frame of the project, with the minimum conditions, insulating and connecting to the district heating, comfort conditions improve higher than the current regulation in Spain*. Criteria such as maintenance costs were not relevant for the owners due to their perception of future uncertainties, the interviewee quoted one of the owners: *I do this investment now and who knows what will happen in 15 years*. However, the supervisor considered *how a material will perform in the future, trying to reduce the maintenance of it*.

In the Dutch case, the main stakeholders were the social housing company (owner), contractor, and producer of the prefabricated façade. Moreover, architects and energy consultants worked together with the contractor to evaluate the different scenarios. The final decision was made by the owners in conjunction with the experts, *they really looked at the energy and comfort also, and of course the investment*. Other criteria comprise *durability, if materials age good* and *maintenance cost, mostly in the form of endurance of materials.* Aesthetics was also included since it was going to be *a whole new architecture of the district, the whole district has a new face*. A group of tenants was involved, they were inquired to know their preferences. The main stakeholders *looked very closely at how to maintain and how to make it easy for tenants*.

In both cases, social aspects were highlighted. In the Spanish case, the supervisor stated: *we realized that going from the beginning with the energy efficiency idea is ok, but we have to mix it with other social aspects.* This is aligned with statistics in Spain showing that energy efficiency is relevant for renovations, but owners focus on other aspects such as accessibility, noise and safety (Ministerio de Fomento, 2017). In the Dutch case, the aesthetic was highlighted through statements such as *the architecture will be totally different, it is a whole new house, so it is like you have a new district, it is not the most important aspect, but it is an impressive asset.*

Tools and Methods

In the Spanish case, different tools were used to estimate the criteria, the supervisor mentioned multiple commercial software available for cost estimation. Moreover, for energy performance assessment, the usage of an official software tool is mandatory in Spain. The assessment of criteria such as aesthetics and maintenance needs relied on

experts and *the technical knowledge of the company… after building more than 8000 apartments we have a very good experience*. Neither decision-making framework nor weighting or integration methods were applied during the process. Additional tools were used to support visualization, *the alternatives had at least a picture based on the BIM model, working with photoshop we created different images, so they can decide*.

The experts from the Dutch case used excel sheets to assess the different scenarios. The analysis of the different alternatives relied mainly on comparisons of the quantitative criteria, energy consumption and investment. They had specific models for energy performance and financial tools for the investment. Neither decision-making framework nor weighting or integration methods were implemented during the process, the interviewee stated that *they did not weight or have a formula to say: this is four-time more important than that*. Moreover, the experts used renderings to present how the alternatives would look like, they built a sample of the façade and presented also material samples to show the external texture of it.

Sequence of the Decision-Making Process

One of the questions from the interview was explicitly intended to identify the steps followed during the decision-making process, based on the interview from the Spanish case, the sequence chart in Figure 1 was developed.

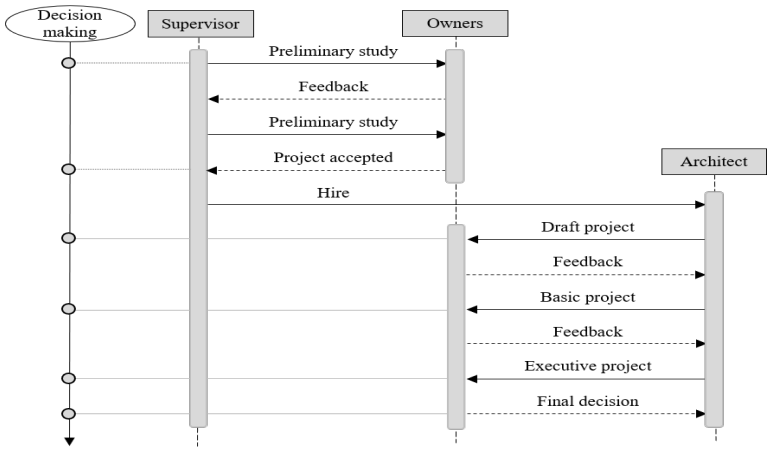

Figure 1: Sequence chart for the decision-making process case study Spain

The first step is a preliminary study, including a technical inspection. A proposal is presented to the owners, *we explain to them the different possibilities and what is the approximate cost and then they can decide if they want this project*. Then, the designer follows three steps: 1) To discuss a draft including energy efficiency actions and other possible tasks. 2) To introduce the basic project to discuss diverse aspects and provide advice to the owners. 3) To prepare the executive project, at this point *everything must be decided*. The owners analyse each renovation element, they vote and decide. In this case, the decision-making process took one year. In the Dutch case, it took around 4-5 months, however, the available data was not enough to develop a sequence chart.

Restrictions

The funding institutions in the Spanish case imposed some restrictions, they defined the connection to the district heating and insulation of the envelope as mandatory activities, influencing directly the final solution. Fire regulation influenced also the design, *when we offer the polystyrene, we have to divide the façade into different sectors just in case of fire to be under control.* Moreover, conflicts between apartment

owners and the owner of one of the commercial units ended in the partial insulation of the first-ground floor slab. In the Dutch case, restrictions came from the building borders, the new façade was installed over the existing one and enlargement thresholds had to be held. Additional, since the solution was a new prefabricated product, special attention was given to the quality assessment of the products.

Gaps and Opportunities

This section contrasts the findings with some of the concepts presented in the related literature to identify gaps and elements that should be addressed by decision-making tools for renovation projects. For instance, only a few studies such as (Dirutigliano *et al.,* 2018) consider renovation at the building and district scale in conjunction. However, in the Spanish case, the building renovation is executed simultaneously with a renovation at the neighbourhood level, funds and requirements for the alternatives were assigned in this context. This scenario calls for decision-making tools able to consider different scales and represent the effects of decisions made at different levels.

Most of the tools in the literature address only energy-related tasks, though renovation focuses on diverse activities. In the Spanish case, the project in the neighbourhood is *a comprehensive project to improve the quality, to improve the public space, to improve energy performance.* At the building level, *apart from this project of energy consumption reduction, we have also to add these particular things to solve what the technical inspection said*. Stakeholders may seek comprehensive alternatives, *some of the people understood this refurbishment as the possibility to do more things at the same time… they considered that once they have to invest money on the building, they prefer to invest once and solve everything.* Therefore, decision-making tools for renovation should be able to analyse not only the energy-related aspects but also other renovation tasks with different goals, that are performed simultaneously.

On the other hand, economic and environmental criteria are included in most of the related studies, while social aspects are barely considered. However, criteria such as low intrusiveness might have been relevant. In the Spanish case, the designers offer to the owners installing the pipelines from outside, *once we have the scaffolding, then we can do it from outside… what is very good because then we do not go inside the apartments.* In the Dutch case, the interviewee highlighted that the prefabricated solution was mounted in one day, and the renovation was performed in a habited condition. Moreover, other insights suggest that criteria may evolve along the process. At the beginning of the Spanish project, technical criteria such as energy efficiency were not relevant for the owners, *now maybe it is improving, but at the beginning of the project nobody was worried about the energy consumption, it was something like: I do not care, I have a heating system and it works, I do not care about that.*

Users and other stakeholders play a key role in the decision-making process, even though they are not considered in the development of most of the tools for renovation. In Spain, at least 60% of the owners must agree on the final alternative to obtain permission for construction. Multiple owners may have different preferences and even investment capacities. The supervisor stated that *this particular limit has been a barrier for us to get more communities involved in this type of refurbishments.* In The Netherlands, the owner must offer compensation and 70% of the tenants must agree on it. Asking the tenants their preferences might have contributed to reaching the 70% level. The monitor stated that *having the tenants happy with the renovation was an important part of the process*. In both cases, communication channels were

relevant, in the Spanish case, there was a campaign to engage the owners with aspects such as building insulation and district heating. The supervisor stated: *it was very important to have direct communication with me, everyone has my e-mail… if it is something important then we can organize a meeting with all the community.* In the Dutch case, *all tenants got personalized information, consultation hours were scheduled*.

Finally, not only the landlord/tenant dilemma brings opposite perspectives into the process, diverse interactions are encountered in renovation projects, these should be studied further. For instance, the owners of the commercial units in the Spanish case had the right to decide whether the first-ground floor slab is insulated or not. There was a conflict *between the community of apartments and the owner of one local, he did not want to do anything in this project.* This impacted the renovation solution since *on the first floor there are three apartments, two of them will be insulated from the ground floor and the other one no. Even if the whole community will improve the energy performance, in this particular first floor the improvement will be less*. The supervisor highlighted also the role of Community managers, *they do not take an official part, but in the process, they are very important… if they agree or they think somehow that the project is interesting, they push the community in that direction.*

DISCUSSION

One of the limitations of the study is related to the particularity of the two cases, both cases were conducted under research funding projects, this might have influenced the way the decision-making process was performed, and the definition of alternatives and criteria. Moreover, findings show that stakeholders' interactions may impact the renovation solution. However, the two cases represent very specific scenarios, in the first case, most of the units are occupied by the owners; while in the second case all the inhabitants are tenants. Scenarios with comparable quantities of owners and tenants may provide additional insights into the decision-making process and how the objectives, criteria and alternatives are modified by stakeholders' interactions.

CONCLUSION

The process fragmentation, the large number of proposed criteria and the lack of studies regarding stakeholders' interactions may reflect the complexity of the decision-making process in renovation. This paper studied how the decision-making process was performed in two real residential cases. The results suggest that not only energy-related activities are considered in the decision-making process, but also other renovation tasks that are performed simultaneously. Social criteria seem to play an important role in engaging stakeholders. Moreover, renovation projects may deal with stakeholders' interactions, not related to the landlord/tenant dilemma, which impact the process and final solution. Studies covering these aspects may support the development of future decision-making tools in this field.

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