Ref. Ares(2021)7575066 - 08/12/2021

D7.1 - Multi-criteria decision-making method and tool for housing renovation projects

Deliverable Report: D.7.1, issue date on 31.10.2020

BIM-SPEED
Harmonised Building Information Speedway for Energy-Efficient Renovation

This research project has received funding from the European Union's Programme H2020-NMBP-EEB-2018 under Grant Agreement no 820553.

D7.1 - Multi-criteria decision-making method and tool for housing renovation projects

Issue Date 31.10.2020

Produced by Technical University of Berlin

Main author Jerson Pinzon

Co-authors Tofan Bogdan-Andrei (ARC), Agnieszka Lukaszewska (FAS), Mikel Cepeda (LKS), Piotr Dymarski (MOW), Oskar Bell Fernandez (VIS)

Contributors UNIVPM, ARC, MTB, FAS, MOW, LKS, VIS

Version: 1.0

Reviewed by Samaneh Rezvani (DMO), Maria Chiara Caruso (STRESS)

Approved by Timo Hartmann

Dissemination Public

Type Other

Colophon

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Change log

Description	Author	Date
Initial version for internal review	Jerson Pinzon (TUB)	30.09.2020
Internal reviewing	Samaneh Rezvani (DMO)	13.10.2020
	Maria Chiara Caruso (STRESS)	16.10.2020
Addressed internal review comments	Jerson Pinzon (TUB)	24.10.2020
Finale editorial review	Samaneh Rezvani	26.10.2020
Addressed monitor's review comments	Jerson Pinzon (TUB)	10.08.2021

Publishable executive summary

This report summarizes the results of Task 7.1 *Multi-criteria decision-making of renovation strategies*. It is important to notice that this report is only a supporting document to facilitate the use of the BIM-SPEED multi-criteria decision-making tool which is the final deliverable of Task 7.1. The goal of this report is to introduce the BIM-SPEED multi-criteria decision-making tool and its features. The tool allows main stakeholders involved in a residential renovation project to decide upon a renovation option that is satisfactory for all and at the same time identify the optimum chosen renovation design options based on the different criteria relevant for them. The developed decision-making tool leverages the results from different BIM-SPEED tasks, including the tools from work package 4 *Conducting performance simulations of renovation scenarios*, and additional tasks related to design rules and LCC assessment from work package 7. The approach includes a criteria framework, suggested methods to quantify the criteria, a weighting method to capture the preferences of the decision-makers over the criteria, and a raking method which enables a transparent and inclusive process to support the different stakeholders to rank the different alternatives.

This supporting tool for the stakeholders is available for downloading for external users on the DepositOnce TU Berlin repository[1]. In the context of the BIM-SPEED project, the tool will be integrated with a decision-making dashboard in the context of the BIM-SPEED deliverable D4.5: *BIM-based procedures and tool for holistic performance assessment of renovation design options*, led by the partner Metabuild.

The BIM-SPEED multi-criteria decision-making tool is described in the following sections. First, Section 1 presents a short introduction and the general structure of the proposed framework. Section 2 presents the motivation of the tool and general information regarding the stakeholders involved in the decision-making process in renovation projects. Section 3 introduces the objectives and criteria lists, weighting approach, and alternatives ranking method. Section 4 summarizes the implementation and presents some features of the developed tool in conjunction with a brief illustrative example of the tool in action. Sections 5 and 0 present a short characterization of the BIM-SPEED demonstration sites and conclude the report, respectively.

The general information of the deliverable is as follows:

The type of this deliverable is “Other”.

The due date is M24

Task Leader: Technical University of Berlin

Task contributors: UNIVPM, ARC, MTB, FAS, MOW, LKS, VIS.

Deliverable reviewers: DMO, STRESS.

[1] http://dx.doi.org/10.14279/depositonce-10659

List of acronyms and abbreviations

AHP: Analytical Hierarchy Process

BEM: Building Energy Model

BIM: Building Information Model

EPD: Environmental Product Declaration

ETICS: External Thermal Insulation Composite System

HVAC: Heating Ventilation Air Conditioning

KPI: key performance indicator

LCA: Life Cycle Analysis

LCC: Life Cycle Costing

TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution

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1. Introduction

Buildings account for 40% of the EU's energy consumption, 36% of its CO_2 emissions and 55% of its electricity consumption (Artola, et al., 2016). They play an important role in implementing energy efficiency at the urban level. Since new buildings account just for 1% of the stock, the largest opportunity to implement energy-efficient strategies comes from the renovation of existing buildings. Nevertheless, the current renovation rate of existing buildings is low, even as renovation accounts for 57% of all construction activity, only about 1-2% of the building stock is renovated each year (Artola, et al., 2016).

Building owners and investors need the right encouragement, information, support, and incentives to choose cost-effective, energy-efficient, and suitable renovation alternatives. Most of the decision-making frameworks for choosing renovation strategies in residential buildings presented in the related literature are based on literature reviews, researchers' suggestions or certification schemes, the latter being originally developed for new buildings in most of the cases. While decisions in the context of new buildings most of the times involve only designers, architects and investors, one of the particularities of renovation projects is the involvement of final users, building managers and other stakeholders during the process (Jensen, et al., 2018). A more specialized decision-making framework for the building renovation field is required. The proposed structure for the BIM-SPEED decision-making framework is presented in Figure 1. The approach comprises three main stages that will support the direct stakeholders in renovation projects to:

- (1) select specific economic, environmental and social objectives and criteria to assess the performance of a set of alternatives. These alternatives can be generated in an independent approach, based on designers recommendations or in an assisted way using the tools developed in BIM-SPEED D7.2: *Machine-learning for As-Built diagnostics and enrichment of design rules for deep renovation*, D7.3: *Semantic design rules and tool for deep renovation design*, D4.2: *Real demonstration results of BEM performance simulation using BIM-SPEED Toolset* and D4.5: *BIM-based procedures and tool for holistic performance assessment of renovation design options*;
- (2) assign weights to the selected criteria, and quantify the performance of each alternative according to each criterion;
- (3) rank the alternatives according to the criteria and weights that represent the interests of the different stakeholders, making easier the final decision to select the renovation alternative that will be implemented in the project.

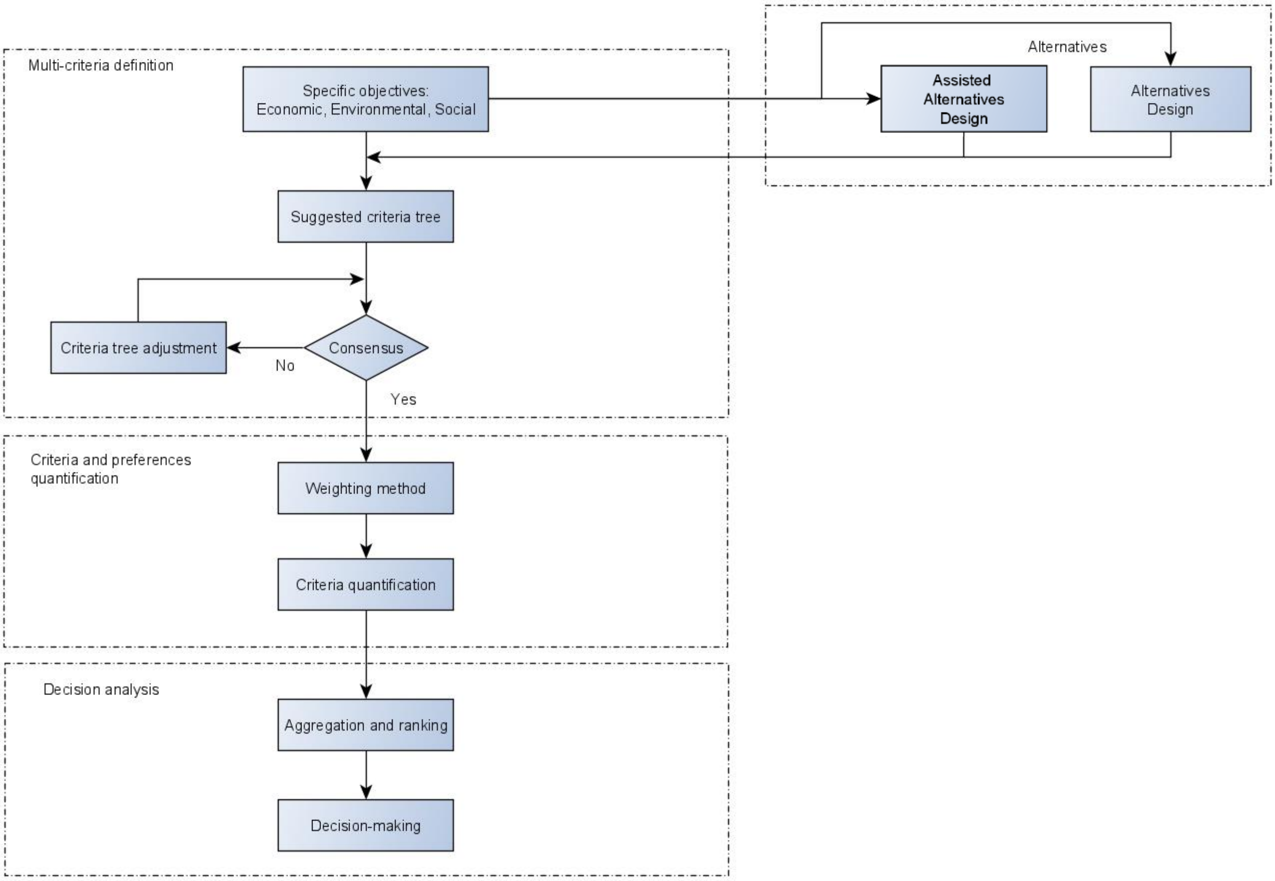


Figure 1. BIM-SPEED Decision-making framework

The three stages of the framework can be described as follows:

- **1. Multi-criteria definition:** In the first stage of the framework, specific objectives for the renovation project are defined. The stakeholders select the specific objectives they intend to achieve within the renovation, from a predefined set of economic, environmental, and social objectives proposed by the framework. Once these objectives are defined, a suggested criteria tree for the specific project will be presented, including only criteria related to the specific objectives selected by the stakeholders. For instance, if one of the specific objectives is *to maximize indoor comfortable conditions*, the criteria *Indoor air quality*, *Acoustic comfort*, *Visual comfort*, and *Thermal comfort* are included in the tree.
- **2. Criteria and preferences quantification:** Once the stakeholders agree on the objectives and criteria that would be included in the criteria tree, it is necessary to capture the preferences of the diverse stakeholders over those criteria. To do this, a weighting method is implemented. The aim is to allow the stakeholders to identify and represent their preferences in an easy and transparent way. Then, for each alternative, the value of each criterion is quantified.
- **3. Decision analysis:** The weights and results for the criteria from the second stage will be aggregated to obtain a final ranking of the renovation alternatives showing their performance regarding the criteria. This will support the decision-makers to analyse the set of alternatives available and select, in a transparent and inclusive way, the one that should be implemented, taking into account the preferences of the different stakeholders. Section 3 describes each stage in detail.

1.1 Interaction with other work packages and tasks

The decision-making framework developed in task 7.1 is directly linked to other BIM-SPEED tasks and tools. As presented in Figure 2, different renovation scenarios can be developed by the stakeholders based on the recommendations and design rules proposed in the deliverables from task 7.2 or in a conventional approach relying on experts suggestions. Once these renovation scenarios are defined, tools and Key performance indicators (KPIs) developed in work package 4 can simulate and assess the different renovation alternatives. Stakeholders may use also external tools to quantify some of the indicators. Then, the decision-making framework gathers the results obtained for the KPIs, results from the LCC tool developed in task 7.3, input from the stakeholders regarding their preferences, and results of additional criteria. The final ranking obtained through the decision-making framework will support the stakeholders to select the final renovation solution.

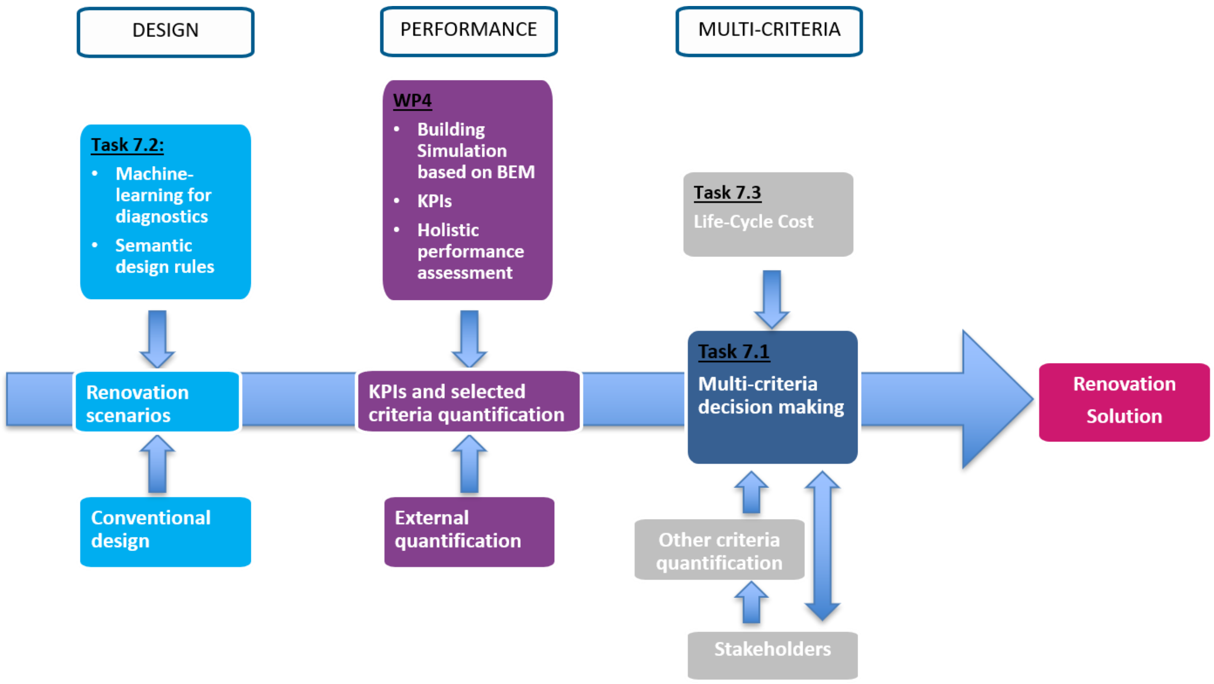


Figure 2. Deliverable interactions with other tasks in BIM-SPEED

2. Stakeholders in renovation projects

The purpose of developing a decision-making tool is to support the main stakeholders involved in renovation projects to evaluate multiple alternatives while considering multiple criteria capturing the goals of the renovation, and the preferences and perspectives of the diverse participants in the decision-making process. Table 1 presents a list of diverse stakeholders involved in renovation projects. This list was established through a questionnaire conducted with the practitioner partners from the BIM-SPEED consortium. This list can be used to identify which are the direct stakeholders in renovation projects and which of them will be the end-users of the BIM-SPEED multi-criteria decision-making tool.

Table 1. Stakeholder list for renovation projects

	Stakeholder	Description
1	**Municipality**	regulates the policies for renovation at local level
2	**Apartment/Business owners**	own the apartment/house or commercial spaces in the building
3	**Investors**	Depending on the scale of the project and type of building, it can be a person, administrator, company, or the municipality
4	**Occupants**	are the final users of the building
5	**Building manager and administrator**	have access to detailed building information, user requirements and previous issues addressed by the building. They often represent the occupants and are responsible for managing the renovation activities.
6	**Financial institutions**	asses the financial feasibility of the project before providing loans
7	**Energy companies**	In some countries, should provide advice regarding technologies, energy demand goals and other aspects
8	**Project manager/Site-Directors**	manage/supervise the renovation activities
9	**Engineers and technical advisors**	comprise MEP engineers, energy auditors, and consultants supporting the renovation project
10	**Architects/designers**	They design the renovation alternatives and play an important role in the decision-making process
11	**Main contractor**	is the construction company in charge of the project
12	**Sub-contractors**	are hired by the main contractor to execute specific activities such as products installation, façade renovation, demolition and among others
13	**Community managers**	have a high level of influence on the community's decisions
14	**Technical architects**	manage the site technically (quality and quantity) in collaboration with the Site-Director
15	**Craft**	executes installing activities
16	**Suppliers**	supply products and materials such as carpentry, insulation, finish panels, HVAC elements
17	**Public institutions**	usually stablish the policies, provide grants and regulate them
18	**Real estate agents**	may take part in the process as long as the property values increase
19	**Fire department**	may monitor restrictions related to evacuation routes and materials behavior in case of fire, according to the local fire regulation
20	**Others**	comprise 3D scanning companies, acoustic performance companies, thermal scanning companies that may play a role during the renovation project

Stakeholders such as architects/designers, the main contractor, engineers, and energy companies may take part in the decision-making as advisors to support main stakeholders such as apartment owners and investors, which play a key role in making the final renovation decision. Moreover, occupants, building managers, and community managers may have a relevant role in the decision-making process as well. They can provide valuable information regarding the existing conditions and performance of the building, before and after renovation. The preferences of all these participants should have a special consideration during the decision-making process.

In renovation projects, the kind of owner, kind of inhabitants, type of building, and type of investment may lead to different scenarios regarding the way the decision-making process is performed. For instance, in some cases, the renovation project consists of a single house owned by a single private owner that occupy the property. In multi-family buildings, it may exist multiple private owners, some of them living in the apartments to be renovated, but some of them could be also absent and their apartments may be occupied by tenants. Another possible scenario includes a single owner (a housing company) that owns a multi-family building where all the inhabitants are tenants. According to the local regulation and the presence of these diverse stakeholders, in each renovation project, the interactions during the decision-making process are different, some stakeholders can vote while others are only informed during the process. For instance, according to the Spanish regulation, in multi-family buildings, at least 60% of the owners must agree with the final alternative to obtain permission for renovation. Notice that multiple owners may have different preferences and even investment capacities. In this case, if some of the dwelling units were occupied by tenants, they will be informed but without the right to vote any decision. On the other hand, in The Netherlands, the owner of the dwelling unit must offer to the tenants a compensation and at least 70% of the affected persons must agree on the offer. Table 2 summarizes some common scenarios, the way the decision is made in each scenario can vary according to local regulation and the rights assigned to the owners and tenants. In all the scenarios, additional stakeholders such as the local municipality, funding institution, architect, and energy companies may participate in the project to monitor, advise or control the way the decision-making process is performed.

Table 2. Common stakeholders' scenarios in renovation projects

Scenario	Owner	Inhabitant	Decision
1	Single owner	Owner	Simple decision
2	Single owner	Tenants	A kind of accord/compensation may be required between the owner and tenants. In the case of multi-family units, a certain level of agreement between tenants may be also required. In this case, tenants' associations and community managers play a key role.
3	Multiple owners	Owners	Usually there is a required level of agreement/consensus that should be reached.
4	Multiple owners	Owners and tenants	Usually there is a required level of agreement/consensus that should be reached by the owners. Tenants may only be informed of the activities.
5	Multiple owners	Tenants	A kind of accord/compensation may be required between the owners and tenants. A certain level of agreement between tenants may be also required. In this case, tenants' associations and community managers play a key role.

3. Proposed decision-making framework

3.1 Multi-criteria definition

Energy-efficient renovation of buildings deals with multiple environmental, social, and economic aspects and brings additional benefits that should be considered when choosing the final renovation solution. Each renovation project has particular requirements that may lead stakeholders to focus on specific goals such as enhancing the building aesthetics, reducing the payback period, improving indoor conditions or reducing CO_2 emissions. The first stage of the proposed decision-making framework is shown in Figure 3. At the initial stage of a project, the framework allows stakeholders to select specific environmental, social, and economic objectives from a predefined list as presented in Section 3.1.1. Then, a suggested criteria tree is built based on those selected objectives.

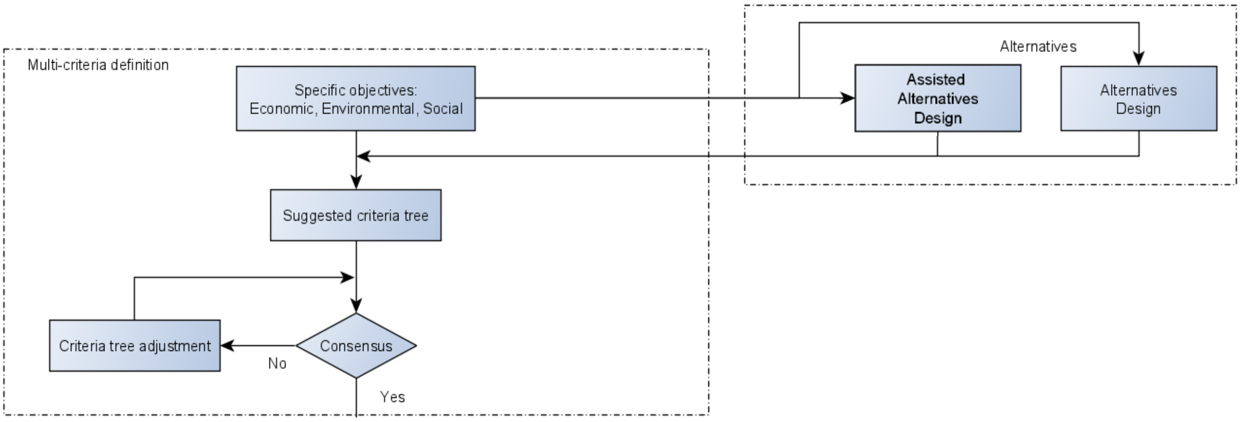


Figure 3. Decision-making stage 1, multi-criteria definition

3.1.1 Objectives

The framework includes a list of specific objectives that will support stakeholders to represent the relevant aspects of their project. The list of objectives presented below was developed based on existing literature reviews (Jensen & Maslesa, 2015; Jafari & Valentin, 2018, Nielsen et al., 2016) and the group of KPIs proposed in BIM-SPEED deliverable D4.1 *Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation*, these objectives comprise:

- Environmental
  - *To reduce primary energy*
  - *To reduce energy demand*
  - *To reduce environmental impacts*
- Social
  - *To improve indoor conditions*
  - *To increase social acceptance*
  - *To increase social technical benefits*
- Economic
  - *To reduce cost*

- *To reduce operational and maintenance cost*
- *To increase financial benefits*

3.1.2 Alternatives

Once the objectives are defined, different alternatives can be designed to fulfil those objectives, considering different materials, configurations, technologies, manufactures and other aspects. For instance, the stakeholders may be interested in analysing different materials and thickness for the insulation of the façade, diverse types of windows, comprising different frames and glazing, different heating technologies and other multiple options for additional elements. Moreover, there are other alternatives that may be relevant for the analysis such as a non-renovation scenario, which analyses the case when no renovation is performed, i.e. the building keeps operating with the current deficiencies it may have. This case may be interesting to analyse how aspects such as maintenance costs, comfort, environmental impacts, and energy cost will evolve if a renovation is not executed. Another relevant scenario may be an alternative considering only the replacement of the old elements in the building for equivalent products without pursuing energy performance improvement.

The combination of all these options creates a large set of possible renovation alternatives that could be implemented in the building. The design of the renovation alternatives is conducted externally from the framework. It can be performed in a conventional way by designers defining different scenarios and combinations, analysing the aspects they consider are relevant to achieve the goals of the project. Moreover, the generation and analysis of multiple alternatives can also be supported by the BIM-SPEED tools developed in D7.2: M*achine-learning for As-Built diagnostics and enrichment of design rules for deep renovation*, D7.3: *Semantic design rules and tool for deep renovation design*, D4.2: *Real demonstration results of BEM performance simulation using BIM-SPEED Toolset* and D4.5: *BIM-based procedures and tool for holistic performance assessment of renovation design options*. These tools will facilitate the process and will allow the stakeholders to explore more renovation alternatives and find a set of potential renovation measures that could be implemented. The set of alternatives identified through the different possible design approaches (conventional or assisted) is an input for the decision-making framework. These potential alternatives are evaluated in the second stage of the framework according to the criteria selected by the stakeholders.

3.1.3 Criteria pool

The selected objectives may be associated with diverse criteria and attributes that quantify the performance of each renovation alternative in a specific aspect. Figure 4 presents the proposed criteria pool gathering all the possible objectives and associated attributes that allow assessing the renovation alternatives. This criteria pool corresponds to the general proposed tree which is adjusted according to the objectives selected by the stakeholders in each particular renovation case as presented in the following section. The shadowed criteria correspond to the KPIs presented in the BIM-SPEED deliverable D4.1; the additional criteria were identified through an extensive literature review, including technical guidelines such as Level(s) – A common EU framework of core sustainability indicators for office and residential buildings (Dodd, et al., 2017), and results from International projects such as IES EBC Annex 56 (Romagnoni, et al., 2017).

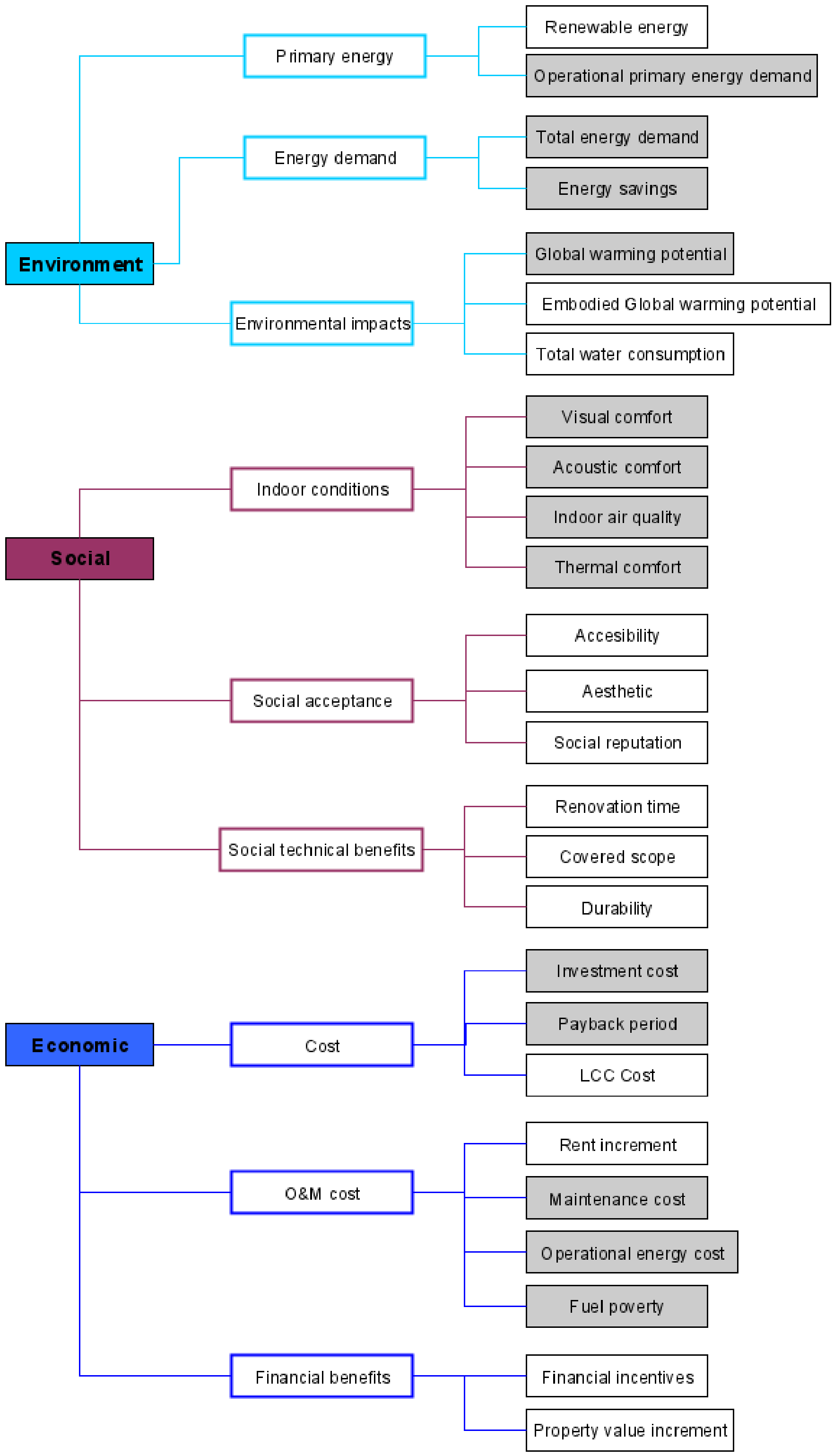


Figure 4. Criteria pool

The preliminary pool of criteria introduced in Table 3 was presented to the BIM-SPEED partners responsible for six of the BIM-SPEED demonstration projects located in five different European countries to evaluate their relevance according to the characteristics of each project. In general, most of them defined most of the criteria as relevant for the renovation project, some criteria were catalogued as "it could be" relevant. On the other hand, criteria such as *Social reputation* and *Dwelling value increment* were considered not relevant for two of the cases. *Rent increment* was considered not relevant in three of the projects, however, in two of them, the dwelling units are completely occupied by the owners of the apartments, making this criterion irrelevant for them. The *Accessibility* and *Fuel poverty* criteria were included later according to the recommendations of some of the BIM-SPEED projects. Then, the final criteria pool presented in Figure 4 was established.

Table 3. Preliminary criteria tree relevance for the BIM-SPEED demonstration projects

			Relevant		
Category	**Objective**	**Criteria**	**Yes**	**It could be**	**No**
Environmental	To reduce Primary energy	Renewable energy	3	2	1
		Operational primary energy	4	1	1
	To reduce Energy demand	Total energy demand	6	0	0
		Energy savings	6	0	0
	To reduce Environmental impacts	Global warming potential	4	2	0
		Embodied global warming potential	2	2	2
		Total water consumption	4	2	0
Social	To improve Indoor conditions	Visual comfort	3	1	2
		Acoustic comfort	2	3	1
		Indoor air quality	1	5	0
		Thermal comfort	5	1	0
	To increase social acceptance	Durability	4	1	1
		Reliability	4	1	1
		Aesthetics	3	3	0
		Social reputation	1	3	2
		Renovation time	5	1	0
Economic	To reduce Cost	Investment cost	6	0	0
		Payback period	4	2	0
		Life cycle cost	3	3	0

	To reduce O&M Cost	Rent increment	3	0	3
		Maintenance cost	5	1	0
		Operational energy cost	5	1	0
	To increase Financial benefits	Financial incentives	4	0	2
		Dwelling value increment	3	1	2

3.1.4 Criteria tree suggestion

The criteria pool introduced in the previous section corresponds to the general proposed criteria tree. In each particular renovation project, stakeholders will be asked to select their objectives from the tree, based on their selection a subset of the general criteria tree will be suggested accordingly. For instance, if stakeholders select the specific objectives *to reduce energy demand, to reduce environmental impacts, to improve indoor conditions* and *to reduce renovation cost*, the suggested criteria tree will correspond to the tree presented in Figure 5 which can be also adjusted by the stakeholders as explain in the following section.

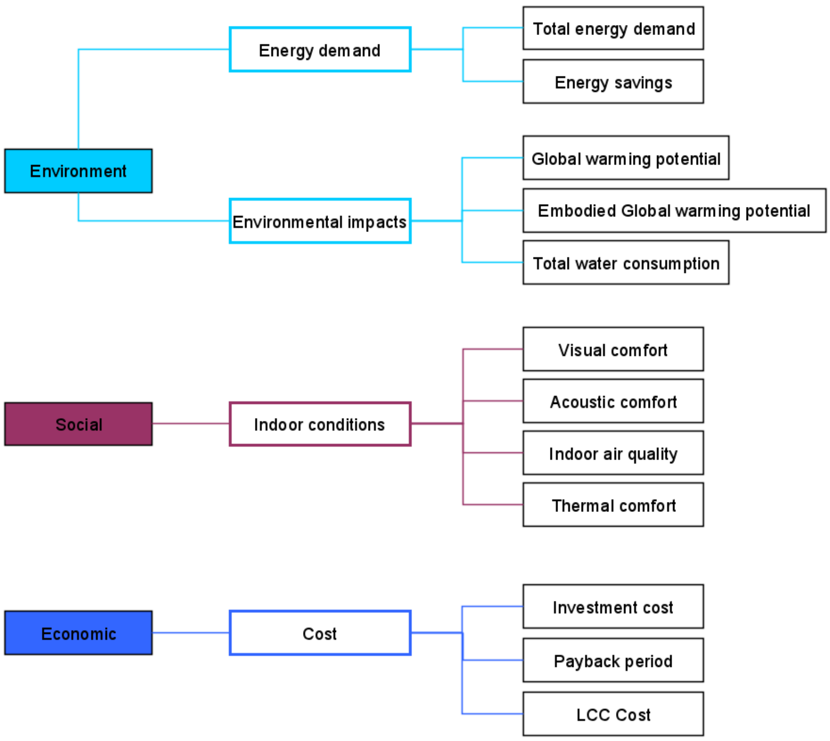


Figure 5. Criteria tree example

3.1.5 Criteria tree adjustment

In general, decision-making tools should be flexible with regard to choosing and weighting criteria, making the process more transparent for the involved stakeholders (Nielsen, et al., 2016). It is important to point out that even though in each case the suggested criteria tree aims at representing comprehensively the specific objectives selected by the stakeholders, yet each project has particular requirements. For this reason, stakeholders should be able to add or remove criteria regarding their particular preferences and the context of the renovation project. For instance, if the building is located in the periphery of the city, without main roads on its vicinity, stakeholders may consider that acoustic aspects are not relevant, so they can modify the suggested tree by removing the *Acoustic comfort index* from the social branch to adjust the tree as shown in Figure 6. Defining the criteria tree that will be used to evaluate the different alternatives is a key task of the decision-making process since all the following steps relied on these strategic aspects, multiple stakeholders should agree on the criteria that will be considered. This activity can be performed in a single meeting or a series of workshops including the main stakeholders, they should agree on which criteria are relevant for them according to their expectations, the goals being pursued as part of the renovation, the current state of the building, and the as-built, occupants, and environmental information available.

Figure 6. Social branch adjusted according to stakeholders' requirements

3.2 Criteria and preferences quantification

The second stage of the proposed framework is presented in Figure 7. After defining the criteria, some decision-making approaches such as the well-known Analytical Hierarchy Process (AHP) assign weights to capture the stakeholders' degree of importance for each criterion. The selection of the weighting method and the weights themselves have repercussions on the final rank of alternatives. There are multiple weighting methods such as Direct ranking, SMARTER, Entropy, and the Pairwise comparison that stems from the AHP. The latter has particular application in group decision making and is used in multiple disciplines such as government, business, industry, health care, and education (Majumder, 2015). Pairwise comparison is a well-developed method of ordering criteria. It was selected to be applied in the BIM-SPEED proposed framework because the method asks stakeholders to compare two criteria at one time, facilitating the analysis and encouraging stakeholders to give thorough consideration to all elements represented in the criteria tree. Moreover, with this method, it is possible to measure the consistency of the stakeholders' judgement, as explained further. Calculating weights with this method comprises three main steps (Zardari, et al., 2015), that are summarized in the following three sections.

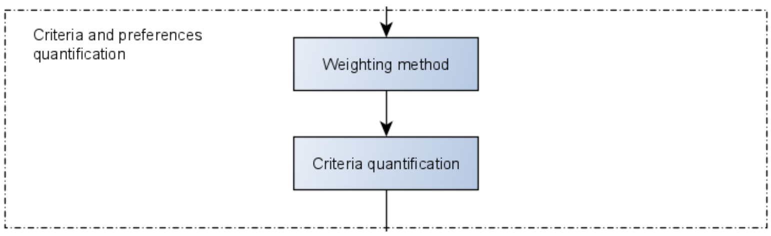


Figure 7. Decision-making stage 2, criteria and preferences quantification

3.2.1 Pairwise comparison

The first step is to develop a matrix comparing the criteria. The comparison can be made based on the 1-9 scale developed by (Saaty, 1990). The scale presented in Figure 8 will be used. When comparing two criteria, stakeholders can indicate their preference over the criteria or if both criteria are equally important for them.

$$M = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \begin{cases} 1/9 \leq \mathrm{a_{i,j}} \leq 9 \text{ if i} \sim \text{j} \\ \mathrm{a_{i,j}} = 1, \text{if i} = \text{j} \end{cases} \quad (1)$$

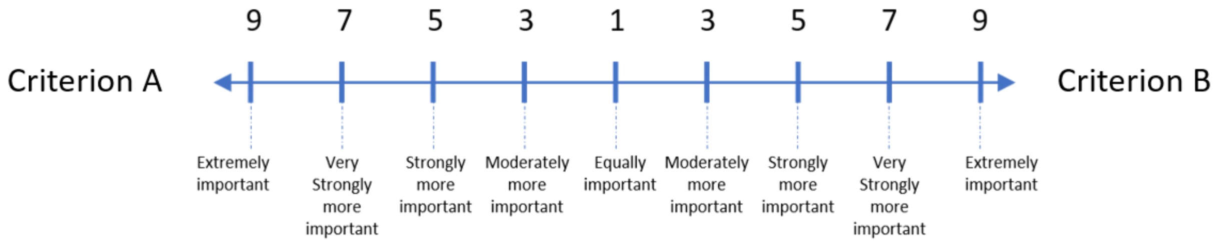


Figure 8. Comparison scale. (Adapted from (Si & Marjanovic-Halburd, 2018))

For instance, on the tree presented in Figure 9, each of the coloured squares represents one of the matrices that should be built in this particular case. When comparing the first two elements at the first level, if *Environment* aspects are moderately more important than *Social* aspects, $\mathbf{a_{ij}}$ received a value 3, while the reciprocal $\mathbf{a_{ji}}$ will be 1/3. The process goes on with the other possible comparisons *social-economic* and *economic-environment* to build up the first matrix (3x3 dimension). Once the comparisons at the first level are finished, the possible comparisons at the second level should be defined. Only the elements that are associated with the same root at the previous level are compared. For instance, the first two elements at the second level *Environmental impact* and *Energy demand* are compared together since they share the same root *Environment*. *Indoor conditions* is the only element associated to the *Social* branch, then any comparison is required. The same analysis can be performed for the last element *Cost*. At the third level, *Global warming potential* and *Total water consumption* are compared together. The second branch includes only one element *Energy savings,* which is not compared with any other criteria. In the third branch, the possible comparisons between *Visual comfort*, *Indoor air quality* and *Thermal comfort* are analysed. A similar approach is performed for the three criteria in the last branch, *Investment cost*, *Payback period,* and *LCC cost*. In a case with multiple stakeholders involved directly in the decision-making process, each group should perform the pair-wise comparisons individually to capture their preferences. The process to compute the criteria weights based on the pair-wise comparison matrices is explained in the following section.

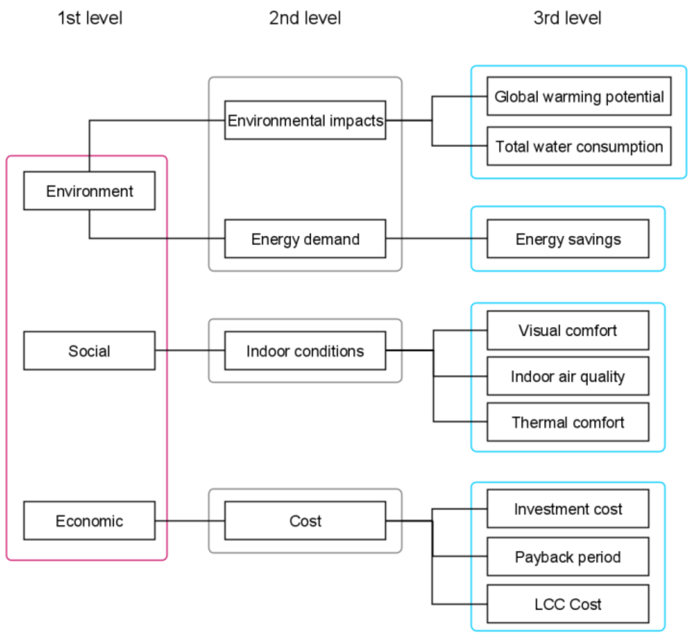


Figure 9. Example criteria tree for pairwise comparison

3.2.2 Computing the criterion weights

Once the matrices with the comparisons are completed for each level, the weights are calculated by summing the values in each column $\boldsymbol{i}$, dividing each element $\boldsymbol{a_{kj}}$ by the column total $\sum_{i=1}^{n} \boldsymbol{a_{ij}}$, and dividing the sum of the normalized scores for each row $\boldsymbol{j}$ by the number of criteria $\boldsymbol{n}$ in each matrix as follows:

$$\boldsymbol{w_k} = \frac{\boldsymbol{1}}{\boldsymbol{n}} \sum_{j=1}^{n} \frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} \quad for\ k = 1, 2, 3, \dots, n \quad \textbf{(2)}$$

Multiple stakeholders and consensus

In case multiple stakeholders take part directly on the decision-making process, it should be defined how they will participate, i.e. do they have the right to vote? Are they only informed? Do they participate as advisors? This will allow establishing the procedure to analyse the preferences of the diverse participants. In case different stakeholder groups have the right to vote (e.g. multiple owners), each group should perform the pair-wise comparisons individually as explained in the previous section and the corresponding sets of criteria weights for each stakeholder group are calculated according to Equation 2. Then, to integrate the preferences of the stakeholders and reach consensus between them, the average value of the weights of each criterion (obtained from each stakeholder group) is calculated.

Furthermore, in some specific cases, the main decision-maker would be interested in capturing the preferences of other stakeholders (e.g. tenants (without the right to vote) or a designer team (advising)) only to make better informed decisions. In these cases, the preferences of these additional stakeholders are captured through the pair-wise comparison as well and the criteria weights for each stakeholder group can also be computed. Nevertheless, these weights are calculated and display only to support the analysis of the main stakeholder, which make the final decision on its own. These weights are not integrated as explained for the previous case (with multiple stakeholders with the right to vote).

Once the criteria weights are obtained, the final aggregated weights of each criterion at the third level can be quantified as follows: the weights from the first level multiply the weights of the elements associated to them at the second level, then, the results multiply the weights of the associated criteria at the third level as presented in Figure 10.

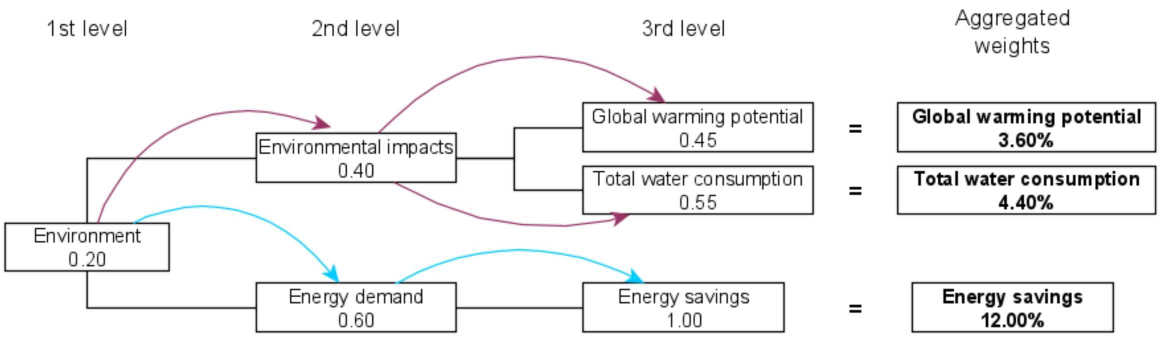


Figure 10. Aggregated criteria weights calculation

3.2.3 Checking the consistency:

The consistency ratio allows assessing the consistency of the judgement delivered by the stakeholders during the pair-wise comparison of the criteria. For instance, if a stakeholder informed that *Thermal comfort* is more important than *Visual comfort*, and *Visual comfort* is more important than *Acoustic comfort*, it is expected that the same stakeholder informed that *Thermal comfort* is more important than *Acoustic Comfort*. If the consistency ratio is less than 0.10, then the ratio indicates a reasonable level of consistency in the pairwise comparisons, If it is larger than 0.10, the values of the ratio are indicative of inconsistent judgments (Zardari, et al., 2015). This analysis should be performed for each matrix, and for each stakeholder group individually. The consistency ratio **CR** can be defined as:

$$CR = \frac{CI}{RI} \quad (3)$$

Where ***CI*** is the Consistency index and ***RI*** the Random index. The latter corresponds to the average consistency index of 500 reciprocal matrices filled with values from the fundamental scale of 1-9, which can be obtained automatically. Table 4 presents the RI for different cases according to the number of criteria included in a certain matrix.

Table 4. Random Index RI for different number of criteria

Number of criteria	RI
2	0
3	0.58
4	0.9
5	1.12

The consistency index can be then calculated as:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

Where λ_{max} corresponds to the maximum eigenvalue of each of the matrices resulting from the comparisons, which can be computed automatically as well.

Once the final aggregated weights are established, it is required to measure the performance of each alternative per criteria. For some of the proposed criteria, quantification methods were already defined in deliverable D4.1 of BIM-SPEED. For the additional criteria introduced in Section 3.1, possible quantification methods are proposed in Appendix A.

3.3 Decision Analysis

After capturing the preferences of the stakeholders through the criteria and their weights, it is necessary to evaluate the renovation alternatives according to those preferences. To this end, the last stage of the framework focuses on the decision analysis as presented in Figure 11. At this stage, the performance of each alternative per criteria is integrated with the weights established in the previous step to obtain a global performance score for each alternative. This score allows ranking the alternatives to facilitate the final decision-making process. There are multiple approaches to conduct this integration, methods such as a simple additive aggregation, AHP, Promethee, and TOPSIS are used in different areas.

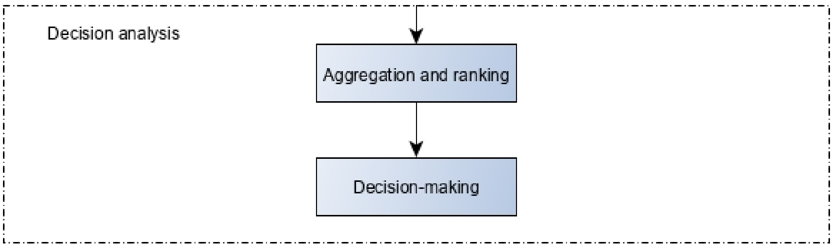


Figure 11. Third stage, decision analysis.

Particularly, TOPSIS is an approach to identify an alternative which is closest to the ideal solution and farthest to the negative ideal solution in a multi-dimensional space (Qin, et al., 2008). Its simplicity and its ability to maintain the same number of steps regardless of problem size may be an advantage to encourage transparency in the decision-making process and facilitate the engagement of some of the stakeholders that do not have a scientific or technical background. The method intends to measure the distance of each alternative from an ideal best possible solution and a negative-ideal solution as shown in the two-dimension example in Figure 12.

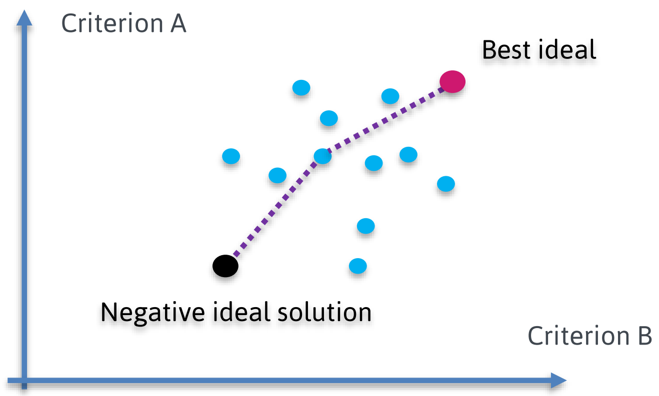


Figure 12. TOPSIS method representation

Consider the following decision matrix where each row represents one of the ***m*** alternatives that are evaluated in terms of the ***n*** selected criteria (the attributes at the third level of the tree):

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (5)$$

TOPSIS evaluates this decision matrix through the following steps (Triantaphyllou, 2000):

- **1. Construct the Normilized Matrix**: The method first converts the various criteria dimensions into non-dimensional criteria. An element $\boldsymbol{r_{ij}}$ of the normalized matrix **R** can be calculated as follows:

  $$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}} \quad (6)$$

  Where x_{ij} correspond to the elements of the matrix **D** introduced above, and ***m*** is the number of alternatives.

- **2. Construct the Weighted Normilized Matrix:** The set of weights W=(w_1, w_2, … w_n) obtained in the second stage (see Section 213.2.2) of the general framework is used to generate the weighted matrix **V** as follows:

  $$V = \begin{bmatrix} w_1 r_{11} & \cdots & w_n r_{1n} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & \cdots & w_n r_{mn} \end{bmatrix} \quad (7)$$

- **3. Determine the Ideal and Negative-Ideal solutions:** These two alternatives are fictitious. The ideal solution A* indicates the most preferable alternative, which gathers the best performance of all the criteria. The non-ideal solution A^- indicates the least preferable alternative or the negative-ideal solution, which gathers the worst performance across all the criteria.

  $$A^* = \{v_{1*}, v_{2*}, \dots, v_{n*}\} \quad (8)$$

  $$A^- = \{v_{1-}, v_{2-}, \dots, v_{n-}\} \quad (9)$$

- **4. Calculate the separation measure:** The distances from the ideal solution can be calculated as follows:

$$S_{i*} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{i*})^2} \; for\ i = 1,2,3,\ldots,m \quad (10)$$

Similarly, for the distances from the negative-ideal solution we have:

$$S_{i-} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_{i-})^2} \; for\ i = 1,2,3,\ldots,m \quad (11)$$

- **5. Calculate the relative closeness to the ideal solution:** The relative closeness of each alternative A_i with respect to the ideal solution A^* is defined as:

$$\boldsymbol{C_{i*}} = \frac{\boldsymbol{S_{i-}}}{\boldsymbol{S_{i*}+S_{i-}}} \quad (12)$$

Where $0 \leq C_{i^*} \leq 1$. Apparently, $C_{i^*}= 1$, if $A_i = A^*$, and $C_{i^*}= 0$, if $A_i = A^-$.

- **6. Rank the preference order:** The alternatives can be ranked based on the value of ***C***, the first positions will be occupied for the alternative that have the shortest distance to the ideal solution.

When the final ranking is obtained, decision-makers will have a better overview of a set of suitable options for the renovation project and will be able to analyse them, look for trade-off and select the final strategy that fits the project requirements and attempt to fulfil the preferences of multiple stakeholders.

4. BIM-SPEED Decision-making tool

4.1 Implementation

The decision-making framework presented above was implemented in an Excel spreadsheet, which facilitates the characterization of each renovation project, the pairwise comparison of the criteria, the criteria weighting estimation, and the final ranking calculation. This tool is available on the DepositOnce TU Berlin repository[2] and can be downloaded by interested readers and potential users. The tool is intuitive, well-documented, and can be used independently. In the context of the BIM-SPEED project, this Excel tool will be integrated to a dashboard linked to the tool that will be developed as part of D4.5: *BIM-based procedures and tool for holistic performance assessment of renovation design options* that will enable the integration and visualization of the results obtained from the diverse tools available on the BIM-SPEED platform, and the input of criteria results in the case stakeholders use other external tools to quantify the criteria.

Figure 13 presents the general workflow for the implementation of the BIM-SPEED decision-making tool in a renovation project. When an external user performs the decision-making process independently, using only the excel tool, the workflow follows the six steps shown in the figure. The core of the decision-making process, including steps 1, 3, 4 and 6 is assisted by the Excel BIM-SPEED decision-making tool. The renovation alternatives are designed externally in step 2, while criteria should be quantified by the stakeholders in step 5. When the decision-making process is conducted in the context of BIM-SPEED, steps 2 and 5 can be assisted for some of the BIM-SPEED tools as presented in Figure 13. Even though

[2] http://dx.doi.org/10.14279/depositonce-10659

most of the criteria related to the performance of the building can be calculated in an automated way through the tools developed in BIM-SPEED work package 4, some of the additional proposed criteria such as Aesthetics, Renovation time, and Rent increment should be estimated and defined by the stakeholders involved in the renovation project. Suggested methods are presented in Appendix A. When the tool is used in the context of BIM-SPEED, the workflow is equivalent to the procedure described by steps 1 to 6, but information exchanges occur between the Excel tool and the dashboard linked to the tool developed in D4.5, which allows managing and visualizing the information in a more user-friendly approach. The data exchanged between the Excel tool and the dashboard includes the criteria tree, the alternatives description, the final aggregated criteria weights, and the TOPSIS ranking results. Moreover, the dashboard also gathers the criteria quantification results from the different tools linked to the BIM-SPEED platform and allow stakeholders to enter manually other criteria results (e.g. in the case of Aesthetics, Renovation time). Each step is presented in more detail in the following section.

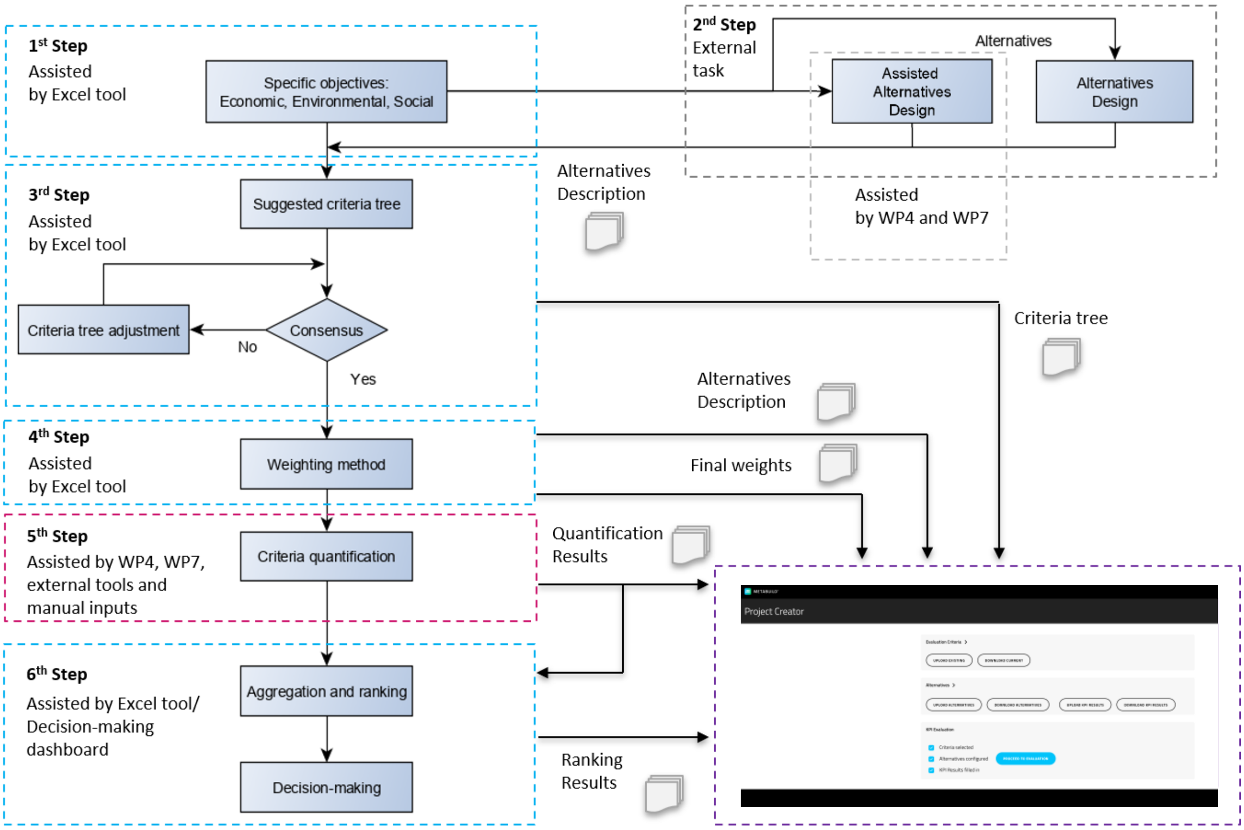


Figure 13. BIM-SPEED decision-making tool implementation

4.2 Decision-making tool and illustrative example

In order to exemplify the functionality and some of the features of the BIM-SPEED decision-making tool, the workflow for a brief fictional case is presented. The presented workflow corresponds to the case when an external user implements the tool on its project individually, using only the Excel tool. Nevertheless, some of the general features of the dashboard liked to D4.5 - *BIM-based procedures and tool for holistic performance assessment of renovation design options* are also briefly introduced.

More detailed real implementation cases will be reported as part of the results of BIM-SPEED work package 8, where the tool will be implemented in selected BIM-SPEED demonstration projects.

Figure 14 presents an overview of the steps of the decision-making process and the tabs included in the decision-making tool supporting them. Each of the steps and tabs included on the tool are described in detail below. A short supporting video regarding the use of the decision-making tool is also available on the BIM-SPEED you tube channel[3].

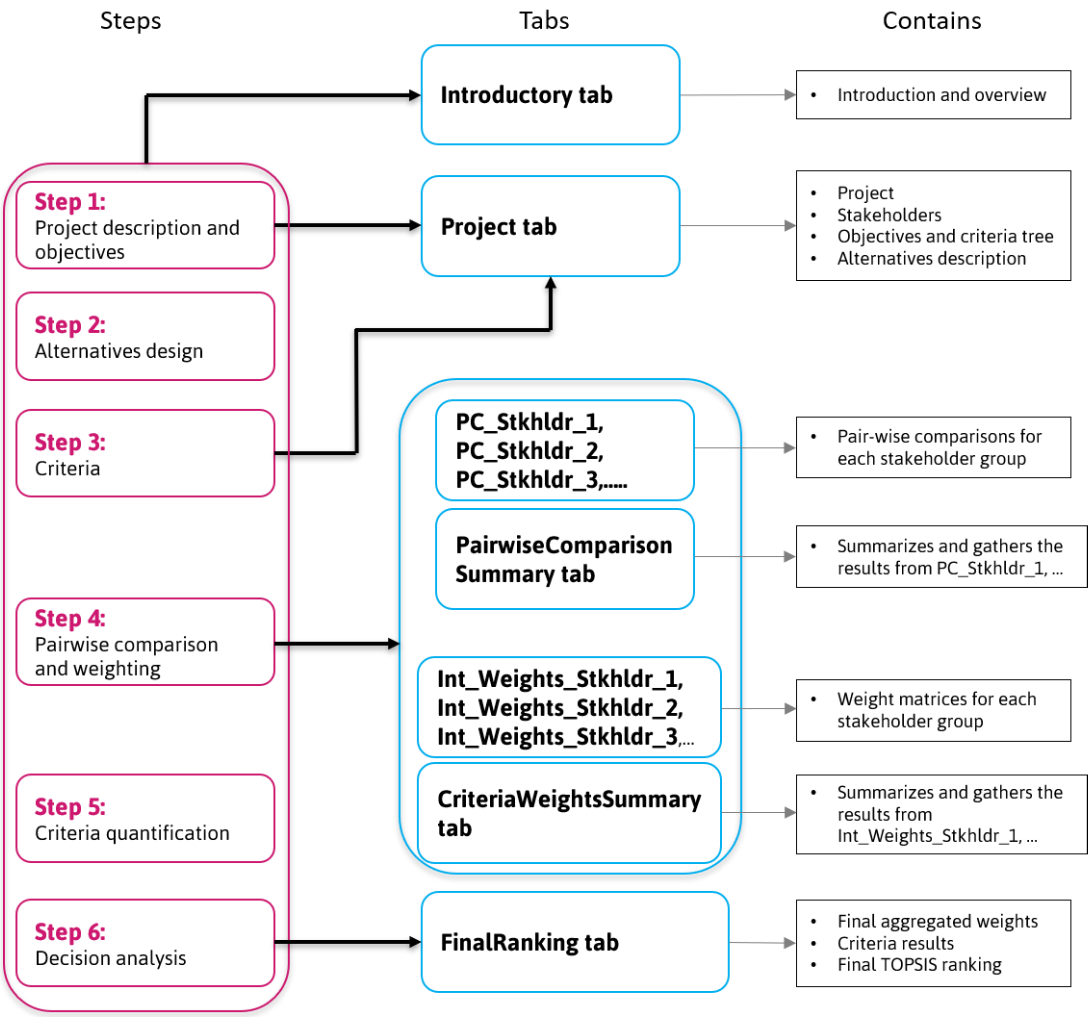


Figure 14. Decision-making steps and tool overview

The ***Introduction tab*** shown in Figure 15 outlines the steps and guides the users through the tabs that support the different tasks and calculations during the decision-making process.

[3] https://www.youtube.com/watch?v=vIVi9PGANb8&feature=youtu.be

Figure 15. Decision-making tool, introductory tab

Step 1: Project description and objectives

The ***Project tab*** of the decision-making tool requests the stakeholders to prepare a brief description of the renovation project as presented in Figure 16. Users should enter general information regarding the project such as location, type of dwelling unit, type of owner, and other features. A dedicated table on the right-up section of the tab gathers the information regarding the different stakeholder groups as well. This table allows identifying the main stakeholders involved directly in the decision-making process and establishing their rights on the final decision. The entire criteria pool is also presented as can be seen on the bottom-left corner of the tab. There, stakeholders can pick up the objectives that are relevant to them. To define these objectives, stakeholders should get a complete comprehension of the current status of the building, the main challenges that they intend to address through the renovation project, restrictions around the project, the expectations from the different stakeholder groups, and additional aspects such as budget ranges, time and constructive limitations, and others.

In the illustrative example presented in Figure 16, there are three groups of stakeholders: Owner, tenants in the form of tenant's association, and the architect hired by the owner to perform the renovation design. Only the Owner can vote to make the final decision. The tenants are only informed, and the designer is included as an advisor in the process. The stakeholders discarded two of the proposed objectives: *To reduce environmental impacts* and *To Increase financial benefits*. Since these objectives are discarded, the criteria associated with them are deactivated from the options to facilitate the understating and interpretation of the criteria tree as shown in Figure 17.

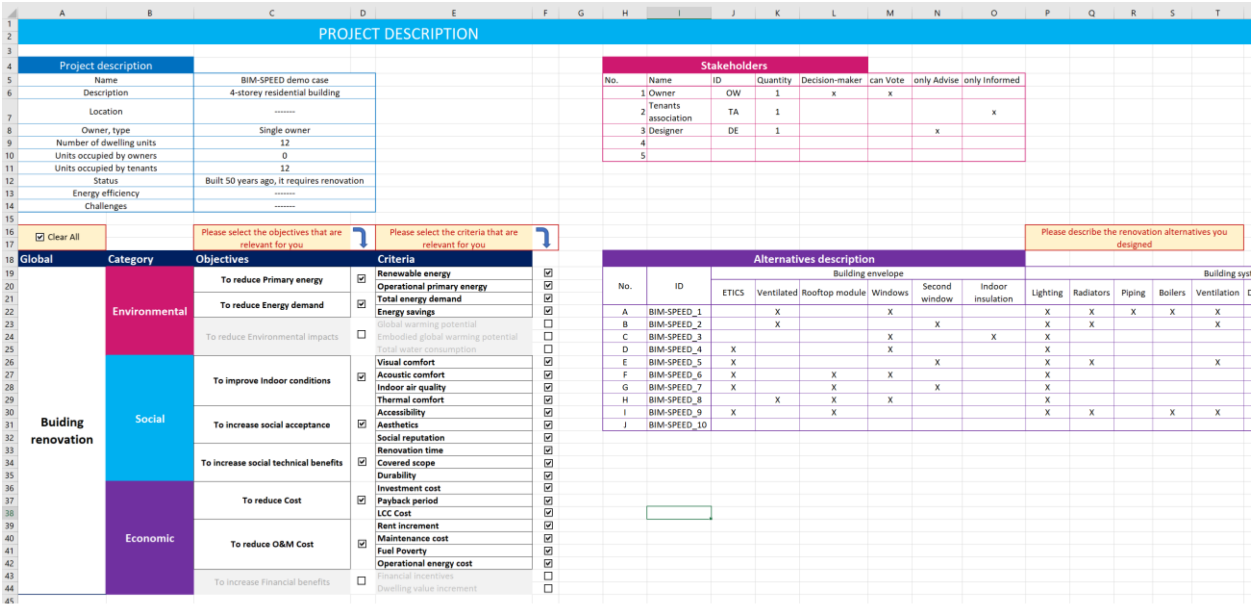


Figure 16. Decision-making tool, Project tab

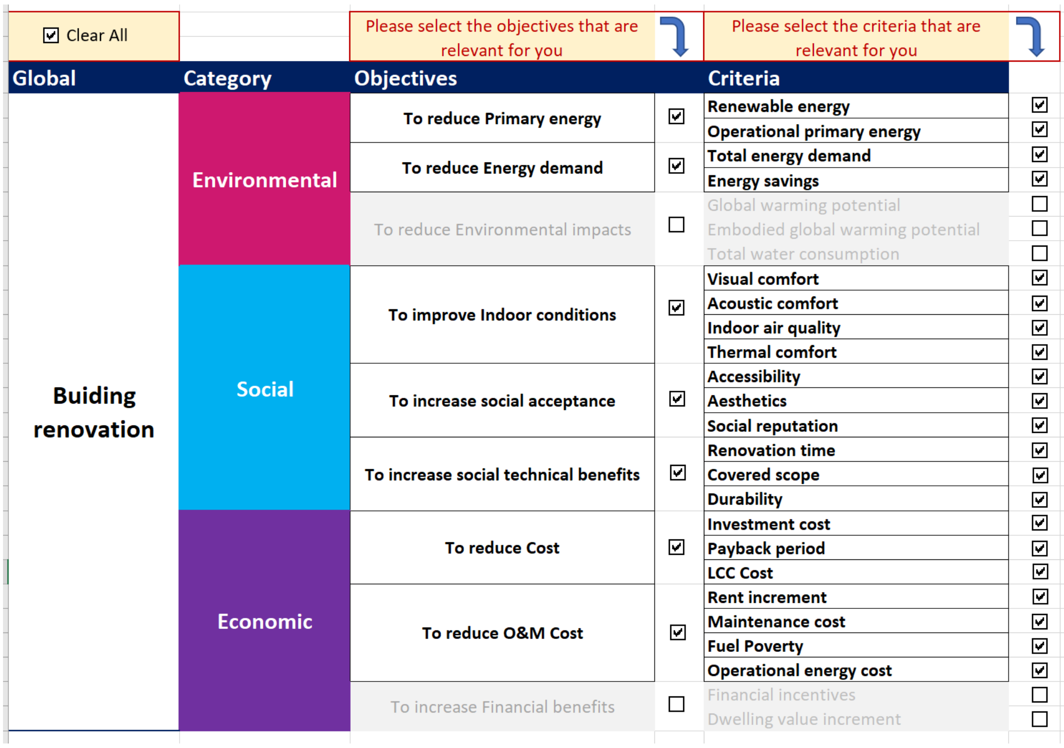


Figure 17. Project tab, objectives selection

Step 2: Alternatives design

As mentioned previously, the renovation alternatives should be designed externally. The design can be performed with a conventional approach or, in the context of BIM-SPEED, assisted by the tools developed in BIM-SPEED D7.2: *Machine-learning for As-Built diagnostics and enrichment of design rules for deep renovation*, D7.3: *Semantic design rules and tool for deep renovation design*, D4.2: *Real demonstration results of BEM performance simulation using BIM-SPEED Toolset* and D4.5: *BIM-based procedures and tool for holistic performance assessment of renovation design options*.

Once the designers identify and define the set of relevant renovation alternatives they intend to evaluate as part of the decision-making process, users should describe them according to the dedicated section on the right-bottom of ***Project tab***, as presented in Figure 18.

Please describe the renovation alternatives you designed

Alternatives description																	
		Building envelope						Building systems									
No.	ID	ETICS	Ventilated	Rooftop module	Windows	Second window	Indoor insulation	Lighting	Radiators	Piping	Boilers	Ventilation	District heating	PV	Thermal solar	Rainwater	Balconies
A	BIM-SPEED_1		X		X			X	X	X	X	X					
B	BIM-SPEED_2		X			X		X	X			X	X				
C	BIM-SPEED_3				X		X	X									
D	BIM-SPEED_4	X			X			X									
E	BIM-SPEED_5	X				X		X	X			X	X				
F	BIM-SPEED_6	X		X	X			X									
G	BIM-SPEED_7	X		X		X		X					X				
H	BIM-SPEED_8		X	X	X			X					X				
I	BIM-SPEED_9	X		X				X	X		X	X					
J	BIM-SPEED_10																

Figure 18. Project tab, alternatives description

Step 3: Criteria

The last task to be performed in ***Project tab*** is the adjustment of the criteria tree according to the requirements of the stakeholders. The participants should discuss the tree suggested by the tool and identify which criteria are completely relevant to them. The criteria tree is adjusted according to the expectations of the stakeholders, the information available from the as-built situation, and other aspects. This activity can be performed in a single meeting or a series of workshops according to the complexity of the renovation and the interests of the stakeholders involved. In the illustrative example, the owner may prefer doing this by itself or including the designer to orientate the process. The tenants may also be included since they can provide relevant information regarding the current status and operational problems of the building. For the illustrative example in Figure 19, the stakeholders adjusted the criteria tree by removing the criterion *Renewable energy* from the suggested tree since no renewable systems will be considered during the renovation. Other criteria such as *Acoustic comfort*, *Accessibility*, *Renovation time*, *Payback period*, *LCC cost*, and *Financial incentives* were also removed from the proposed tree.

☑ Clear All

Please select the objectives that are relevant for you

Please select the criteria that are relevant for you

Global	Category	Objectives		Criteria	
Buiding renovation	Environmental	To reduce Primary energy	☑	Renewable energy	☐
				Operational primary energy	☑
		To reduce Energy demand	☑	Total energy demand	☑
				Energy savings	☐
		To reduce Environmental impacts	☐	Global warming potential	☐
				Embodied global warming potential	☐
				Total water consumption	☐
	Social	To improve Indoor conditions	☑	Visual comfort	☑
				Acoustic comfort	☐
				Indoor air quality	☑
				Thermal comfort	☑
		To increase social acceptance	☑	Accessibility	☐
				Aesthetics	☑
				Social reputation	☑
		To increase social technical benefits	☑	Renovation time	☐
				Covered scope	☑
				Durability	☑
	Economic	To reduce Cost	☑	Investment cost	☑
				Payback period	☐
				LCC Cost	☐
		To reduce O&M Cost	☑	Rent increment	☑
				Maintenance cost	☑
				Fuel Poverty	☐
				Operational energy cost	☑
		To increase Financial benefits	☐	Financial incentives	☐
				Dwelling value increment	☐

Figure 19. Project tab, criteria tree adjustment

Step 4: Pairwise comparison and weighting

Once the general information regarding the project, alternatives, objectives is collected, and the criteria tree is defined, the pairwise comparison can be performed. Multiple tabs ***PC_Stkhldr_1***, ***PC_Stkhldr_2***, ***PC_Stkhldr_3***, etc. facilitate the participation of all the stakeholder groups, allowing each of them to enter individually its preferences regarding the criteria through the slide bars linking each pair of elements as shown in Figure 20. The filter on the upper-left corner of the tab is applied and only the required comparisons are presented. In the illustrative case, the criteria tree defined by the stakeholders is large, and they should perform sixteen comparisons in total (see Figure 20). The owner can enter its preferences on the ***PC_Stkhldr_1 tab***. Depending on the owner requirements, he/she could be interested in capturing also the preferences of the designer and tenants, even they do not vote on the final decision, their perspective may give the owner relevant information. In case the owner decides to request the input from the two additional stakeholders, they can do it on the respective tabs ***PC_Stkhldr_2*** and ***PC_Stkhldr_3***.

PAIRWISE COMPARISON STAKEHOLDER 1: Owner

Please use the filter to adjust the comparisons tha should be performed

Please compare each paior of criteria according to the scale

Extremely important	Very strongly more important	Strongly more important	Moderately more important	Equally important	Moderately more important	Strongly more important	Very strongly more important	Extremely important
9	7	5	3	1	3	5	7	9

Row	Level		Criterion		Criterion	Comparison by stakeholders, 1-9 AHP scale (used for calculations): Owner
8	1st level	TRUE	Environmental	< >	Social	1/3
9		TRUE	Social	< >	Economic	1/5
10		TRUE	Economic	< >	Environmental	7
14	2nd level	TRUE	To reduce Primary energy	< >	To reduce Energy demand	5
20		TRUE	To improve Indoor conditions	< >	To increase social acceptance	7
21		TRUE	To increase social acceptance	< >	To increase social technical benefits	1
22		TRUE	To increase social technical benefits	< >	To improve Indoor conditions	1/5
26		TRUE	To reduce Cost	< >	To reduce O&M Cost	1/5
30	3rd level	TRUE	Operational primary energy	----No comparison required----		
32		TRUE	Total energy demand	----No comparison required----		
47		TRUE	Indoor air quality	< >	Thermal comfort	1/3
48		TRUE	Thermal comfort	< >	Visual comfort	5
49		TRUE	Visual comfort	< >	Indoor air quality	1/3
55		TRUE	Aesthetics	< >	Social reputation	5
61		TRUE	Covered scope	< >	Durability	3
63		TRUE	Investment cost	----No comparison required----		
73		TRUE	Rent increment	< >	Maintenance cost	1/5
76		TRUE	Operational energy cost	< >	Rent increment	3
78		TRUE	Maintenance cost	< >	Operational energy cost	3

Figure 20. Decision-making tool, PC_Stkhldr_1 tab

PAIRWISE COMPARISON SUMMARY

Please use the filter to adjust the comparisons tha should be performed

Please ask the stakeholders to fill in the sheets PC_Stakhldr_1, PC_Stakhldr_2,...according to their preferences

Row	Level		Comparison to be performed			Owner	Tenants ass	Designer	0	0
8	1st level	TRUE	Environmental	vs	Social	1/3	1/3	1/3		
9		TRUE	Social	vs	Economic	1/5	1/5	1/5		
10		TRUE	Economic	vs	Environmental	7	7	7		
14	2nd level	TRUE	To reduce Primary energy	vs	To reduce Energy demand	5	9	5		
20		TRUE	To improve Indoor conditions	vs	To increase social acceptance	7	7	7		
21		TRUE	To increase social acceptance	vs	To increase social technical benefits	1	1	1		
22		TRUE	To increase social technical benefits	vs	To improve Indoor conditions	1/5	1/5	1/5		
26		TRUE	To reduce Cost	vs	To reduce O&M Cost	1/3	1/3	1/3		
30	3rd level	TRUE	Operational primary energy	----No comparison required----						
32		TRUE	Total energy demand	----No comparison required----						
47		TRUE	Indoor air quality	vs	Thermal comfort	1/3	3	3		
48		TRUE	Thermal comfort	vs	Visual comfort	5	1/9	1/9		
49		TRUE	Visual comfort	vs	Indoor air quality	1/3	7	7		
55		TRUE	Aesthetics	vs	Social reputation	5	3	3		
61		TRUE	Covered scope	vs	Durability	3	3	3		
63		TRUE	Investment cost	----No comparison required----						
73		TRUE	Rent increment	vs	Maintenance cost	1/5	1/7	1/7		
76		TRUE	Operational energy cost	vs	Rent increment	3	3	3		
78		TRUE	Maintenance cost	vs	Operational energy cost	3	5	5		

Figure 21. Decision-making tool, Pairwise Comparison Summary tab

The preferences collected on tabs ***PC_Stkhldr_1***, ***PC_Stkhldr_2***, ***PC_Stkhldr_3***, etc. are gathered and summarized in the ***PairwiseComparisonSummary tab*** as shown in Figure 21. The results are used to build the weight matrices as explained in Section 3.2.2. Tabs ***Int_Weights_Stkhldr_1***, ***Int_Weights_Stkhldr_2***, ***Int_Weights_Stkhldr_3***, etc. are included on the tool to quantify the criteria weights according to the preferences of each stakeholder group as shown in Figure 22. The weights matrices are automatically adjusted on the respective tabs. As can be noticed from the matrix in the centre of Figure 22, for the illustrative example, the objective *To reduce environmental impacts* is not considered during the calculations since it was removed from the criteria tree in the first step. The consistency of the comparisons can be checked on the upper-right corner of each matrix, the consistency is only checked when the matrix contains more than 2 attributes since a 2x2 matrix implies only one comparison which cannot be inconsistent.

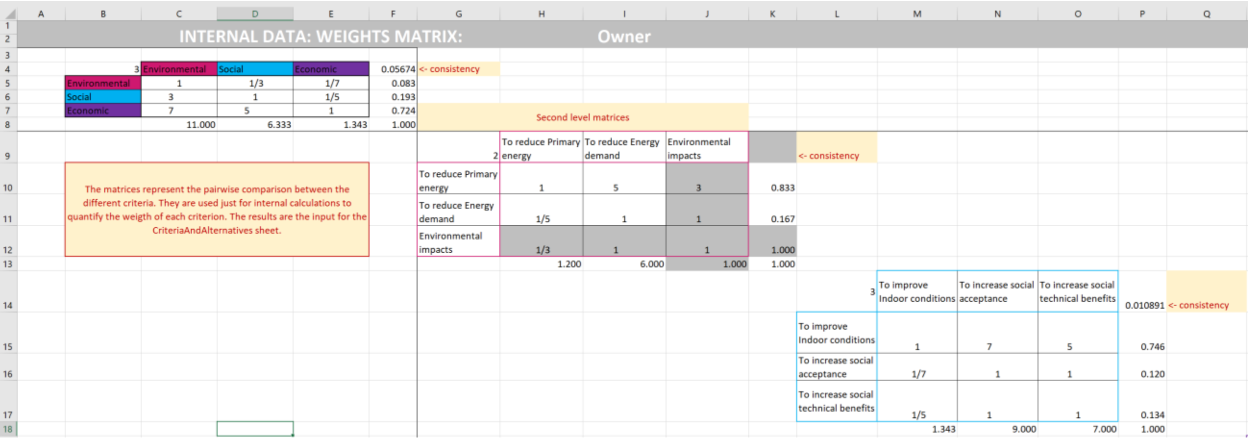


Figure 22. Decision-making tool, Int_Weights_Stkhldr_1 tab

The results are gathered together in the ***CriteriaWeightsSummary tab*** as presented in Figure 23. There, the main stakeholders can check the weights obtained for the diverse stakeholder groups (in case they were asked to perform the comparisons). When diverse stakeholders are involved in the process, and multiple of them have the right to vote on the final decision, the mean value of the weights of each criterion obtained for each stakeholder group is calculated to establish the final weight that is assigned to the criterion as explained in Section 3.2.2. In the illustrative example, the owner (main stakeholder) collected also the preferences from the Tenants and Designer, therefore their results are also shown on the table in Figure 23. Nevertheless, it is important to notice that in this case only the owner has the right to vote, consequently, the results from the other stakeholder groups are merely informative, and they are not integrated to compute the final weights. The final aggregated weights of each criterion at the third level are quantified by multiplying the weights from the first level with the weights of the elements associated to them at the second level and the weights of the associated criteria at the third level as explained in Section 3.2.2.

INTERNAL DATA: WEIGHTS FOR EACH STAKEHOLDER GROUP

		Level weights / STAKEHOLDERS: Owner	tenants	Designer	0	0
	Right to vote -->	TRUE	FALSE	FALSE	FALSE	FALSE
Buiding renovation	Environmental	0.083	0.083	0.083		
	Social	0.193	0.193	0.193		
	Economic	0.724	0.724	0.724		

	Level weights / STAKEHOLDERS: Owner	tenants	Designer	0	0
Right to vote -->	TRUE	FALSE	FALSE	FALSE	FALSE
To reduce Primary energy	0.833	0.900	0.833		
To reduce Energy demand	0.167	0.100	0.167		
To improve Indoor conditions	0.746	0.746	0.746		
To increase social acceptance	0.120	0.120	0.120		
To increase social technical benefits	0.134	0.134	0.134		
To reduce Cost	0.167	0.250	0.250		
To reduce O&M Cost	0.833	0.750	0.750		

Please use the filter to see only the criteria tree that applies to your project

	Level weights / STAKEHOLDERS: Owner	tenants	Designer	0	0	
Right to vote -->	TRUE	FALSE	FALSE	FALSE	FALSE	
Operational primary energy	1.000	1.000	1.000			TRUE
Total energy demand	1.000	1.000	1.000			TRUE
Visual comfort	0.106	0.777	0.777			TRUE
Indoor air quality	0.260	0.155	0.155			TRUE
Thermal comfort	0.633	0.069	0.069			TRUE
Aesthetics	0.833	0.750	0.750			TRUE
Social reputation	0.167	0.250	0.250			TRUE
Covered scope	0.750	0.750	0.750			TRUE
Durability	0.250	0.250	0.250			TRUE
Investment cost	1.000	1.000	1.000			TRUE
Rent increment	0.106	0.083	0.083			TRUE
Maintenance cost	0.633	0.724	0.724			TRUE
Operational energy cost	0.260	0.193	0.193			TRUE

Figure 23. Decision-making tool, CriteriaWeightsSummary tab

Step 5: Criteria quantification

After calculating the criteria weights in step 4, the performance of the alternatives on the multiple criteria should be quantified. In case an external user implements the tool on its project individually (i.e. using only the Excel tool), the stakeholders should quantify the performance of the different alternatives based on their own approaches/tools or following one of the methods suggested in Appendix A of this report. Once the quantification of the criteria has been conducted, the results should be entered on the ***FinalRanking tab.*** This input is introduced easily in the form of a single table as shown in Figure 24. The values entered for this illustrative example are only a representation. The alternative J corresponds to the non-renovation scenario, where any renovation measure is implemented. This alternative performs the worst in most of the criteria, except on criteria such as Investment cost or Rent increment.

N AND RANKING

Please use the filter to see only the criteria tree that applies to your project

Please fill in the table with the performance of each alternative according to each criterion.

	3rd Level weights		Aggregated weights	Mode	Ideal and ideal-negative solutions: Best	Worst	No. / ID	A B-S_1	B B-S_2	C B-S_3	D B-S_4	E B-S_5	F B-S_6	G B-S_7	H B-S_8	I B-S_9	J B-S_10
Operational primary energy	1.000	TRUE	6.94%	Minimising	78.000	130.000		100	85	95	106	78	90	93	102	109	130
Total energy demand	1.000	TRUE	1.39%	Minimising	68.000	115.000		75	68	77	92	70	78	80	89	88	115
Visual comfort	0.106	TRUE	1.53%	Maximising	4.400	2.000		4.2	4	3.8	4.2	4	4.4	3.6	3.6	4	2
Indoor air quality	0.260	TRUE	3.75%	Maximising	4.800	1.000		4.8	4	4.5	4.1	4.2	3.9	4	4.4	4	1
Thermal comfort	0.633	TRUE	9.12%	Maximising	4.800	1.000		4.8	4.1	4.3	4	4	3.9	4	3.9	4.5	1
Aesthetics	0.833	TRUE	1.93%	Maximising	4.800	0.000		4.8	4	4	4.2	4	4.4	4.4	3.8	4	0
Social reputation	0.167	TRUE	0.39%	Maximising	4.500	0.000		4.5	4.2	4.2	4	3.9	4	4.2	4	4.1	0
Covered scope	0.750	TRUE	1.95%	Maximising	4.200	0.000		4.2	3.8	3.6	3.9	4	4	3.6	3.5	3.9	0
Durability	0.250	TRUE	0.65%	Maximising	15.000	0.000		15	12	11	10	11	9	13	12	12	0
Investment cost	1.000	TRUE	12.06%	Minimising	0.000	1.300		1.3	1.1	0.98	0.99	1.1	0.97	0.98	0.97	0.96	0
Rent increment	0.106	TRUE	6.40%	Minimising	0.000	8.900		8.9	8.5	8.1	8.2	8.5	8	8.1	8	8	0
Maintenance cost	0.633	TRUE	38.20%	Minimising	6000.000	9000.000		6000	6500	6800	6200	7000	6500	6300	6100	6100	9000
Operational energy cost	0.260	TRUE	15.71%	Minimising	2600.000	4800.000		2600	2750	2700	2800	2650	2940	2650	2980	2780	4800
		Total	100%														

Figure 24. Decision-making tool, FinalRanking tab, Alternatives performance according to each criterion

In case the decision-making tool is used in the context of the BIM-SPEED platform, the criteria tree, alternatives description, and weights are exported to the decision-making dashboard linked to D4.5 - *BIM-based procedures and tool for holistic performance assessment of renovation design options* as presented in Figure 25. The different tabs on the dashboard allow visualizing general information, criteria and alternatives description as shown in Figure 26, Figure 27, and Figure 28. The dashboard offers an interface to the BIM-SPEED platform where multiple tools can be used to calculate the criteria. These tools include D4.2: *Real demonstration results of BEM performance simulation using BIM-SPEED Toolset*, where the different renovation scenarios are simulated based on the BEM model of the building, D4.3: *Practical framework for BIM-based acoustic, thermal comfort, and indoor air quality assessment in renovation projects* and D7.4: *Life-Cycle Cost and asset management tool* which calculate criteria such as Indoor air quality and LCC cost (if they were included in the criteria tree defined by the stakeholders). The results of simulations and automated calculations are then imported from the BIM-SPEED platform into the decision-making dashboard. The results for other criteria should be entered manually by the stakeholders through the decision-making dashboard. All the results of the criteria are then imported into the Excel tool, which performs the step 6 of the decision-making process as explained in the following section.

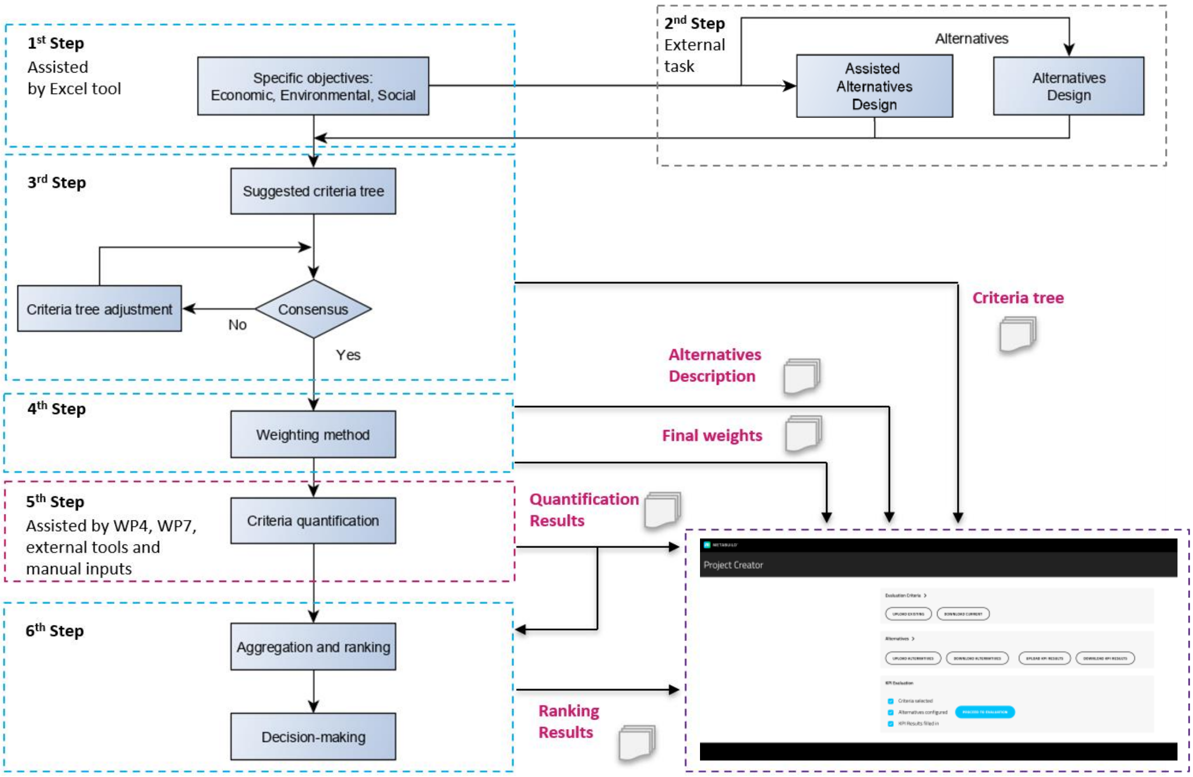


Figure 25. Information exportation to BIM-SPEED decision-making dashboard

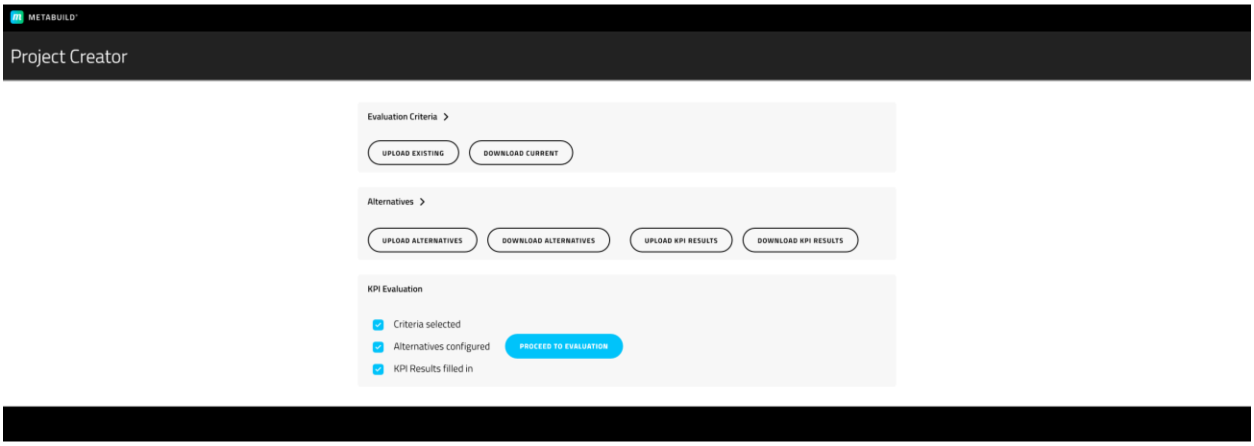


Figure 26. Decision-making dashboard, general tab

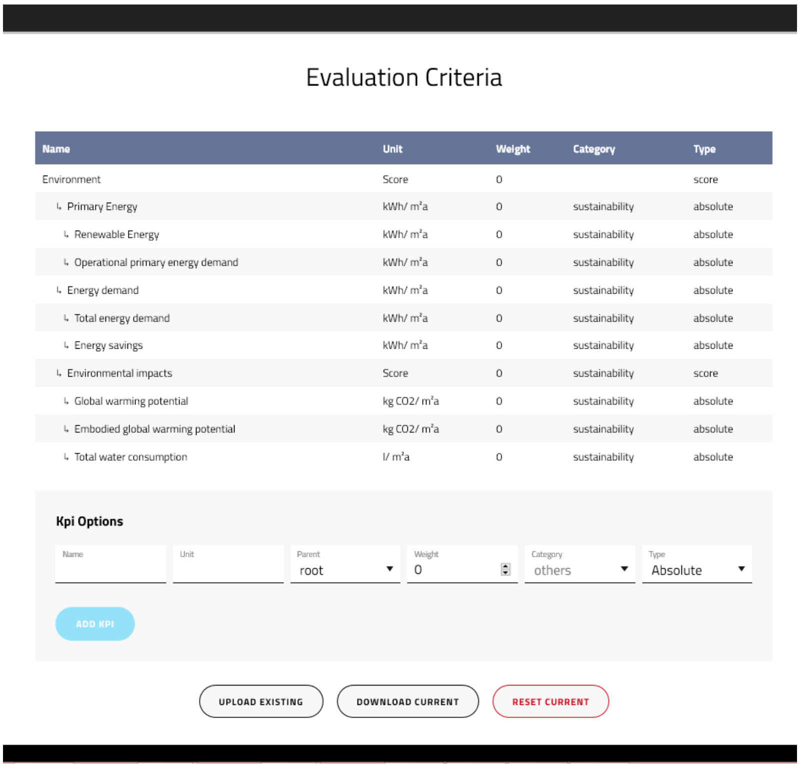


Figure 27. Decision-making dashboard, criteria tab

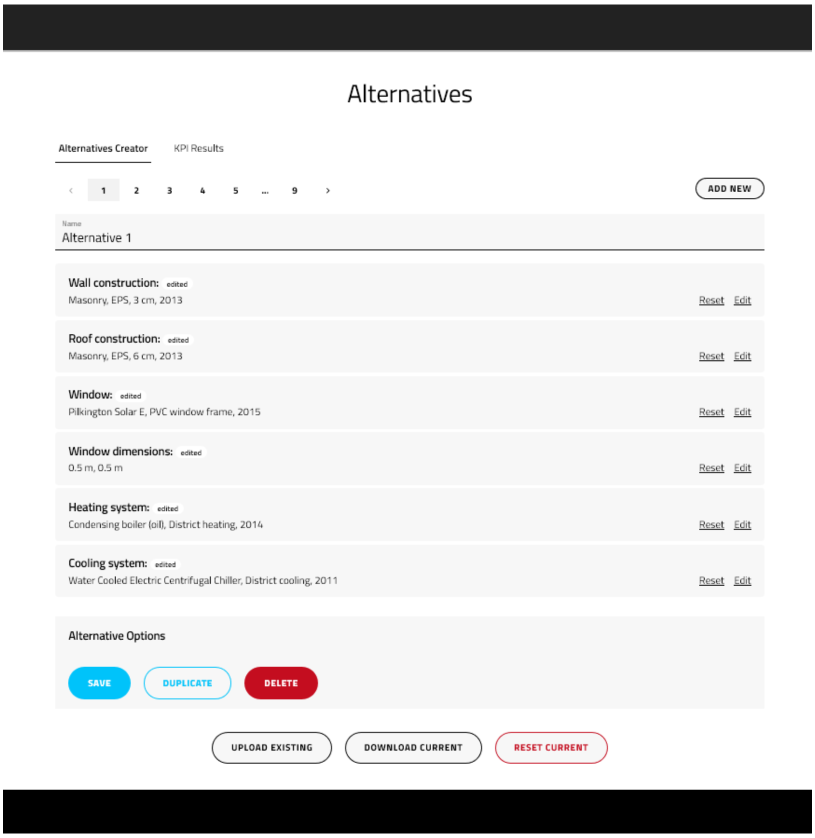


Figure 28. Decision-making dashboard, alternatives tab

Step 6: Decision analysis

At the final stage, step 6 is performed. Based on the results obtained on step 5, the normalized matrix is built as described in Section 3.3 and the TOPSIS method is applied in the ***FinalRanking tab*** in Figure 29.

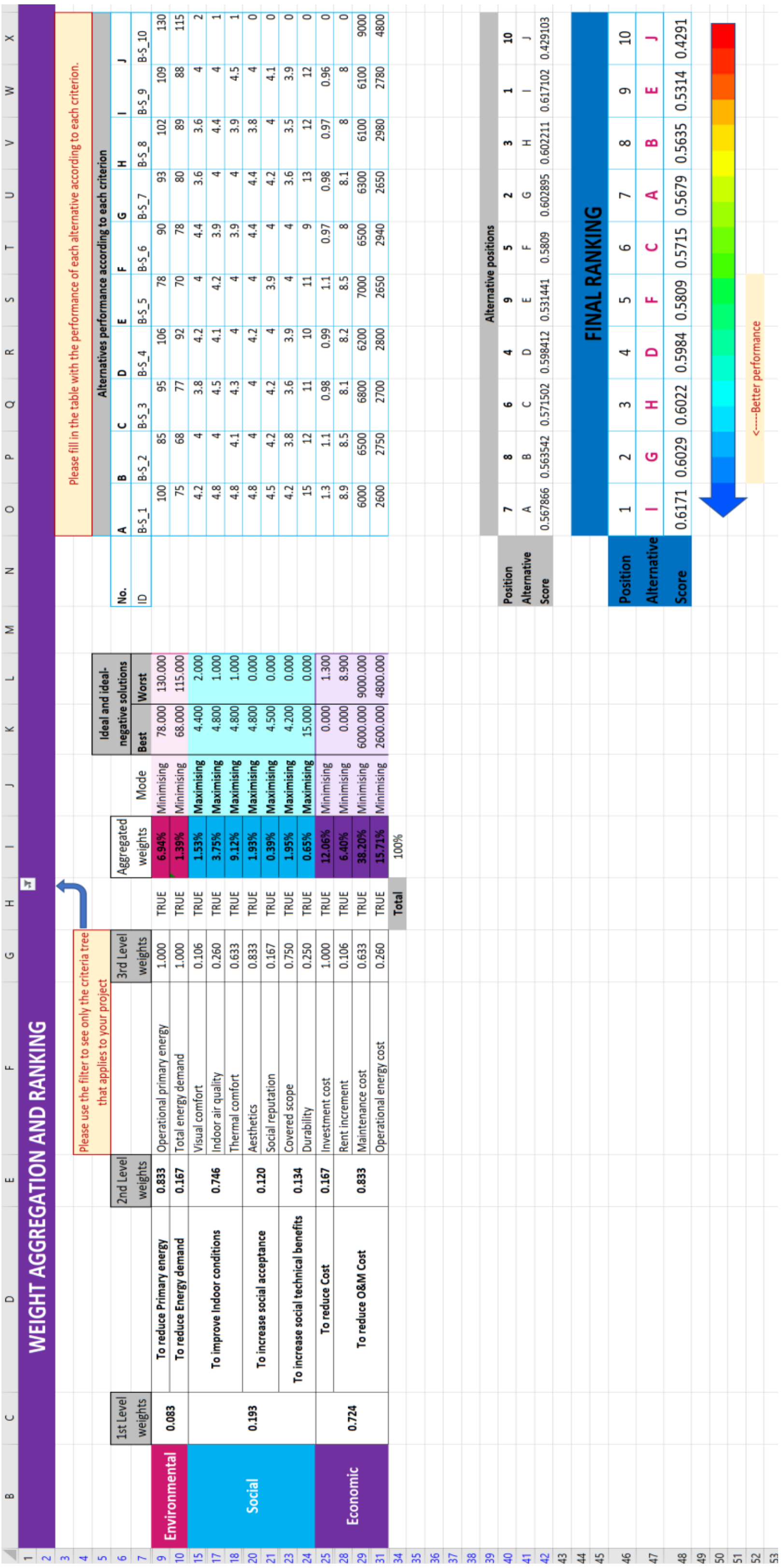


Figure 29. Decision-making tool, FinalRanking tab

The ***FinalRanking tab*** summarizes the criteria weights obtained in step 4 for each of the criterion, in conjunction with the desired behaviour for each attribute. For instance, criteria such as *Operational primary energy*, *Total energy demand*, and *Investment cost* should be minimised, while *Thermal comfort* and *Aesthetics* should be maximise as shown in Figure 30. The best ideal and ideal negative solutions according to the TOPSIS method definition are also presented. This additional information allows the stakeholders to have a better understanding of the alternatives and the criteria being evaluated.

WEIGHT AGGREGATION AND RANKING

Please use the filter to see only the criteria tree that applies to your project

	1st Level weights		2nd Level weights		3rd Level weights		Aggregated weights	Mode	Ideal and ideal-negative solutions: Best	Worst
Environmental	**0.083**	**To reduce Primary energy**	**0.833**	Operational primary energy	1.000	TRUE	**6.94%**	Minimising	78.000	130.000
		To reduce Energy demand	**0.167**	Total energy demand	1.000	TRUE	**1.39%**	Minimising	68.000	115.000
Social	**0.193**	**To improve Indoor conditions**	**0.746**	Visual comfort	0.106	TRUE	**1.53%**	**Maximising**	4.400	2.000
				Indoor air quality	0.260	TRUE	**3.75%**	**Maximising**	4.800	1.000
				Thermal comfort	0.633	TRUE	**9.12%**	**Maximising**	4.800	1.000
		To increase social acceptance	**0.120**	Aesthetics	0.833	TRUE	**1.93%**	**Maximising**	4.800	0.000
				Social reputation	0.167	TRUE	**0.39%**	**Maximising**	4.500	0.000
		To increase social technical benefits	**0.134**	Covered scope	0.750	TRUE	**1.95%**	**Maximising**	4.200	0.000
				Durability	0.250	TRUE	**0.65%**	**Maximising**	15.000	0.000
Economic	**0.724**	**To reduce Cost**	**0.167**	Investment cost	1.000	TRUE	**12.06%**	Minimising	0.000	1.300
		To reduce O&M Cost	**0.833**	Rent increment	0.106	TRUE	**6.40%**	Minimising	0.000	8.900
				Maintenance cost	0.633	TRUE	**38.20%**	Minimising	6000.000	9000.000
				Operational energy cost	0.260	TRUE	**15.71%**	Minimising	2600.000	4800.000
						Total	100%			

Figure 30. Final aggregated criteria weights

The final ranking is generated automatically on this tab as shown in Figure 31. The alternatives located more on the left side of the ranking perform better according the preferences of the stakeholders. The stakeholders can focus their attention on certain alternatives and analyse possible trade-off between the criteria, and potential consequences resulting from selecting a specific renovation alternative. For the illustrative example, the alternative located in the position 10 corresponds to the non-renovation scenario, where any renovation measure is implemented.

	Alternative positions									
Position	**7**	**8**	**6**	**4**	**9**	**5**	**2**	**3**	**1**	**10**
Alternative	A	B	C	D	E	F	G	H	I	J
Score	0.567866	0.563542	0.571502	0.598412	0.531441	0.5809	0.602895	0.602211	0.617102	0.429103

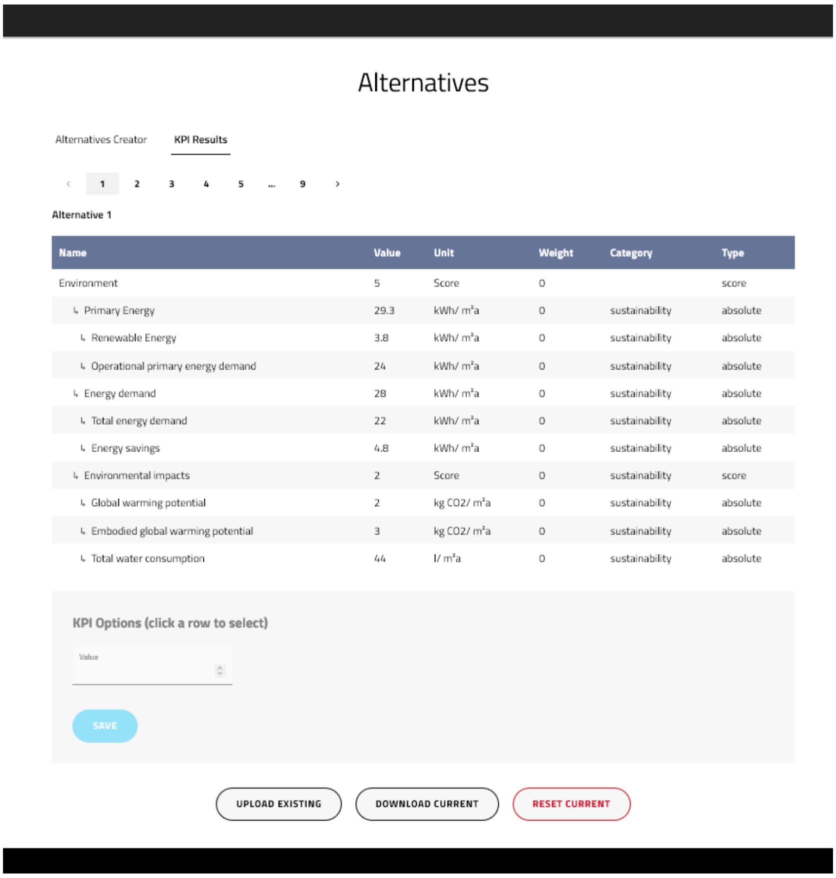
FINAL RANKING

Position	1	2	3	4	5	6	7	8	9	10
Alternative	I	G	H	D	F	C	A	B	E	J
Score	0.6171	0.6029	0.6022	0.5984	0.5809	0.5715	0.5679	0.5635	0.5314	0.4291

<-----Better performance

Figure 31. Final alternatives ranking

In case the decision-making tool is used in the context of the BIM-SPEED platform, the results are exported to the decision-making dashboard and presented as depicted in Figure 33, Figure 32, and Figure 34. The decision-making dashboard allows the stakeholders to visualize the results associated with each of the alternatives, the final weights assigned to each criterion, some trade-off between criteria and the final ranking. The dashboard enables to present the information in a more transparent way and to analyse the best alternatives according to the criteria stakeholders defined as relevant for their renovation project.



Name	Value	Unit	Weight	Category	Type
Environment	5	Score	0		score
↳ Primary Energy	29.3	kWh/ m²a	0	sustainability	absolute
↳ Renewable Energy	3.8	kWh/ m²a	0	sustainability	absolute
↳ Operational primary energy demand	24	kWh/ m²a	0	sustainability	absolute
↳ Energy demand	28	kWh/ m²a	0	sustainability	absolute
↳ Total energy demand	22	kWh/ m²a	0	sustainability	absolute
↳ Energy savings	4.8	kWh/ m²a	0	sustainability	absolute
↳ Environmental impacts	2	Score	0	sustainability	score
↳ Global warming potential	2	kg CO2/ m²a	0	sustainability	absolute
↳ Embodied global warming potential	3	kg CO2/ m²a	0	sustainability	absolute
↳ Total water consumption	44	l/ m²a	0	sustainability	absolute

Figure 33. Decision-making dashboard, individual results

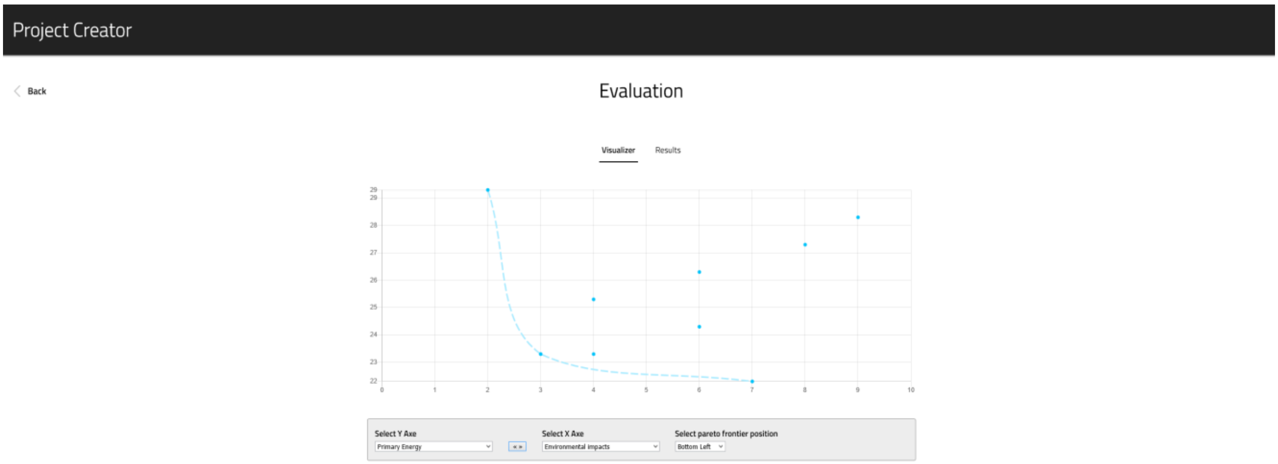


Figure 32. Decision-making dashboard, pareto fronts

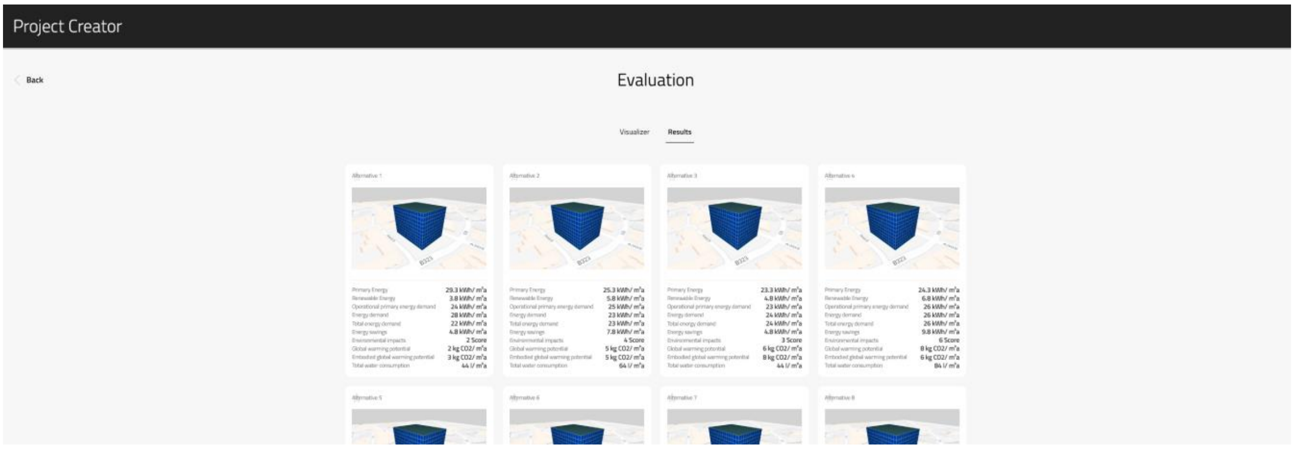


Figure 34. Decision-making dashboard, general results

5. Implementation on the BIM-SPEED demonstration projects

The multi-criteria decision-making tool introduced in this report will be implemented to support the selection of the final renovation solution in selected BIM-SPEED demonstration sites. Table 5 presents the characterization of the thirteen total demonstration sites. As can be noticed, renovation projects may represent multiple scenarios as mentioned in Section 2. Some of the dwelling units are occupied only by owners, only by tenants, or a combination of them as in the case in Victoria-Gasteiz, in Spain. In most of the cases, the decision is made only by the owner, while tenants are only informed. The owner corresponds to a social housing association in most of the cases. Some of the demonstration projects intend to involve additional stakeholders such as architects or designers to support the decision-making process. The renovation alternatives focus on building envelopes and HVAC systems in most of the cases. At the time this report is delivered, most of the projects are developing their BIM and BEM models, which will allow moving on with the design stage and define detailed renovation alternatives that will be evaluated.

Table 5. BIM-SPEED demo sites characterization

Demo site	Type of owner	Inhabitants	Units	Decision-maker	Additional stakeholders involved	Renovation alternatives focus on:
Victoria-Gasteiz, Spain	12 private owners	Owners and tenants	12	Only owners	Designers (Advise). Tenants (Only voice)	Building envelopes, windows, slabs, terraces, HVAC system

Berlin, Germany (Lichtenrade)	Single owner, Social housing	Tenants	53	Only owner	Planning team (advise). Tenants (Informed)	Building envelopes and HVAC system
Tempelhof, Berlin, Germany	Single owner, Social housing	--------	-----	Only owner	--------	Repurpose of the building and energetical modernization
Warmond, the Netherlands	Single owner, Social housing	Tenants	60	Only owner	Tenants (Only voice)	Building envelopes and HVAC system
Antony, France	Single owner, Social housing	Tenants	158	Only owner	Tenants association (Only voice)	Glazing, outdoor walls, and HVAC system
Massy, France	Single owner, Social housing	Tenants	101	Only owner	Tenants association (Only voice)	Glazing, outdoor walls, and HVAC system
Warsaw II, Poland	Single owner, public	--------	-----	Only owner	--------	Repurpose of an underground passage
Barland, Romania	20 private owners	Owners	20	Design company, Municipality	--------	Building envelopes
Frigento, Italy	2 private owners	Owners	2	Only owners	--------	Interior layout optimization, windows, HVAC systems
Malko Tarnovo, Bulgaria	Single owner, Social housing	Temporal guests	21	Only owner	--------	Building envelopes
Varna, Bulgaria	Single private owner	Owner	1	Only owner	--------	Interior layout optimization, windows, HVAC systems
Warsaw I, Poland	Single owner, Social housing	--------	-----	--------	--------	Building envelopes and HVAC system
Gdynia, Poland	Single private owner	Owner	1	Only owner	Architect (Advise)	Building envelopes and HVAC system

6. Conclusion

This report introduced the BIM-SPEED Decision-making tool, comprising a list of objectives, a comprehensive criteria pool, a weighting approach, and a ranking method. The tool can be used individually by external users or in the context of the BIM-SPEED project in conjunction with a decision-making dashboard and additional tools developed within the project. The developed tool is flexible and allows the stakeholders involved in renovation projects to define specific objectives and adjust the criteria according to the specific conditions of the unit under renovation and its context. The objectives and criteria included in the tool are relevant for renovation projects with different requirements and different stakeholders involved. It also enables the active participation of the main stakeholders of the project by capturing their preferences individually. The pairwise comparison method used to capture the preferences of the stakeholders allows participants to focus on specific attributes at a time, making easier the analysis. The TOPSIS method used to rank the alternatives is very simple and allows the stakeholders to understand the way the alternatives are compared. The tool can support multiple stakeholders in the building renovation field to implement a more structured strategy to evaluate multiple renovation alternatives and reach consensus between the different parties involved in the decision-making process.

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Appendix A - Criteria calculation methods

A1. Criteria description

As mentioned in the main document, the criteria tree is composed by the KPIs developed in the BIM-SPEED deliverable D4.1 - *Baseline and Use Cases for BIM-based renovation projects and KPIs for EEB renovation*, and the criteria described in this Appendix. Table 6 summarized the categories, objectives, and additional proposed criteria. The suggested quantification methods are presented in the following sub-sections.

Table 6. Criteria tree and responsible partners

Category	Objective	ID/[Unit]	Criteria	Contributor
Environmental	To reduce Primary energy	BS.REP [kWh/year]	Renewable energy production	TUB
	To reduce Environmental impacts	BS.EGWP [$kgCO_{2eq}/m^2$]	Embodied global warming potential	TUB
		BS.TWC [m^3/year]	Total water consumption	ARC
Social	To increase social acceptance	BS.AES [-]	Aesthetics	TUB
		BS.SR [-]	Social reputation	TUB
		BS.ACC [months]	Accessibility	TUB
	To increase social technical benefits	BS.CSCP [%]	Covered scope	VIS
		BS.RT [months]	Renovation time	TUB
		BS.DRT [Years]	Durability	VIS
Economic	To reduce Cost	BS.IC [€]	Investment cost	ARC/LKS
	To reduce O&M Cost	BS.RI [%]	Rent increment	TUB
		BS.MC [€]	Maintenance cost	FAS
	To increase Financial benefits	BS.FI [€]	Financial incentives	MOW/VIS
		BS.DVI [%]	Dwelling value increment	FAS

A1.1 Environmental

A1.1.1 Renewable energy production

ID: BS.REP [kWh/year]

RESPONSIBLE PARTNER: TUB

TYPE: Quantitative

DEFINITION: It corresponds to the energy produce in-situ by renewable systems. It is considered only If a renewable energy system is installed as part of the renovation project. Particularly, the criteria description focuses on PV energy production. However, other renewable sources can also be considered, especially in hybrid systems such as PV-Wind arrangements.

OBJECTIVE: Even the use of renewable systems at the residential level has increased during the last decade, there are still existing buildings that do not exploit the potential renewable sources in-situ, the execution of renovation activities may create the right scenario to facilitate the integration of new renewable systems in the building. Therefore, the goal of this criterion is to promote the installation of renewable energy systems in-situ.

ASSESSMENT CRITERION: The renewable energy production in-situ is calculated in [kWh/year], it depends on the local weather conditions, renewable potential available at the building location and the size of the renewable system consider in the renovation alternatives.

Data required: The data required to calculate the PV energy production for one year is summarized in Table 7.

Table 7. Data requirements for PV energy production estimation

Input	Unit/Format
Weather Data File including Irradiance data	.epw, .fwt
Coordinates of the PV system, Lat/Lon	Degrees, minutes, seconds
Total system area	m^2
PV module efficiency	-
DC/CA conversion efficiency	-

Calculation method: One of the simplified methods available on Energyplus software to estimate the PV energy production can be described as:

$$E_{PV} = \eta_{cell}\eta_{inverter}\ x\ A_T\ x\ f_{act} \sum G_T\ x\ \Delta t$$

Where:

E_{PV}, total energy production from the PV array [kWh/year]

A_T, total system area [m2]

f_{act}, fraction of surface area with active solar cells [-]

G_T, Total solar irradiance incident on PV array [W/m2]

η_{cell}, PV module conversion efficiency [-]

$\eta_{inverter}$, DC to AC conversion efficiency [-]

Δt, time step of the data [h]

The summation is performed along one year, using historical data for the total solar irradiance. This is a general simplified method, there are other approaches based on the average solar hours associated to the region, and more elaborated methods based on software tools such as HOMER, PVSyst, Energyplus (detailed models) or the PVGIS tool[4] developed by the Joint Research Centre (JRC) science and knowledge service. The detailed models used by these tools consider the effects of temperature, diffuse radiation, panels inclination/orientation, azimuth and other aspects.

BENCHMARKS: Figure 35 shows the total PV capacity that could be installed on roofs in each country in the NUTS region. As can be seen, there are a large potential to installed new PV systems in the rooftop area in many regions in Europe, this integration could be made during the renovation.

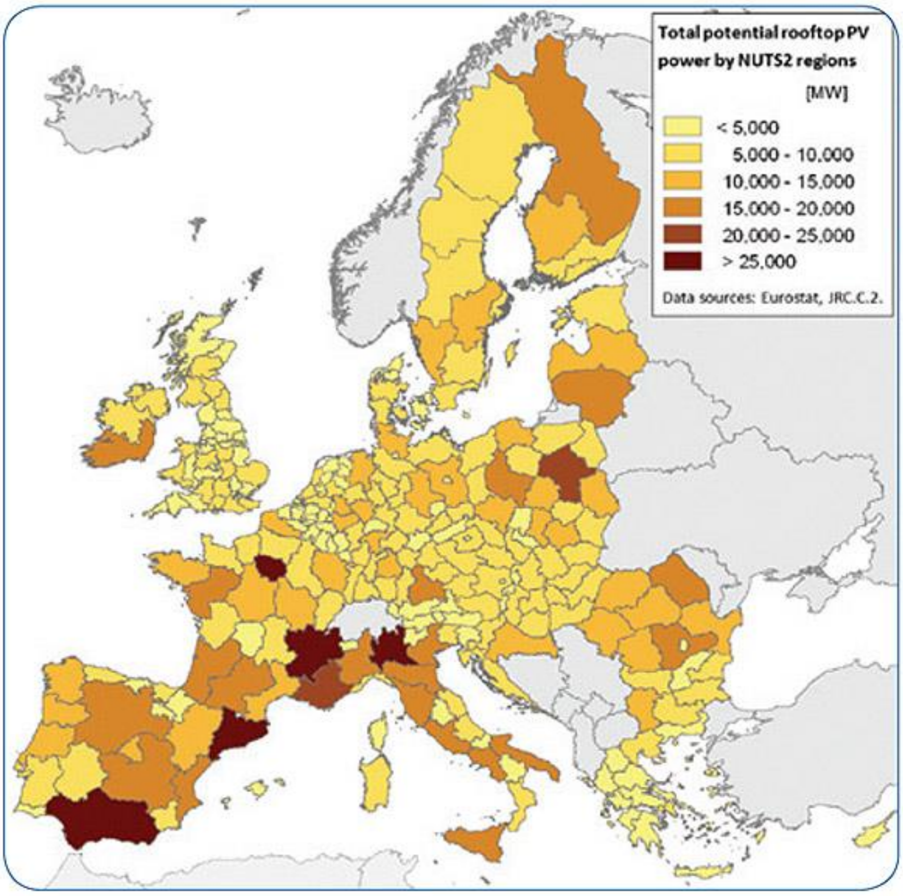

Figure 35. Potential PV capacity per NUTS2 region [2]

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[2]. Huld Th, Bodis K, Pinedo Pascua I, Dunlop E, Taylor N, Jäger-Waldau A, "The Rooftop Potential for PV Systems in the European Union to deliver the Paris Agreement", European Energy Innovation, Spring 2018, pp. 12-15

[4] https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

A1.1.2 Embodied global warming potential

ID: BS.EGWP [$kgCO_{2eq}/m^2$]

RESPONSIBLE PARTNER: TUB

TYPE: Quantitative

DEFINITION: It comprises the cumulated CO_2 emissions for the cradle-to-gate processes in the production stages A1-A3 of a Life Cycle Assessment of building components for the thermal envelope and building integrated technical systems. Thus, this criterion quantifies the environmental impacts of the added components and technical systems used during the renovation. This criterion complements the KPI *BS.GWP Global warming potential* developed in *Deliverable 4.1*, which comprise the CO_2 emissions due to the operational energy use of the building. According to the examples presented in the technical report *Model for Life Cycle Assessment (LCA) of buildings* from the Joint Research Centre (JRC) [1], A1-A3 modules may be often the second major contributor of environmental impacts after the Operational energy use in the Module B6.

OBJECTIVE: This criterion aims at promoting the selection of more sustainable and environmentally friendly renovation components to reduce the environmental impacts caused by the renovation of the building.

ASSESSMENT CRITERION: Global Warming Potential is expressed in CO_2 emissions (or equivalent) in kg per unit floor area of the building, it is based on Environmental Product Declarations - EPD.

Data required: The data required to estimate the embodied global warming potential can be obtained from a database or EPDs. Common databases comprise Ecoinvent, ELCD, GaBi, (LCI) Database, ÖKOBAUDAT, Athena and ESUCO. It is necessary to check the consistency, geographical coverage and validate period for the data, especially for the individual EPDs.

Calculation method: it is necessary to consider new products that will be installed as part of the renovation project to aggregate. The general methodology for carrying out an LCA describes four main phases: Goal and Scope definition, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Assessment (LCIA), Interpretation. Here the scope is the A1-A3 modules.

The LCI analysis phase consists of the compilation and quantification of inputs (e.g. raw materials, water and energy flows) and outputs (e.g. co-products, waste emissions to air, water and soil) for a product throughout its life cycle, in this case, the A1-A3 models. The LCI comprise a) gathering of information about the resources consumed and the emissions released, these are typically quantified through data collection sheets; b) identification of sources of information for quantifying the associated elementary flows, typically quantified with the support of LCA databases; c) documentation of all data collected per life cycle stage [2].

The LCIA phase evaluates the magnitude of the Global warming potential. Inputs and outputs quantified in the LCI are assigned to the GWP category, then the GPW is calculated by applying characterization factors. For further guidance on each step in this process, it is recommended to consult the EN 15978 and ISO 14040/44 standards and guidelines such as EeB and Annex 56.

BENCHMARKS: While the average share of embodied greenhouse gas emissions from buildings following current energy performance regulations is approximately 20–25% of life cycle GHG emissions, this figure escalates to 45–50% for highly energy-efficient buildings and surpasses 90% in extreme cases [3]. In some countries, there are initial standards that identify benchmarks for embodied and operational GHG emissions such as Swiss SIA [4]. The SIA 2040 provides benchmarks for buildings based on the 2000 Watt society[5] concept. The benchmark provides a lifecycle-based target value for buildings, including embodied impacts. These benchmarks were established following a top-down approach based on a global greenhouse gas budget, which was transferred to a budget per capita. According to the Swiss 2000 Watt society principles, and according to the German Environment Agency, reaching a goal of reducing GHG emissions to 1 t CO2eq per capita and year by the year 2050 puts us on track to achieve climate neutrality [4]. The benchmark establishes 9 kgCO2/m^{2}a as the embodied emissions target.

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A1.1.3 Total water consumption

ID: BS.TWS [m^3/occ.year]

RESPONSIBLE PARTNER: ARC

TYPE: Quantitative

DEFINITION: It estimates the water consumption of sanitary fittings/devices and relevant water-consuming appliances. It is considered only If water appliances are modified during the renovation. No water usage for irrigation or cleaning is considered.

OBJECTIVE: The target of this criterion is to promote renovation alternatives that reduce the water consumption of the building and check also the compliance of certain minimum water efficiency requirements imposed by planning authorities at local, regional or national levels.

ASSESSMENT CRITERION: The BS.TWS criterion is calculated considering the data for the number of occupants, usage of the building, consumption rates, number and types of sanitary fittings or water-consuming devices.

Data required: The data required is summarized on Table 8.

[5] https://www.2000watt.swiss/english.html

Table 8. Data input required for BS.TWS criterion calculation

Input	Unit/format
Specific water consumption values of devices and fittings	[liter/min]
Specific water consumption values for appliances (i.e. dishwashers and washing machines)	[liter/year], [cycles/occupant.d]
Usage factor	[min/occupant.d], [flushes/occupant.d] for toilets
Occupancy rate	[d/year]

Calculation method: The calculation method includes all the appliances and water consumption devices from a residential building.

$$BS.TWS\ [m3/occ.year]\ =\ Occ.Cons.[l/occ.d]\ x\ 0{,}001\ [m3/l] x\ Rate\ [d/year]\ x\ NO\ [occupants]$$

Where:

Occ. Cons: water consumption for an occupant considering taps, showers, toilets, water devices. Is calculated with the following formula:

$$Occ.cons\left[\frac{l}{occ.d}\right] = \sum(T+S) + \sum TO + \sum WD$$

T – consumption for taps [l/occ.d] = Consumption Rate [l/min] x usage factor [min/occ.d]

S – consumption for showers [l/occ.d] = Consumption Rate [l/min] x usage factor [min/occ.d]

TO – consumption for toilets [l/occ.d] = Consumption Rate [l/flush] x usage factor [flushes/occ.d]

WD – consumption for water devices [l/occ.d] = Consumption Rate [l/cycle] x usage factor [cycle/occ.d]

Rate: occupancy rate, how many days a year the buildings is occupied. [d/year]

NO: number of occupants [occupants]

BENCHMARKS: This criterion is proposed in the Level(s) – A common EU framework of core sustainability indicators for office and residential buildings, which was an important reference for the development of KPIs in WP4. Please check the *use stage water consumption indicator* in the following documents:

REFERENCES:

[1]. Dodd, N., Cordella, M., Traverso, M. & Donatello, S., 2017. *Level(s) – A common EU framework of core sustainability indicators for office and residential buildings*, s.l.: European Comission.

A1.2 Social

A1.2.1 Aesthetics level

ID: BS.AES [-]

RESPONSIBLE PARTNER: TUB

TYPE: Qualitative

DEFINITION: It is related to the level of beautification of the built environment, how beautiful and pleasing in appearance the building will look like after the renovation. For instance, a new façade improves the aesthetics of the building, the building will look better. On the other hand, replacing an element such as a boiler in the technical room will not have an effect on aesthetics. This criterion is also linked to the architectural, cultural and historical values of the building and to the building context. If these elements should be explicitly preserved during the renovation, a low aesthetics level should be assigned to any alternative affecting them.

OBJECTIVE: Aesthetics is included as one of the co-benefits in the Annex 56 methodology developed by the International Energy Agency to optimize renovation alternatives [1]. The aesthetic improvement of the renovated building may be considered one of the main reasons for building renovation. According to the two case studies analysed in [2], aesthetics may play an important role in engaging users in renovation projects and the selection of the final renovation solution. The goal of this criterion is to represent this benefit and encourage energy efficiency solutions that considered this relevant aspect for the final users.

ASSESSMENT CRITERION: The aesthetics level will represent how much a certain renovation alternative impacts the aesthetics of the building or dwelling units. A scale is proposed in the calculation method section.

Data required: The input data required to evaluate and analyse the aesthetic level of each alternative includes 1) the current physical description of the building, this can include photos, BIM-model or other visual representation of the current state of the building; 2) Data regarding the architectural aspect of the surrounding buildings, this will support the experts in case some aspects of the building should be preserved or align with the context of the building; 3) A checklist including the main renovation elements and a brief description on how each one impact the aesthetics of the building; 4) when available, a visualization of the building appearance after renovation may support the experts during the analysis.

Calculation method: Due to the qualitative nature of this criterion, it is necessary to establish a representation that facilitates the quantification of the aesthetics level. The evaluation of the improvement regarding the aesthetics relies on the designers' experiences. Table 9 presents the proposed scale with examples that can help during the quantification process. The renovation of façade, envelope, windows replacement, balconies and loggias usually have a positive impact on the aesthetic of the building. Other elements with positive impacts on the energy performance or other aspects of the building may have negative impacts on the aesthetics, e.g. the installation of solar systems in the roof covering, facade cladding, and sun shading. In these cases, negative impacts on aesthetics should be considered. Nevertheless, each building represents a single case and the aesthetics should be analysed accordingly.

Table 9. Aesthetics level scale

	Ordinal scale				
Score	1	2	3	4	5
Description	**Very negative** **None** of the elements included in the renovation alternative have a **positive** effect on the aesthetics, **most** of the elements have **negative** effects.	**Negative** There are some elements with positive effects but **most** of the elements included in the renovation alternative have a **negative** effect on the aesthetics.	**Neutral** The renovation alternative does not modify the aesthetics in any form.	**Positive** There are some elements with negative effects but **most** of the elements included in the renovation alternative have a **positive** effect on the aesthetics.	**Very positive** **None** of the elements included in the renovation alternative have a **negative** effect on the aesthetics, **most** of the elements have **positive** effects.
Sample renovation alternatives	Thermal solar heating system. Rainwater recycling system.	Individual ventilation units.	Updated of the heating system devices in the technical room of the building, e.g. boiler or pumps. Roof insulation.	Façade insulation, installation of windows in the internal side. The windows would look smaller, affecting the building appearance.	Ventilated façade installation and replacement of windows.

BENCHMARKS: Since each building or dwelling unit has a current state, specific context and specific goals, it is difficult to established a benchmark regarding the aesthetics level after renovation, nevertheless, Table 10 summarizes a list of common individual renovation measures and their impact on the aesthetics of the building, the list was developed by the practitioner partners of the BIM-SPEED project.

Table 10. Impact of renovation measures on the aesthetics of the building

	Impact on Aesthetics		
Renovation measure	Positive	Neutral	Negative
ETICS insulation for facade	+		
Ventilated facade	+++		
Windows replacement	++		
Second external window installation	+		
Individual boiler replacement*	+		
Roof insulation		x	
Ventilation units			-
Air conditioning units			--
Hot water under floor heating	+		
Wall heating radiator	+		
District heating connection	++		
Lighting system replacement	+++		
Rooftop photovoltaic systems*	+		

Façade PV system	++		
Thermal solar heating			-
Rainwater recycling system			--
Water devices replacement	+		
Heating system piping			--

*It is necessary to check in detail each particular case, the effects could be the opposite, for instance, in buildings with external decoration, especially those built before 1950 which are the potential buildings to be refurbished, the ventilated facade is considered aggressive or negative for them, the ETICS solution could be better in those cases.

REFERENCES:

[1]. Almeida, M., Ferreira, M., and Rodrigues, A., 2017. *Co-benefits of energy related building renovation - Demonstration of their impact on the assessment of energy related building renovation (Annex 56),* Guimarães: International Energy Agency.

[2]. Pinzon., J. and Hartmann, T., 2020. Decision-Making Process to Select Energy-Efficient Renovation Alternatives for Residential Buildings: Two Case Studies. ARCOM 2020 Building A Common Good in Construction.

A1.2.2 Social reputation

ID: BS.SR [-]

RESPONSIBLE PARTNER: TUB

TYPE: Qualitative

DEFINITION: It represents the enhanced pride and prestige, an improved sense of environmental responsibility due to the renovation alternative. People who have performed relevant energy-related improvements in their dwellings report these kinds of feelings. Measurements such as a new facade can have an impact on this criterion since the rest of the community will notice that the building owners perform a renovation. Other examples include connecting to a district heating system, this kind of measures increase the awareness of the users regarding energy efficiency and environmental responsibility. Moreover, geographic and socio-economic of the building may impact also this criterion. When a building located in a degraded area is renovated, even the simplest solution has a high impact and could tract other actions. The opposite situation may occur in other kinds of neighborhoods.

OBJECTIVE: Social reputation is included as one of the co-benefits in the Annex 56 methodology developed by the International Energy Agency to optimize renovation alternatives [1]. The objective is to highlight some of the benefits that are usually not quantified as a result of a renovation. The increment of pride or prestige as a result of a new façade or the increment of the awareness regarding environmental responsibility as a result of a new PV system in-situ or less water consumption can be represented through this criterion. This may promote strategies to present in a more explicit way the benefits from the renovation to the different stakeholders.

ASSESSMENT CRITERION: The social reputation level will represent how much a certain alternative rises the users' awareness of the environmental benefits and their pro-active behavior. A scale is proposed in the calculation method section.

Data required: The input data required to evaluate and analyse the social reputation level of each alternative includes 1) the current physical description of the building, this can include photos, BIM-model or other visual representation of the current state of the building; 2) Data regarding the architectural aspect of the surrounding buildings and socio-economic characteristics of the district; 3) A checklist including the main renovation elements and a brief description on how each one impact the social reputation.

Calculation method: Due to the qualitative nature of this criterion, it is necessary to establish a representation that facilitates the quantification of the social reputation. The evaluation of the criterion relies on experts' judgements and particularities of each project. Table 11 presents the proposed scale which is based on the approach presented in [2]. Each building represents a single case, the way the project is conducted, the previous state of the building, the way the stakeholders engage in the project and other aspects will determine the benefits coming from the renovation and the awareness of the stakeholders.

Table 11. Social reputation level scale

	Ordinal scale				
Score	1	2	3	4	5
Description	**Unacceptable** Alternative not in the cultural tradition of the area and stakeholders not aware about the benefits	**Low** Alternative not diffused in the area and citizen are scarcely aware about the benefits	**Medium** Alternative normally adopted in the area and the related benefits are mostly known	**High** Alternative normally adopted in the area and the related benefits are well known	**Very high** Alternative widely adopted in the area and the related benefits are well known

BENCHMARKS: This criterion depends strongly on the current state of the building, its surroundings, and the renovation alternatives. It also requires a high level of abstraction from the experts to determine the level at which each alternative impact the social reputation. No benchmark is suggested due to the complexity of this attribute.

REFERENCES:

[1]. Almeida, M., Ferreira, M., and Rodrigues, A., 2017. *Co-benefits of energy related building renovation - Demonstration of their impact on the assessment of energy related building renovation (Annex 56)*, Guimarães: International Energy Agency.

[2]. Dirutigliano, D., Delmastro, C. & Torabi Moghadam, S., 2018. A multi-criteria application to select energy retrofit measures at the building and district scale. Thermal Science and Engineering Progress, pp. 457 - 464.

A1.2.3 Durability

ID: BS.DRT [Years]

RESPONSIBLE PARTNER: VIS

TYPE: Quantitative

DEFINITION: It refers to the lifetime of the products installed during the renovation. For instance, PVC and Aluminium window frames have different durability. A renovation alternative may include different components such as windows, roof and façade insulation, and heat radiators which have a different lifespan. A method to integrate them in a single value is proposed.

OBJECTIVE: This criterion may help the stakeholders to evaluate indirectly the quality of products and to estimate when will be necessary a replacement or additional renovation of the components that will be installed during the current renovation activities.

ASSESSMENT CRITERION: The durability will be calculated as the weighted arithmetic mean of the durability (lifespan in years) of the main components included in the renovation alternative under assessment.

Data required: The data required to calculate this criterion is summarized in Table 12.

Table 12. Data input required for BS.DRT criterion calculation

Input	Unit/format
List of the main products and constructive systems	[-]
Durability, number of years	[years]
Component price	[€]
Maintenance cost by component	[€]
Replacement cost by component	[€]
Number of replacements during the required service life of the building	[-]
Inflation rate	[%]

Calculation method: The Durability is assessed considering the durability guarantee (years) of the different constructive elements that will be placed during renovation works. This guarantee of duration should be checked with the cost of maintenance and replacement to get the right balance. More durable products have a higher initial cost but less maintenance cost. To do this, the Net present value of the diverse costs related to each component is calculated. It comprises the initial price, the maintenance costs through the required service life of the building, and the cost of replacements:

$$NPV_i = C_i + \sum_{n=1}^{t} \frac{MC_i}{(1+r)^n} + \sum_{n}^{T} \frac{RC_i}{(1+r)^n}$$

Where,

C, component price

MC, component maintenance cost

RC, component replacement cost

r, inflation rate

T, is the set of years when the component will be replaced

The Net present value of each component is used to estimate the weights, thus, components with a higher NPV will have a higher impact on the quantification of the durability. The BS.DRT criterion is then calculated such as the weighted arithmetic mean of the durability (lifespan in years) of the main components included in the renovation alternative under assessment.

$$w_i = \frac{NPV_i}{\sum_{j=1}^{k} NPV_j}$$

$$BS.DRT = \frac{1}{k} \sum_{i=1}^{k} w_i \; x \; drt_i$$

Where,

w_i, weight defined for the importance of the component during the building lifecycle

drt_i, durability of the product [years]

k, number of components included in the renovation alternative

BENCHMARKS: It is difficult to establish a common definition of durability, should it be the lifespan of the building, the durability of the components, the level of operations and maintenance required, or some combination of the three? In the GreenSpec directory, durability and low maintenance are considered together as a criterion [1]. Furthermore, there is a lack of well-established strategies to consider durability during the design stage, certification methodologies such as LEED Canada encourage the designers to develop a Building durability plan, however, it grants just one credit for the certification.

REFERENCES:

[1] Muldavin, S. R. 2010. Value Beyond Cost Savings: How to Underwrite Sustainable Properties. Green Building Finance Consortium.

A1.2.4 Covered scope

ID: BS.CSCP [%]

RESPONSIBLE PARTNER: VIS

TYPE: Qualitative

DEFINITION: In renovation projects, a preliminary inspection of the building is usually conducted to identify relevant problems to be addressed during the renovation, some of them being mandatory. Different renovation alternatives address partially or completely these problems. This criterion represents the percentage of the problems solved by the renovation alternative under study.
OBJECTIVE: Stakeholders are usually interested in renovation alternatives that integrate multiple aspects and solve as much as possible the deficiencies of the building [1]. A comprehensive solution represents the possibility of avoiding additional renovations and investments in the short and medium terms. The goal of this criterion is to represent how comprehensive is the renovation alternative being studied.
ASSESSMENT CRITERION: For each identified problem, a score of importance will be assigned by the experts. Mandatory and critical elements should receive a higher level of importance. Then, each alternative will gather the different scores according to the importance of the problems being covered by it.
Data required: The data required to calculate this criterion is summarized in Table 13.

Table 13. Data input required for BS.CSCP criterion calculation

Input	Unit/format
List of the main products and constructive systems	[-]
Importance of each problem to be addressed	[-]

Calculation method: This criterion involves some qualitative and quantitative aspects, the proposed approach to quantify it relies on experts' judgements. They should check each of the problems that should be addressed and assign them a score from 1-100 according to the priority, importance, and benefits of each one. Mandatory aspects will receive a score of 100 points. Once the list with the level of importance is established, the total score for a certain renovation alternative is quantified summing up the individual scores, and the BS.CSCP can be calculated as follows:

$$BS.CSCP = \frac{\sum_{i=1}^{k} Level\ of\ Importance_i}{\max\left(\sum_{i=1}^{k} Level\ of\ Importance_i\right)}$$

Where,

$Level\ of\ Importance_i$, the level of importance of each of the problems covered by the alternative
$\max()$, represents the maximum score obtained by the total set of alternatives

It is important to notice that some alternatives may include elements addressing aspects that were no identified during the inspection of the building. In these cases, those elements should be included in the list and a level of importance according to their benefits should be assigned in order to quantify their positive impact on the final scope.

BENCHMARKS: This criterion depends entirely on the current state of each building and the renovation goals, alternatives and even budget. As the best of our knowledge, it may represent a new concept that has not been quantified or modelled previously with any strategy, therefore, defining a benchmark is a challenging if not unpractical task. Further research will be conducted to study how different project take this criterion into account and which are other strategies to quantify it.

REFERENCES:

[1]. Pinzon., J. and Hartmann, T., 2020. Decision-Making Process to Select Energy-Efficient Renovation Alternatives for Residential Buildings: Two Case Studies. ARCOM 2020 Building A Common Good in Construction.

A1.2.5 Renovation time

ID: BS.RT [months]

RESPONSIBLE PARTNER: MOW

TYPE: Quantitative

DEFINITION: It corresponds to the duration of the execution stage required by a certain renovation alternative. Since this criterion varies according to the contractors and technologies, a specific method is not proposed.

OBJECTIVE: Renovation projects performed for long periods represent limitations and discomfort for the final users. This criterion aims at promoting a faster execution of renovation activities. It may encourage the installation of innovative prefabricated and plug-and-play solutions that reduce considerably the duration of the execution stage.

ASSESSMENT CRITERION: The criterion is represented by the total months required to performed the execution stage of the renovation, including the installation (and removal) of equipment such as scaffolding, removal, demolition or preliminary activities on site, the entire renovation tasks, and commissioning.

BENCHMARKS: The renovation time is closely related to the renovation aspects to be addressed, the technologies to be implemented, and aspects such as the operational restrictions of the building, the contractor construction process, and building size. Traditional approaches for envelope refurbishment need scaffolding on the outer façade for very long times (12 to 24 months) for a seven-floor building, requiring occupants to seal windows and introduce safety issues [1].

REFERENCES:

[1]. Salvalai, G., Sesana, M. M. and Iannaccone, G. (2017), 'Deep renovation of multi-story multi-owner existing residential buildings: A pilot case study in Italy', Energy and Buildings 148, pp. 23 – 36.

A1.2.6 Accessibility

ID: BS.ACC [-]

RESPONSIBLE PARTNER: TUB

TYPE: Quantitative

DEFINITION: It represents the level of accessibility of the building, and how well people with or without disabilities can use products, devices, services, or spaces of the building. Based on the current state of the building, accessibility solutions may be required or suggested. Any improvement regarding this aspect should be included as a benefit of the renovation project. Renovation solutions not covering any accessibility requirement identified should be reviewed and analysed in detail.

OBJECTIVE: A large number of buildings being renovated across Europe were built without following any kind of accessibility standard. For instance, in Spain, residential buildings with more than four floors should have a lift. Currently, 13,5% of the residential stock there lacks this key accessibility measure [1]. A renovation project may represent the opportunity to improve the building accessibility in conjunction with the energy-efficient and additional measures to be implemented. Therefore, this criterion may promote strategies that include accessibility solutions such as lifts, ramps, accessible toilets, wide doorways, signs and among others covering the needs of people with hearing or vision impairment.

ASSESSMENT CRITERION: The accessibility level will represent how much a certain renovation alternative improves the current building accessibility.

Data required: Accessibility is a very specific feature that could be not relevant for all renovation projects and stakeholders involved. When relevant, it demands a detailed review, especially before starting a renovation to identify the measures lacking and possible solutions. The input data required to evaluate and analyse the accessibility level of each alternative includes 1) the current physical description of the building, this can include photos, BIM-model or other visual representation of the current state of the building; 2) a list of the accessibility requirements that should be addressed by the possible renovation alternatives.

Calculation method: Due to the qualitative nature of this criterion, it is necessary to establish a representation that facilitates the quantification of it. The proposed approach is similar to the strategy implemented for the BS.CSCP Covered scope criterion, it relies on experts' judgements. Experts should check each of the accessibility problems that should be addressed and assign them a score from 1-100 according to the priority, importance, and benefits of each one. Mandatory aspects will receive a score of 100 points. Once the list with the level of importance is established, the total score for a certain renovation alternative is quantified summing up the individual scores, and the BS.ACC can be calculated as follows:

$$BS.ACC = \frac{\sum_{i=1}^{k} Level\ of\ Importance_i}{\max\left(\sum_{i=1}^{k} Level\ of\ Importance_i\right)}$$

Where,

$Level\ of\ Importance_i$, the level of importance of each of the accessibility issues covered by the alternative max (), represents the maximum score obtained by the total set of alternatives

It is important to notice that some alternatives may include elements addressing accessibility aspects that were no identified during the inspection of the building. In these cases, those accessibility measures should be included in the list and a level of importance according to their benefits should be assigned to quantify their positive impact on the final accessibility level.

BENCHMARKS: According to the European Disability Forum, currently, there is no general obligation on EU level for public authorities or the private sector to meet accessibility requirements when building new or renovating existing infrastructure. Nevertheless, The M/420 mandate[6] from the European Commission addressed to CEN, CENELEC and ETSI supports disability policies and concerns European accessibility requirements for public procurement in the built environment. One of the expected outcomes of it would be a European standard on accessibility of the built environment, having the ISO 21542 standard as a base document. Moreover, guidelines from certification bodies such as BREEAM Refurbishment Domestic Buildings[7] may support the stakeholders to identify and evaluate accessibility strategies.

REFERENCES:

[1]. Ministerio de Fomento, 2017. ERESEE 2017: Actualización de la Estrategia a largo plazo para la rehabilitación energética en el sector de la edificación en España. ERESEE 2017: Update of the Long-term Strategy for the Energy Renovation in the Spanish Building Sector., Spain: Ministerio de Fomento.

[6] https://ec.europa.eu/eip/ageing/standards/home/accessibility-and-design-all/m420_en
[7] https://www.breeam.com/domrefurb2014manual/

A1.3 Economic

A1.3.1 Investment cost

ID: BS.IC [€]

RESPONSIBLE PARTNER: ARC/LKS

TYPE: Quantitative

DEFINITION: It estimates the total initial investment to implement a certain renovation alternative.

OBJECTIVE: The initial investment may be one of the main limitations to start a renovation project. This criterion is a relevant aspect in the case of multi-family buildings where multiple owners (investors) with diverse investment capacity should reach consensus on the renovation solution to be implemented. Furthermore, renovations being conducted across Europe rely often on grants or subsidies, and the investment cost is essential to estimate how these resources will be integrated with the private investment of the stakeholders involved in the renovation.

ASSESSMENT CRITERION: The BS.IC criterion is determined considering average prices for materials and labour, engineering costs, and equipment costs. The methodology takes into account the total construction cost of a certain renovation alternative and the related expenses to carry it out. It is required a labour and materials cost estimation appraisal for every renovation alternative prior to establishing an Initial Investment Cost.

Data required: The input required is summarized in Table 14.

Table 14. Data input required for BS.IC criterion calculation

Input	Unit/format
Labour costs	[€/h], [€/m^2],
Material prices	[€]
Equipment prices	[€]
Studies, collecting data	[€]
Design and Engineering	[€]
Costs related to disposing materials	[€]
Other legal & administrative costs	[€]

Calculation method:

The investment cost considers all costs related to a renovation project, having multiple layers. These layers are based upon the solution of the renovation strategies and some can be omitted.

$$IC\ [€] = CAE + CDEM + CDB + CFE + CIR + CS + CEL + CHVAC + LC$$

Where:

CAE: Costs related to studies, design and engineering part, consultancy [€]

CDEM: Costs related to demolition work necessary to perform de renovation project [€]

CDB: Costs related to disposing of waste materials, equipment, etc. [€]

CFE: Costs considering the renovation of facades and the exterior of the building. Includes material and labour costs [€]

CIR: Costs that take into account renovation of interior elements (interiors walls, interior doors, floors, etc.). Includes material and labour costs [€]

CS: Costs required for rehabilitation of structure elements. Includes material and labour costs [€]

CEL: Costs related to electrical installations (wiring, new lighting fixtures, changings lamps, electrical panels, etc.). Includes material and labour costs [€]

CHVAC: Costs related to HVAC systems (piping replacement, insulating pipes, equipment changes, etc.). Includes material, equipment, and labour costs [€]

LC = Indirect costs [€] = Legal costs & administrative fees [€]

BENCHMARKS:

Investment costs in renovation depend on the type of renovation (low or deep renovation process), specific country labour costs, prices, age of the building, etc. However, the report Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU [1] presents the estimation of the average investment costs per year in Europe, as shown in Table 15.

Table 15. Specific investments in residential buildings (average investment costs per year in the period 2012-2016)

Region	Energy related: Total [€/m²]	Energy related: Below threshold [€/m²]	Energy related: Light [€/m²]	Energy related Medium [€/m²]	Energy related Deep [€/m²]	Non-energy related Total [€/m²]
EU28	83	56	104	154	219	-
France	97	64	121	193	310	103
Germany	112	58	146	285	306	124
Italy	62	44	66	121	204	84
Netherlands	113	98	124	181	242	162
Poland	55	42	66	78	111	64
Romania	34	27	37	84	82	57
Spain	46	46	52	38	51	80

REFERENCES:

[1]. Esser, A., Dunne, A., Meeusen, T., Quaschning, S., Wegge, D. 2019. Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU. European Commission, Ipsos Belgium, Belgium.

[2]. Kohler, N., König, H., Kreissig, J., Lützkendorf, T., 2010. “A life cycle approach to buildings: Principles - Calculations - Design tools”.

[3]. MOEEBIUS project, 2016. " D2.3. MOEEBIUS Energy Performance Assessment Methodology".
[4]. Saheb, Y., Bódis, K., Szabó, S., Ossenbrink, H., Panev, S., 2015. Energy renovation: The trump card for the new start for Europe. JRC Science and Report Policy Reports.
[5]. Saheb, Y., 2016. Energy transition of the eu building stock — unleashing the 4th industrial revolution in europe, Technical report, Build up. Available at: https://www.buildup.eu/en/practices/publications/energy-transition-eubuilding-stock-unleashing-4th-industrial-revolution-0.
[6]. The Building Performance Institute Europe – BPIE. 2010. Cost Optimality – Discussing methodology and challenges within the recast Energy Performance of Buildings Directive.

A1.3.2 Rent increment

ID: BS.RI [%/year]

RESPONSIBLE PARTNER: TUB

TYPE: Quantitative

DEFINITION: It represents the possible increment in the rent after renovation. Some countries across Europe regulate the possible rent increment, they establish the value based on the scope of the renovation, the investment cost or the energy efficiency achieved after the renovation. It is important to notice that this criterion is applicable only when the residential units are occupied by tenants.

OBJECTIVE: Since the landlord/tenant dilemma is one of the possible conflicts between the different stakeholders involved in residential building renovation, the goal of this criterion, in conjunction with the KPI BS.OEC Operational Energy Cost from deliverable D4.1, is to present in a transparent way the economic benefits and impacts that the renovation may bring to the main stakeholders involved.

ASSESSMENT CRITERION: The rent increment will be estimated as a percentage of the current rent value. The local regulation in each country may impose restrictions on this increment, defining the thresholds or exact values that are allowed.

Data required: The input data to estimate the criterion is summarized in Table 16.

Table 16. Data input required for BS.RI criterion calculation

Input	Unit/Format
Current rent	[€]
Investment cost, BS.IC	[€]
Current Operational Energy Costs	[€/m^{2}year]
Operational Energy Costs after renovation, BS.OEC	[€/m^{2}year]
Size of the building	[m^2]
Possible energy label after renovation	-
Mandatory threshold	[%]

Calculation method: Since each country has a specific regulation regarding the rent and some of them do not have, in each case it is necessary to investigate the extent to which energy renovations may permissibly result in rent increases. The calculation for some of the countries with a clear regulation on rents is presented below.

In Germany, according to law § 559, the landlord is allowed to increase the annual rent by 11% of the costs incurred as a result of the implementation of modernization measures. In the case of modernization measures for several dwellings, the costs must be distributed appropriately to the individual dwellings. Therefore, the maximum rent increment can be estimated such as:

$$BS.RI = \frac{0.11\ x\ \mathrm{BS.IC}}{Current\ rent}$$

In the case of multiple dwellings, the investment cost should be distributed accordingly.

In The Netherlands, the rent increment depends on the impact of the renovation on energy efficiency. Energy efficiency is part of the point system for the calculation of the maximum permissible rental rate. The monthly rent per point is about five Euros.

Table 17. Scoring system for regulation rent in The Netherlands

Label after renovation	Points for a single-family house	Points for an apartment
Label A++	44	40
Label A+	40	36
Label A	36	32
Label B	32	28
Label C	22	15
Label D	14	11
Label E	8	5
Label F	4	1
Label G	0	0

In France, according to law no ° 2009-323 from 25.03.2009, the owner can demand the financial contribution to the renovation costs for a period of 15 years of up to half of the amount that the tenant could save due to the renovation-related operating cost reduction. Based on the BS.OEC Operational Energy Costs KPI from BIM-SPEED D4.1, the rent increment for the first 15 years after renovation can be calculated as follows:

$$BS.RI = \frac{0.5\ x\ (BS.OEC - Current\ BS.OEC)\ x\ \mathrm{Size\ of\ the\ building}}{Current\ rent}$$

In Poland, If the landlord is unable to obtain an appropriate rent which allows for the preservation and improvement of the dwelling, he/she is entitled to a special right to increase the rent according to Article 8a (4a) TPA. The consequences for an increase in rent due to extensive renovation measures are regulated in Art. 8a (4b) item 1b TPA. Thereafter, the landlord may add to the rent up to 10% of the invested capital for desirable improvement measures. Thus, the rent increment can be estimated as:

$$BS.RI = \frac{0.10\ x\ \mathrm{BS.IC}}{Current\ rent}$$

BENCHMARKS:

In general, in Denmark, Germany, the Netherlands, Austria and Poland, either the rents are regulated or the possibility of rent increment is restricted. In these cases, the legislature establishes to what extent the tenant is involved in the cost of energy renovations [1]. In most countries the participation depends on the costs involved, but these can be limited to adequate (Poland) or local (Austria) measures for energy renovation. The Netherlands is a special case, the investment has no direct influence on the rent increment, it relies on the increase in energy efficiency. Therefore, there is an incentive for the landlord to implement a renovation solution that is at the same time efficient and cost-effective. The risk of a moral dilemma can be avoided, which may be present in systems that are based exclusively on the investment costs, where the landlord may produce high costs for a small increase in efficiency [1].

In Italy can be generally no rent increase due to an energy renovation measure in the short and medium-term. However, a lease term normally limited to 4 years is automatically terminated after the first renewal. After this, the rent can be negotiated.

REFERENCES:

[1]. Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), 2016. Tenancy law and energy renovation in European comparison. Bonn, Germany.

[2]. Jensen, P. A. & Maslesa, E., 2015. Value based building renovation – A tool for decision-making and evaluation. Building and Environment, Volume 92, pp. 1 - 9.

A1.3.3 Maintenance cost

ID: BS.MC [€]

RESPONSIBLE PARTNER: FAS

TYPE: Quantitative

DEFINITION: Maintenance costs cover the cost of labour and material, as well as other related costs that are incurred to keep the building or its parts in the state in which it can perform its required functions. Maintenance implies the conduct of corrective, responsive and preventive maintenance activities on constructed assets, or on some parts of these assets. The objectives of building maintenance are:

- to ensure that the buildings and their associated services are in a safe condition,
- to ensure that the buildings are fit for use,
- to ensure that the condition of the building meets all statutory requirements,
- to carry out the maintenance work necessary to maintain the value of physical assets of the building stock,

– to carry out the work necessary to maintain the quality of the building

According to ISO 15686 (ISO standard dealing with service life planning), there are several types of maintenance: preventive maintenance, scheduled maintenance, corrective maintenance, condition-based maintenance, emergency/unforeseen maintenance, predictive maintenance, deferred maintenance and on-site/off-site maintenance [1].

Within the BIM-SPEED project following types of maintenance cost are taken into account:

- **Cost of statutory periodic inspections**. This cost covers various activities that are regulated by relevant laws and regulations, and are conducted to protect the safety, health and life of people. These activities consist of tests and inspections that are made on particular building parts, equipment and installations.
- **Cost of preventive maintenance**. These activities consist of works and repairs that are repeated at approximately the same time intervals, depending on the service life of the facility or its structural elements. These activities are conducted to keep the facility in a desired state of repair. E.g. cleaning of the façade, replacement of the filters, etc.
- **Cost of replacing and/or repair of degraded materials and elements.** This cost contains the repair and replacing of the building elements that were degraded within the service life.
- **Cost of reactive maintenance.** Such activities are difficult to predict because it is almost impossible to anticipate all possible failures. The number of these activities is large because reactive maintenance activities cover the cost of repair and replacement of components and materials due to failures and sudden defects.

OBJECTIVE: The goal of this criterion is to promote low-cost maintenance products that may encourage the stakeholders to conduct the building renovation. This criterion may be also a measure of how the current maintenance cost may decrease due to the replacement of old non-functional elements of the building and the implementation of new technologies.

ASSESSMENT CRITERION: The BS.MC gathers the costs in €, related to the maintenance of the building in the new scenario created for each of the alternatives studied during the design stage.

Data required: The input required is summarized in Table 18.

Table 18. Data input required for BS.MC criterion calculation

Input	Unit/Format
Cost of statutory periodic inspections	€
Costs of replacing degraded materials and elements	€
Costs of periodic works and repairs	€
Costs of reactive maintenance	€

Calculation method:

$$M_T = \Sigma\, C_{SPI} + \Sigma C_R + \Sigma C_{PW} + \Sigma C_{RM}$$

Data were collected for the following groups of costs:

- C_{SPI} Cost of statutory periodic inspections
- C_R Costs of replacing degraded materials and elements
- C_{PW} Costs of periodic works and repairs
- C_{RM} Costs of reactive maintenance

REFERENCES:

[1]. Krstić H., Marenjak S., 2012. *Analysis of buildings operation and maintenance costs.* GRA ĐEVINAR. 64. pp. 293-303.

A1.3.4 Financial incentives

ID: BS.FI [€]

RESPONSIBLE PARTNER: MOW/VIS

TYPE: Quantitative

DEFINITION: It gathers the potential financial benefits that the stakeholders could receive according to the scope of the renovation alternative. These financial benefits include grants, taxes reductions, loans and subsidies.

OBJECTIVE: Renovations being conducted across Europe rely often on grants or subsidies that promote the implementation of deep renovations. This criterion may encourage stakeholders to align the objectives of the renovation projects with more ambitious goals to receive financial benefits offered by diverse institutions. The final objective is to reduce the final cost of the renovation by using financial incentives. It is necessary to check the compatibility between incentives at national, regional, and municipal levels. It is important to notice that managing the administrative processes to obtain these kinds of financial incentives often implies a large effort.

ASSESSMENT CRITERION: Since the financial incentives vary depending on the year, country, region and even the local municipality policy, it is considered more suitable to create a checklist to analyse different renovation-incentive options.

Data required: To implement the proposed check list, it is necessary to define the scope of each of the renovation alternatives being evaluated. Then, the scope of each alternative is contrasted with the requirements of the different financial incentives available at the national, regional, and local level. Therefore, these two sets of data should be gathered to quantify the BS.FI criterion.

Calculation method: The checklist template presented in Figure 36 was developed to allow stakeholders to evaluate the different financial incentives available. The incentives are classified into four categories: Grants, subsidies, loans, and taxes reduction. They may be obtained at national, regional, or local level. The tax reduction incentives are distributed across all the levels. Figure 37 presents the checklist of the BIM-SPEED Vitoria demo case to exemplify how to use the template. The checklist allows the stakeholders to identify which incentives can be obtained with a certain renovation alternative. If the specific information regarding the values of each incentive can be estimated, the different benefits should be aggregated according to the four categories, then the BS.FI criterion can be calculated as follows:

$$BS.FI = Grants + Subsidies + TaxesReduction$$

Loans are not included directly into the equation since they represent two different effects on the project. They add economic capacity to the stakeholders to improve their investment capacity, nevertheless, they also represent a continuous expenditure along the payment period. Even the approach does not include them directly, loans should be estimated to be able to consider taxes reduction on them.

BENCHMARKS: Most of the countries in the European Union use a combination of measures for general renovation and special measures for energy renovation, relying mostly on a mix of funding and grants. Only in Poland are loans reimbursed, while in Finland the promotion is based on low-cost loans and redemption subsidies. In countries such as Denmark and Sweden, on the other hand, loans are not used, but only on direct payments in the form of grants [1]. Table 19 summarizes some of the financial incentives in five countries.

Table 19. General financial incentives in some European countries

Country	Benefit
Germany	• low-interest loans and redemption subsidies or, alternatively, investment grants for energy-saving investments through KfW's CO2 building renovation program (nationwide) • grants for the supply of energy from solar panels, biomass plants and energy-efficient heat pumps (nationwide) • grants for consultations on energy efficiency (heat protection, heat generation and heat distribution, use of renewable energy) by qualified consultants
France	• interest-free loans for individual energy renovation measures up to EUR 30,000.- • grants for comprehensive energy renovation measures
Italy	• low-interest loans and repayment grants for general renovation • grants for the purchase of dwellings after energy renovation
Poland	• loans with redemption allowance for energy renovation measures • loans with redemption allowance for the construction of solar panels
Netherlands	• low-interest loans for energy renovation (national) • grants for energy renovation (regional and local)

Criteria: 1.3.4 Financial Incentives CHECKLIST

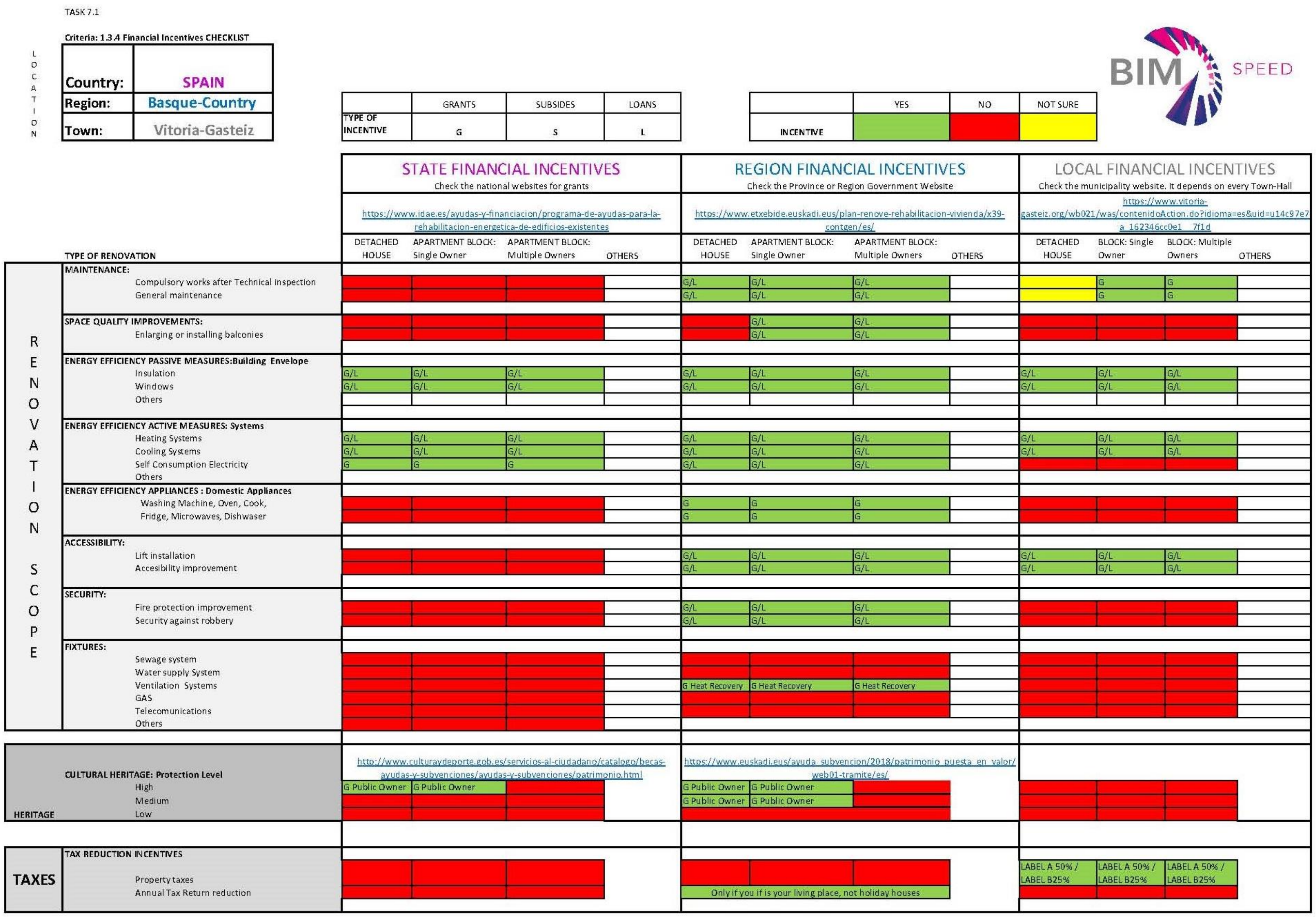
LOCATION	
Country:	
Region:	
Town:	

TYPE OF INCENTIVE	GRANTS	SUBSIDES	LOANS
	G	S	L

INCENTIVE	YES	NO	NOT SURE

		STATE FINANCIAL INCENTIVES Check the national websites for grants				REGION FINANCIAL INCENTIVES Check the Province or Region Government Website				LOCAL FINANCIAL INCENTIVES Check the municipality website. It depends on every Town-Hall			
	TYPE OF RENOVATION	DETACHED HOUSE	APARTMENT BLOCK: Single Owner	APARTMENT BLOCK: Multiple Owners	OTHERS	DETACHED HOUSE	APARTMENT BLOCK: Single Owner	APARTMENT BLOCK: Multiple Owners	OTHERS	DETACHED HOUSE	BLOCK: Single Owner	BLOCK: Multiple Owners	OTHERS
RENOVATION SCOPE	MAINTENANCE:												
	Compulsory works after Technical inspection												
	General maintenance												
	SPACE QUALITY IMPROVEMENTS:												
	Enlarging or installing balconies												
	ENERGY EFFICIENCY PASSIVE MEASURES:Building Envelope												
	Insulation												
	Windows												
	Others												
	ENERGY EFFICIENCY ACTIVE MEASURES: Systems												
	Heating Systems												
	Cooling Systems												
	Self Consumption Electricity												
	Others												
	ENERGY EFFICIENCY APPLIANCES : Domestic Appliances												
	Washing Machine, Oven, Cook, Fridge, Microwaves, Dishwaser												
	ACCESSIBILITY:												
	Lift installation												
	Accesibility improvement												
	SECURITY:												
	Fire protection improvement												
	Security against robbery												
	FIXTURES:												
	Sewage system												
	Water supply System												
	Ventilation Systems												
	GAS												
	Telecomunications												
	Others												
HERITAGE	CULTURAL HERITAGE: Protection Level												
	High												
	Medium												
	Low												
TAXES	TAX REDUCTION INCENTIVES												
	Property taxes												
	Annual Tax Return reduction												

Figure 36. Financial incentives check list



TASK 7.1

Criteria: 1.3.4 Financial Incentives CHECKLIST

LOCATION	
Country:	SPAIN
Region:	Basque-Country
Town:	Vitoria-Gasteiz

TYPE OF INCENTIVE	GRANTS	SUBSIDES	LOANS
	G	S	L

INCENTIVE	YES	NO	NOT SURE

TYPE OF RENOVATION	STATE FINANCIAL INCENTIVES: DETACHED HOUSE	STATE: APARTMENT BLOCK: Single Owner	STATE: APARTMENT BLOCK: Multiple Owners	STATE: OTHERS	REGION FINANCIAL INCENTIVES: DETACHED HOUSE	REGION: APARTMENT BLOCK: Single Owner	REGION: APARTMENT BLOCK: Multiple Owners	REGION: OTHERS	LOCAL FINANCIAL INCENTIVES: DETACHED HOUSE	LOCAL: BLOCK: Single Owner	LOCAL: BLOCK: Multiple Owners	LOCAL: OTHERS
	Check the national websites for grants				Check the Province or Region Government Website				Check the municipality website. It depends on every Town-Hall			
	https://www.idae.es/ayudas-y-financiacion/programa-de-ayudas-para-la-rehabilitacion-energetica-de-edificios-existentes				https://www.etxebide.euskadi.eus/plan-renove-rehabilitacion-vivienda/x39-contgen/es/				https://www.vitoria-gasteiz.org/wb021/was/contenidoAction.do?idioma=es&uid=u14c97e7a_162346cc0e1__7f1d			
RENOVATION SCOPE												
MAINTENANCE:												
Compulsory works after Technical inspection					G/L	G/L	G/L			G	G	
General maintenance					G/L	G/L	G/L			G	G	
SPACE QUALITY IMPROVEMENTS:												
Enlarging or installing balconies						G/L	G/L					
						G/L	G/L					
ENERGY EFFICIENCY PASSIVE MEASURES: Building Envelope												
Insulation	G/L	G/L	G/L		G/L	G/L	G/L		G/L	G/L	G/L	
Windows	G/L	G/L	G/L		G/L	G/L	G/L		G/L	G/L	G/L	
Others												
ENERGY EFFICIENCY ACTIVE MEASURES: Systems												
Heating Systems	G/L	G/L	G/L		G/L	G/L	G/L		G/L	G/L	G/L	
Cooling Systems	G/L	G/L	G/L		G/L	G/L	G/L		G/L	G/L	G/L	
Self Consumption Electricity	G	G	G		G/L	G/L	G/L					
Others												
ENERGY EFFICIENCY APPLIANCES: Domestic Appliances												
Washing Machine, Oven, Cook,					G	G	G					
Fridge, Microwaves, Dishwaser					G	G	G					
ACCESSIBILITY:												
Lift installation					G/L	G/L	G/L		G/L	G/L	G/L	
Accesibility improvement					G/L	G/L	G/L		G/L	G/L	G/L	
SECURITY:												
Fire protection improvement					G/L	G/L	G/L					
Security against robbery					G/L	G/L	G/L					
FIXTURES:												
Sewage system												
Water supply System												
Ventilation Systems					G Heat Recovery	G Heat Recovery	G Heat Recovery					
GAS												
Telecomunications												
Others												
HERITAGE	http://www.culturaydeporte.gob.es/servicios-al-ciudadano/catalogo/becas-ayudas-y-subvenciones/ayudas-y-subvenciones/patrimonio.html				https://www.euskadi.eus/ayuda_subvencion/2018/patrimonio_puesta_en_valor/web01-tramite/es/							
CULTURAL HERITAGE: Protection Level												
High	G Public Owner	G Public Owner			G Public Owner	G Public Owner						
Medium					G Public Owner	G Public Owner						
Low												
TAXES												
TAX REDUCTION INCENTIVES												
Property taxes									LABEL A 50% / LABEL B25%	LABEL A 50% / LABEL B25%	LABEL A 50% / LABEL B25%	
Annual Tax Return reduction					Only if you if is your living place, not holiday houses							

Figure 37. Financial incentive check list example

Regarding taxes benefits, some of the countries apply a reduced rate for value-added tax to the purchase of construction materials and/or the implementation of energy-saving sanitation measures. On the other hand, in many European countries, it is possible to claim a whole or partial exemption from income or corporation tax liability for the costs of energy renovation [1]. Table 20 presents the possible tax reduction incentives in five European countries.

Table 20. Taxes reduction incentives in some European countries

Country	Benefit
Germany	• Landlords are able to deduct expenses for the repair or maintenance of dwellings as business expenses or operating expenses, and in the case of larger measures also distributed to two to five years.
France	• Normal tax rate 20%; reduced tax rate of 10% for general renovation measures and 5.5% for energy renovation; supporting the purchase of building materials and carrying out the work of construction companies. • Homeowner and tenant can deduct 15% to 20% of the costs for energy renovation of the primary dwelling, maximum EUR 8,000, - for one person, EUR 16,000, - for two persons and EUR 400, - for each additional person in the household, but only every 5 years.
Italy	• Normal tax rate 22%; reduced tax rate of 10% for general renovation measures; supporting the purchase of building materials and carrying out the work of construction companies • Homeowners and tenants can deduct up to 65% of the investment costs for investments in renovations
Poland	• Normal tax rate 23%; Reduced tax rate of 8% for general recovery measures; supporting the purchase of building materials; Tax benefit expired in 2014.
Netherlands	• Normal tax rate 21%; reduced tax rate of 6% for energy renovation; supporting the carrying out the work. • Companies can deduct 41.5% of the investment costs for investments in energy-saving technologies each year.

REFERENCES:

[1]. Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), 2016. Tenancy law and energy renovation in European comparison. Bonn, Germany.

A1.3.5 Dwelling value increment

ID: BS.DVI [%]

RESPONSIBLE PARTNER: FAS

TYPE: Quantitative

DEFINITION: It estimates the increment of the property value due to the upgrades and improvements proposed by a certain renovation alternative. It has been proven that housing markets capitalize improved energy performance into dwelling units' value. Since this criterion varies according to the region and the type of dwelling, a sample method is presented, but each case should analyse its context and regulation around this aspect.

OBJECTIVE: This criterion may represent an additional incentive for the stakeholders to select more comprehensive and deep renovation alternatives that could increase the value and marketability of a residential unit due to the economic, environmental, and social benefits expected from those alternatives.

ASSESSMENT CRITERION: the value increment will be estimated as a percentage of the current dwelling value. The local regulation or market context in each country may affect the increment.

Data required: the input data required to evaluate the dwelling value increment resulting from each alternative includes 1) the current dwelling value; 2) the current Energy label of the building; 3) the intended energy label to be obtained after implementing the renovation alternative under analysis.

Calculation method: The method is based on the assumption taken from the study prepared by the European Parliament [2] that A rating of the property is typically worth 11% more than a D rated property in the same location. The increase of the building value is related to the increase of the energy label after renovation as shown Table 21.

Table 21. Dwelling value increment according energy label

Energy label achieved after renovation	Increase in the property value [%]
F	2%
E	1,8%
D	1,6%
C	1,6%
B	2%
A	2%
A+/A++	1,5%

BENCHMARKS: Copenhagen Economics has analysed this question and found that for each step-wise increase on the energy label scale, the house price increases by 5,600-8,100 € for an average house of 100 m^2. This result is based on an extensive econometric analysis using more than 365,000 observations on house sales in Denmark. The energy label rates houses from A to G, with A being the highest standard and G being the lowest standard. This result proved robust to different modelling choices, and the estimation takes into account houses' different qualities, location, owner's characteristics etc. [1].

Both property value and rental income can be assumed to increase from renovation of properties with energy efficiency measures. A study found that a property with an Energy Performance Certificate/energy label A rating is typically worth 11% more, and can attract 1.9% higher rent than a D rated property in the same location [2]. In fact, based on the findings it could be estimated that asset value of buildings with excellent indoor environment is 10% higher than with the standard buildings and the price premium is likely to significantly increase in the next 5 years [3].

REFERENCES:

[1]. Rockwool, Copenhagen Economics, 2018. *Putting renovation on the agenda. Global perspective on the value of renovation.* Rockwool group.

[2]. Directorate General for internal policies, Policy Department Economic and Scientific Policy, European Parliament (2016): *Boosting Building Renovation: What Potential and Value for Europe?* Study for the ITRE Committee.

[3]. Castellazzi L., Bertoldi P., Economidou M. (2017): *Overcoming the split incentive barrier in the building sector. Unlocking the energy efficiency potential in the rental & multifamily sectors.* JRC Technical report.