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Renovation strategies for historic buildings

IEA SHC Task 59 | EBC Annex 76
Renovating Historic Buildings Towards Zero Energy

Renovation strategies for historic buildings

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IEA SHC Task 59 | EBC Annex 76: Deep renovation of historic buildings towards lowest possible energy demand and CO_2 emission (NZEB)

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The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

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- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
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To reach the objectives of SHC Task 59 the IEA SHC implementing Agreement has collaborated with the IEA EBC Implementing Agreement at a "Medium Level Collaboration", and with the IEA PVPS Implementing Agreement at a "Minimum Level Collaboration" as outlined in the SHC Implementing Agreement's Policy on Collaboration.

Contents

Disclaimer

Some of the text presented in this report has been published elsewhere as journal papers and conferences proceedings. All the texts have been written by the authors of these report and as part of the activities developed in the course of Subtask C. All text reproduced here is reference below.

1. Introduction	Rieser, A.; Leonardi, E.; Haas, F; Pfluger, R. A new decision guidance tool for the adaption of energy retrofit solutions in historic buildings. SBE21 Heritage Conference (In press)
2. Tool description	Rieser, A.; Leonardi, E.; Haas, F; Pfluger, R. A new decision guidance tool for the adaption of energy retrofit solutions in historic buildings. SBE21 Heritage Conference (In press) Hüttler, W., Hofer, G., Krempl, M., Trimmel, G. and Wall, I., 2018. Decision support tool for the innovative and sustainable renovation of historic buildings (HISTool). In *The 3rd International Conference on Energy Efficiency in Historic Buildings (EEHB2018)*, Visby, Sweden, September 26th to 27th, 2018. (pp. 226-235). Uppsala University. Stiernon, D., Trachte, S., Dubois, S. and Desarnaud, J., 2019, November. A method for the retrofitting of pre-1914 Walloon dwellings with heritage value. In *Journal of Physics: Conference Series* (Vol. 1343, No. 1, p. 012179). IOP Publishing.

1 Introduction

What is a renovation strategy?

> *Achieving ambitious energy efficiency levels in historic buildings requires both interventions on the building envelope and on the building services. Thus, a renovation strategy is defined as a combination of improvement measures on the passive (building envelope) and active (building services) systems.*

The renovation of historic buildings is a complex task, as standard packages of solutions cannot be applied as in the renovation of buildings without historical significance. Each measure must be assessed on a case-by-case basis. In addition to improving energy efficiency and technical maintenance, the preservation and the respect of the historic values must be guaranteed. The compatibility among the different measures of the renovation strategy must be carefully considered before being implemented.

Numerous examples of energy renovations of historic buildings existing nowadays demonstrate that the preservation of a building's character and heritage values is not incompatible with the improvement of its energy efficiency. Several of these exemplary projects are shown in the Historic Building Energy Retrofit ATLAS HiBERatlas (www.hiberatlas.com). The presentation of case studies in this database includes general information, statements on the renovation process, implemented measures and data on the evaluation of the measure.

In order to benefit from these experiences, it is key to make the technical information and the know-how behind the renovation accessible to other practitioners and homeowners. The identification and implementation of the most suitable solutions for energy refurbishment is of course nothing new and has been dealt with before in several scientific projects and publications [1, 2]. Handbooks and guidelines provide information about theoretical principles and general approaches for the choice of the most suitable solution. What is still largely missing, however, is the technically detailed presentation of solutions that have already been implemented.

In any case, renovation solutions are not directly transferable to other cases. The requirements differ from case to case with regard to the preservation requirements, the structural and material constitution, and the climatic conditions. However, by categorising historic elements commonly used in historic buildings in combination with existing conditions, solutions that have already been implemented can provide a good basis for further planning and identify suitable approaches.

1.1 Supporting the retrofit planning process in historic buildings

The IEA-SHC Task 59 aims at supporting decision-makers in the retrofit planning in historic buildings towards the definition of conservation compatible retrofit solutions in a "whole building perspective".

Since the first EPBD, legislative systems have resulted in a gap between practice and theory in balancing preservation, use and energy efficiency in historic buildings. On one hand, exemptions in the energy directives for historic buildings push towards "doing nothing". On the other hand, there is growing interest in finding integrated solutions to improve the sustainability of our built heritage. How to find a good balance between different aspects is still considered a challenge.

For this reason, one of the goals of Subtask C was to identify replicable procedures on how experts can work together with integrated design approach to maintain both the heritage value of the building and at the same time make it energy efficient.

This report includes an introduction to the decision-making process and a discussion of the common shortfalls and conflicts found in the case of historic buildings, and a review of tools supporting the whole building retrofit planning approach. Experiences of the different partners involved in the project were collected to illustrate the advantages and disadvantages of the individual approaches. In the Appendix, a journal paper looking at relation of the different tools with the EN 16883:2017 [3] guideline procedure to assess retrofit strategies in historic buildings is included. This paper, under submission at the time of writing this report, aimed at demonstrating how a more structured decision-making process is needed to bridge the gap between rigorous, universal standards and ad hoc decision-making processes.

2 A review of decision-making tools to support the identification, assessment, and choice of solutions

A comparative analysis on decision making tools which address the selection and assessment of retrofit solutions and allow defining packages (strategies) was performed to understand the logic behind each tool to carry out the selection of solutions and packaging. The assessment should also help understanding the connection between the tools and the knowledge gap.

2.1 Review methodology

Analogously to the methodology developed in Subtask C for the compilation of retrofit technologies, the work presented here relied on the wide group of international experts that for the working group of the IEA-SHC Task 59, in collaboration with the Interreg Alpine Space project ATLAS [4], for the compilation of the tools. The different experiences of the partners from research and practice as well as the geographical distribution across Europe guaranteed a broad and scientifically relevant sample.

For each tool, we have identified and analysed different elements:

- **Context:** geographical context of application for the item studied
- **Language:** list all (if available) languages of the tool
- **Date published:** last date available of publication and development
- **Author(s):** intended to identify who developed the tool: University / Society / EU Project, etc. If part of a project, the name of the project is mentioned (ex. EFFESUS project)
- **Availability & link:** direct link (if available) to the element, otherwise link to a relevant site or publication
- **Type:** webtool / DSS
- **Scope:** Entire building retrofit / Single measure / District level / Other
- **Structure:** tool's main organisation for navigation, input, and output data
- **Input:** minimum data required to obtain a result
- **Output:** content of the output provided to the end user

2.2 Description of different decision-making support tools

2.2.1 Tools collected

The majority of tools are related to a European context and are in English. Some of them have been translated in different languages. Only a few of them are related to a specific national context.

All the tools are included in the period from 2015-2020. Most of them have been developed within a research project with public funding. The rest were developed by academic institutions and innovation companies.

Table 1. Tools' overview

Tool	Acronym	Context	Language	Date	Author	Link
Historic Building Energy Retrofit Tool	**HiBERtool**	Alpine Space	English	2021	Interreg AS ATLAS / IEA-SHC TASK 59	https://www.hiberatlas.com/en/welcome-1.html
Climate for Culture Expert System	**exDSS**	Europe	English	2014	Climate for Culture Project	http://cfc.exdss.org/dss/riskcon
Alpines Bauen		Europe	German	2018	Alpines Bauen project	https://www.alpines-bauen.com/
Responsible retrofit guidance wheel		UK	English	2013 (2020)	STBA	http://responsible-retrofit.org/wheel/
Guidance wheel (French version)		France	French	2018	CREBA	http://www.rehabilitation-bati-ancien.fr/fr/outils/guidance-wheel
Effesus DSS		Europe	English, Spanish, Basque	2015 (2020)	TECNALIA	https://www.effesus.eu/wp-content/uploads/2016/01/EFFESUS-Deliverable-D6-2_Update-21-01-20161.pdf
Platform for Energetic and Technical Retrofit in Architecture	**PETRA**	Switzerland	English, German French, Italian	2015	SUPSI	http://www.petraweb.ch/
Decision Support Tool für die innovative und nachhaltige Sanierung von Gründerzeitgebäuden	**HISTool**	Central-Europe	German	2015	e7 energy innovation & engineering/ akp Architekten	https://task59.iea-shc.org/Data/Sites/1/publications/Decision%20support%20tool.pdf
Rénovation énergétique du bâti Wallon d'avant-guerre à valeur patrimoniale	**P-RENEWAL**	Wallonia (Belgium)	French	2020	P-RENEWAL	https://iopscience.iop.org/article/10.1088/1742-6596/1343/1/012179/pdf
Guidelines for decision making concerning the possible use of internal insulation in historic buildings	**RIBUILD**	Europe	English, Danish	2020	RIBuild	https://www.ribuild.eu/
Demi More –une approche intégrée du processus de conservation	**DEMI MORE**	Central-Europe	French, Dutch	2019	Interreg V-N DEMI MORE	https://maakmonumentenduurzaam.eu/het-project/resultaten/

2.2.2 Description

In the following, a brief description of the different tools is presented.

Table 2. Brief tool description

Tool	Description
HiBERtool	This tool offers the possibility to make a selection of solutions suitable for the refurbishment of different historic buildings. The selection is made using various decision trees on the topics of walls, windows, heating, solar and ventilation. Based on the answers to the question tree, the user is offered with a pre-filtered set of solutions for a refurbishment. Some documented solutions are partly general solutions, but to a large extent they are based on best practice examples from the HiBERatlas developed jointly between IEA-SHC Task59 and Interreg Alpine Space project ATLAS.
exDSS	The tool is developed as an interactive decision-tree. The system is divided in three parts with one set of questions for each part. First, the “Future outlook” part indicates how the indoor climate and risks related to the indoor climate might change in the near and far future for the building you are interested in. A “Risk assessment” part investigates which climate-induced risks that are relevant to your building and your collection. It gives suggestions for target specifications for temperature and relative humidity. Lastly, the “Indoor climate control methods” part investigates which indoor climate control methods that are suitable for your building, based on the type of building, type of collection, historic indoor climate and more.
Alpines Bauen	This tool, not specific for historic buildings, concentrates on step-by-step refurbishment. The tool provides three services. First, the tool offers detailed information of the connections between measures, and these are shown in two steps. As well, for the building services, targeted advice is shown. Lastly, the tool offers the creation of a targeted renovation timetable. Results can be downloaded as pdf.
Responsible retrofit guidance wheel	The retrofit guidance wheel is a web tool that aims at highlighting the technical, heritage and energy concerns of a whole-house retrofit strategy, considering the individual measures and the connections between measures. The tool considers interventions to fabric and services and behaviour change.
Guidance wheel	This adaptation of the retrofit guidance wheel to the French context includes some specific aspects about the local climate, legislation, etc. to make it better fit to the local reality.
Effesus DSS	The Effesus DSS/R2H is an innovative system for the assessment of energy-related interventions in built cultural heritage at building and district level. It helps users to select and prioritize energy interventions, with full respect to the historical significance of the buildings. The project developed a data model, a solutions repository, two software tools and a methodology that support the implementation of different processes within the framework. First, a categorisation tool was created to facilitate the implementation of a modelling strategy. A decision-making methodology was implemented in an expert system that guides the user in the selection of the best strategies for a historic district. The strategies are selected by using a multiscale heritage significance impact assessment method to estimate the applicability of the solutions, in combination with multi-criteria methods, to rank the strategies according to user preferences.
PETRA	The PETRA platform is a computer-based tool for decisions-making in networks for building (not necessarily historic) estate management that encompasses both a rapid assessment and the planning of renovations works and costs, according to different indicators. The methodology used in PETRA is principally based on a database containing the key dimensional coefficients compared to the intervention costs for all building types, and quick results on building conservation state and renovation scenario costs with an accuracy of +/- 15%.

HISTOOL	HISTool is a software-based tool for the analysis of the current building status, and a decision support tool for the innovative and sustainable renovation specifically of Gründerzeit buildings (partially standardized buildings built between 1840 and 1918 in Central European cities). The tool is designed to be applied particularly in the preparation and decision-making stage of renovation projects prior to the actual planning phase. A model consisting of 40 typical elements of Gründerzeit buildings, is the basis of the Excel-based software tool. Relevant elements and usage zones of Gründerzeit buildings are defined in diverse levels of detail.
P-RENEWAL	The objective of the P-Renewal project is not to "standardize" energy improvement solutions for existing buildings, but to propose, based on a diagnosis of the existing condition, a logical approach for the search of compatible solutions. Based on an analysis of the renovation measures, different intervention strategies combining measures to renovate the envelope and technical systems are proposed. These measures are complementary and make it possible to achieve a high level of interior comfort and energy performance while respecting as much as possible the specificities or the heritage value of the property studied and limiting the financial cost. The method used to propose these strategies takes into account five criteria: heritage value, occupancy of the dwelling and its use, financial investment, interior comfort, and energy performance.
RIBUILD	RIBuild guidelines focus on internal insulation of historic buildings. They use a step-by-step approach starting with setting the goal for the renovation, followed by describing how a visual assessment is to be carried out and what to look for (e.g., mould growth or rising damp), to decide whether the building is suited for internal insulation. This includes a description of remedial measures. The last two steps present the different types of internal insulation systems and their characteristics, and an evaluation of the environmental impact and life cycle cost of the solutions. The RIBuild guidelines are combined with a web tool (beta version) that, based on a number of precalculated simulations and a few user-defined inputs, provides a number of internal insulation solutions to be considered for the specific building.
DEMI MORE	The DEMI MORE tools consist of a visual DSS tool and an "integrated description of the conservation process". The structure and content of the DEMI MORE visual decision tool follows the 7 steps defined in standard EN16883: 1. Design or competition brief: targets and ambitions /2. Building survey and assessment /3. Assessment and selection of measures /4. De-sign implementation /5. Completion and post-occupancy evaluation /6. Operation and maintenance /7. Documentation. For all these steps the tool provides checklists (on building level).

2.2.3 Type, Scope & Structure

To make a link with the EN 16883 procedure, we have collected interactive tools, dedicated to support the selection and assessment of retrofit alternatives in historic buildings, adopting a whole building approach. Two types of tools have been identified for the purpose:

- *Web tools*: tools dedicated to select and assess retrofit measures, according to defined initial criteria. These tools are not necessarily directed to retrofit experts and sometimes help identifying possible interferences among different solutions in combination.

- *Decision Support System – DSS*: software/platform to guide the retrofit planning in a step-by-step procedure. This type of tools aims to support people making more deliberate, thoughtful decisions by organizing relevant information and defining alternatives.

The tools collected among the IEA SHC Task 59 partners are mainly web tools, with few examples of DSS. In the table below it is included also the HiBERtool, the Decision guidance Tool developed within the IEA SHC Task 59 in collaboration with the Interreg Alpine Space project ATLAS.

Table 3. Type and scope of the tools collected

Tool	Type of item	Scope
HiBERtool	Web tool	Single solution for type of building
exDSS	DSS	Single solution for type of building
Alpines Bauen	Web tool	Building details of connection between measures in case of step-by-step refurbishment and tips for building services
Responsible retrofit guidance wheel	Web tool	Entire building retrofit
Guidance wheel	Web tool	Entire building retrofit
Effesus DSS	DSS	Urban or district level
PETRA	DSS	Entire building retrofit
HISTOOL	Software-based tool	Entire building retrofit
P-RENEWAL	Web tool	Entire building retrofit
RIBUILD	Web tool	Single solution for type of building
DEMI MORE	DSS	Entire building retrofit

Differences can be seen in the tools structure as well as the criteria adopted. In general, the DSS tools are structured as decision trees, where questions are asked, and context parameters are defined. In the case of **Effesus DSS/RE2H**, for example, in order to facilitate the implementation of a modelling strategy, a categorisation tool was created linked to GIS-3D technologies to support the identification of the energy rehabilitation potential of historic districts.

In the **Climate for Culture exDSS**, focused on verifying the hygrothermal risk assessment of solutions in historic buildings, the decision automized system receives inputs from the type of building, type of collection, historic indoor climate and more. The **PETRA tool** is structured by a step-step process gathering relevant information of the building (1. information) to check the necessity of intervention (2. diagnosis). This serves for the immediate calculation of the energy balance according to current regulations (3. energy), so the upgraded and efficiency improvement occurs with the creation of rapid scenarios with targeted interventions (4. scenarios). A cost estimation is consequently generated allowing the comparison of the generated scenarios and its economic return (5. analysis) providing digital reports (6. report). There is a further step dedicated to the management and maintenance of the building (7. management).

Web tools, as for example **Alpines Bauen** and **Guidance Wheel** (UK and French versions), focus on the holistic assessment of a retrofit measure or a package of measures, considering the interconnections between the measures. They can be used to inform the development of a retrofit strategy, which may consider a step-by-step refurbishment or a deep renovation. Also, the **HiBERtool** work as a web tool by answering questions about the building, which leads the user to suitable solutions.

The tools are mainly referred to the entire retrofit process. Two of the tools (**Climate for Culture exDSS** and **RIBUILD Tool**) are directed to support both the selection of measures, considering the type of building and of collections, and the risk assessment of measures, considering the hygrothermal risk included in the DSS. The **Alpines Bauen** tool does not aim to give idea on retrofit solutions, but to provide building details and advice for connection between different solutions. **Effesus DSS/RE2H** is particularly useful for policy makers as it is referred to the entire retrofit process at urban level and the provided checklist on measures can support the selection of measures.

The **PETRA tool** is a network platform that can support not only the need for refurbishment in terms of energy of a building, but also the estimation of refurbishment costs. Due to the simplicity of use, the tool is suitable for a large number of users, from the individual owner to professional experts to real estate managers who are in charge of the maintenance, management, and conservation of the building over time.

The methodology used in **P-RENEWAL** is articulated in various steps. First, a typological analysis of buildings from the interest era is completed. Then, based on on-site studies performed on representative case studies, the evaluations of heritage values and performance are conducted. Finally, dynamic energy models are run to support the proposition and validation of retrofitting strategies.

The **RIBuild guidelines and web tool** are developed to explore if the external walls of a building are suitable for internal insulation and if yes (possibly after implementing some remedial measures) what kind of insulation system should be considered. The RIBuild guidelines contain information at different levels of detail, and are targeted at building owners, building professionals and researchers. The RIBuild tool (beta version) can also be used by different target groups as the requested user input are quite simple, however it is not fully developed to be used as a stand-alone tool.

The **DEMI MORE visual decision tool** (and document) is mainly based on four standards and guidelines:

- EN 16853: Conservation of cultural heritage - Conservation process - Decision making, planning and implementation (2017)
- EN 16883 Guidelines for improving the energy performance of historic buildings (2017)
- VDI 3817 Building services in listed and historical buildings (2010)
- CIBSE Guide to building services for historic buildings, Sustainable services for traditional buildings (2002).

The tool provides a methodology seen from a holistic view on 'conservation of heritage' where refurbishment is one part of. The focus is guiding the user (from the individual owner to the professional expert user) through the process rather than suggesting or defining concrete retrofit solutions. Links to appropriate tools to select solutions are provided in the document 'integrated description'.

The **HiBERtool (Atlas)** provides the user with ideas and suggestions for various solutions. The selection is made using different decision trees on the topics of walls, windows, heating, solar and ventilation. Based on the answers to the question tree, the user receives selected solutions for a refurbishment which have been documented from the partners of the ATLAS Interreg project and Task 59. The documented solutions are partly general solutions for the refurbishment of different parts of the building but to a large extent they are based on best practice examples from the Interreg Alpine space project ATLAS. Simple questions provide information about the type and function of the solution and provide the user with links and information about the solutions.

The **Guidance Wheel** provides information on the risks associated with a retrofit strategy, considering the individual measures and their interaction with other current or planned measures. The tool considers interventions to fabric, services, and behaviour change, and was developed specifically to fit the historic building stock and its context in the UK (UK version) and France (French version).

It provides a level of risk, suggests action for minimising or mitigating risks, and points at relevant references for a deeper analysis of the issue. It is a useful tool for risk identification and helps to frame the retrofit process within a wider risk management process. It is not a prescriptive tool but gives the designer the relevant information for the development of a retrofit strategy.

2.2.4 Input and output

In order to support the user best when answering the questions of the decision trees, **HiBERtool** provides information texts for the more complex questions, which should facilitate the choice of the answer options.

The **Guidance Wheel** requires information on the context of the building, namely the heritage value of the building, its condition, the level of exposure to wind-driven rain, the number of exposed sides (for ventilation), the occupant's energy use and interest in the building.

The **PETRA tool** requires accurate information of the building. This is provided by entering energy data collected from an on-site inspection, building plans, photographs or 3D models, information on services, constructive materials, user behaviour, etc. For the analysis, evaluation and protection of the heritage buildings, the tool considers a datasheet developed by the *Ecole Polytechnique Fédérale de Lausanne* (EPFL) that allows inserting descriptive comments for macro elements of analysis and to define a building heritage class based on the regulations in force. The class will be comparable with the new classification after any rehabilitation interventions. It defines six classes from A to G, according to the assessment of the public body for heritage protection and is based on seven criteria: i. Architectural value; ii. Authenticity; iii. Integration on the site; iv. Uniqueness; v. Representativeness; vi. Historical value- cultural; vii. Affective value. Furthermore, it is possible to indicate the level of degradation of every single element of the building.

Different levels of decision making (LoDM) have been established in the **EFFESUS DSS** depending on the information availability and the stage of the process. These LoDMs range from low levels (LoDM 0 and I) where only general information regarding the city is necessary and just generic strategies are provided to medium-high levels (LoDM II and III) where an external data model is necessary to structure the information and tailored strategies are provided to provide the input data regarding the characteristics of the historic district. The DSS will need to take into account the user's input and using a data-driven decision approach, query the solutions repository and provide user with the results.

Following a 'bottom-up' approach, the authors of **P-RENEWAL** propose five steps to achieve its implementation. First, a typological analysis. of dwellings built before 1914, including numerical and geographical distribution analyses, was performed on the Walloon building stock. Representative occupied buildings were selected based on the main building types. Then, a technical analysis of case studies was carried out. During this step, heritage specificities were identified to elaborate appropriate strategies. Furthermore, an evaluation of the potential was made to propose alternative options. Third, the ideal goals to achieve in terms of comfort, energy performances and environment were identified. An inventory of all possible interventions on envelope and systems relevant for each case study was compiled next. Lastly, combinations of measures were evaluated by the means of dynamic energy models. Thus, in order to profit from this methodological tool, the user would need to find the case study that best fits the building under renovation and follow the decision trees implemented in the project. Otherwise, or in the case of different building stock, the methodology proposed here would have to be followed step by step.

The **RIBuild tool** (beta version) is based on a huge number of precalculated simulations using a probabilistic approach to represent the variation in, for instance, material properties and outdoor climate, thereby indicating the risk of applying a certain solution. Simulation input data was pre-selected by RIBuild partners based on the research performed in the project and their previous experience. Thus, user input consists just of location of the specific building, orientation of the wall, the wall type and thickness, and the presence of internal or external rendering.

The **DEMI MORE visual decision tool** requires information on all steps referred to in the EN 16883, namely the ambitions and objectives (future use, budget, sustainability ambitions, regional legislation, research and design team), the building survey and assessment (heritage value of the building, its condition, use of materials, context..), the assessment and selection of measures (preliminary measure, intervention philosophy, conservation options, risk evaluation, evaluation criteria for selection), design implementation (conservation plan, quality assurance), completion and post occupancy evaluation, operation and maintenance (maintenance plan, etc) and documentation (energy performance, external communication).

Table 4. Input and output data of the tools collected

Tool	Input data needed	Output data provided
HiBERtool	The user has to answer different questions depending on the topic of the solution. Questions are mostly generic and do not require any specific pre-survey (e.g., preservation of the appearance of the façade, availability of driving rain protection etc.).	Thanks to the customised decision trees, users will be guided to a suitable solution category where the description of the solutions can be download as PDF. Reports include information on technical and energy performance, interaction with monument conservation, and further links.
exDSS	Information about the building (size, use, location, etc.) is provided by means if a predefined questionnaire following the three parts of the tool (1: future outlook, 2: risk assessment, 3: indoor climate control methods)	Information to support the technical analysis of single retrofit measures is provided. All aspects include further links to more detailed publications.
Alpines Bauen	Information about the building is compiled by means of three different predefined questionnaires depending on the main interest (building envelope, building service, or renovation planning). Information added can be saved to be accessed at a later stage	Output information is focused on the technical details of connections between measures in step-by-step refurbishment. Output is presented can be downloaded as PDF files with all the relevant information, including technical details. In the case of the renovation planning, a suggested Gantt chart of the planned intervention is included.
Responsible retrofit guidance wheel	Building context (heritage value, condition, exposure to wind-driven rain, exposed sides), and occupant's energy use and interest in the building	Report for a selected package of measures presenting a list of concerns, as well as a list of suggested actions to minimise/mitigate the risks before, during and after installation.
Guidance wheel	Building context (heritage value, condition, exposure to wind-driven rain, exposed sides), and occupant's energy use and interest in the building	Report for a selected package of measures presenting a list of concerns, as well as a list of suggested actions to minimise/mitigate the risks before, during and after installation
Effesus DSS	All the information required is structured in a 3D model based in CityGML. Besides the geometry, the model provides information at urban level regarding heritage significance, thermal characteristics of the buildings and their use.	Inputs from the data model and the repository are used to produce a current state of the district, a list of possible solutions classified by their applicability, and a priority list of strategies likely to be suitable in the context of a specific historic district and their impact at district level.
PETRA	Accurate information of the building from an on-site inspection, building plans, photographs or 3D models, information on plants, constructive materials, user behaviour, etc.	Technical and energy buildings analysis. Estimation refurbishment costs Alternative retrofit scenarios and its economic return and financial impact; Information for future management and maintenance; Digital reports.
HISTOOL	A model of the building consisting of 40 predefined elements is the basis of the Excel-based software tool. Relevant elements and usage zones of Gründerzeit buildings are defined in diverse levels of detail. The level of detail depends on the influence of a certain zone on the renovation costs.	The integrated energy performance and life-cycle cost calculation leads to the derivation of life-cycle costs of different renovation variants. A comparison of life-cycle costs of different renovation options leads to information-based renovation decisions.
P-RENEWAL	'Bottom-up' approach with five steps, 1 Typological analysis, 2 Investigation of	Various retrofitting strategies for each case study are elaborated by combining individual

	case studies, 3 Discussion of retrofitting objectives, 4 Listing of retrofitting measures, and 5 Evaluation of retrofitting strategies	retrofitting measures (on the envelope and on the technical system) in order to improve energy performance and comfort.
RIBUILD	Location and orientation of the building, wall thickness, presence of plaster internally or externally	List of relevant solutions for internal insulation
DEMI MORE	Requires information (answers to questions in checklist) on all steps referred to in the EN 16883, some info is mandatory, other not	For solutions is referred in the integrated description to legislation, guidelines, and tools such as for instance the assessment frameworks for specific refurbishment measures developed by the regional authority

In the **HiBERtool**, solutions were assigned to the respective questions by the decision tree. The storage of solutions was done by the authors. Several categories are available, and it was up to the authors to decides under which category the solution belongs to. A total of about 120 solutions were documented at the time of writing this report, but the tool is designed in a way that it can be extended at any time and new solutions can be integrated.

The results of the solutions from the HiBERtool provide an overview of the solution (e.g., What is the solution? Why does it work?). In most cases, these solutions have been previously implemented and thus serve as an inspiration to find ideas for the respective case. Links to further publications and documentation allow the user to develop a better understanding of the solution.

The **Guidance Wheel** identifies the advantages of a measure, the level and type of technical, heritage and energy concerns, and the possible measures that are related to the selected measure. The measures can be selected from a number of possible measures (e.g., 68 measures in the UK version). From this initial analysis, renovation strategies can be considered.

The result of the Guidance Wheel is a report for a selected package of measures. The report presents a list of the level and type of concerns for the package of measures, as well as a list of suggested actions to minimise and mitigate the risks (associated with the identified concerns) before, during and after installation. This information can be used for the assessment of the selected package of measures and the comparison with possible alternatives. Moreover, the Guidance Wheel points to relevant academic and technical references.

The **PETRA tool** allows to indicate the level of degradation of every single element of the building and to implement an initial planning of the interventions by choosing the priorities at the time of diagnosis. It allows also to plan targeted and controlled interventions to maintain the real estate value of the building and entire real estate parks. In the PETRA tool, renovation solutions are proposed for individual building elements, there is no general repository. Two maintenance interventions are included for each element, and one to four improvement interventions for energy efficiency. The solutions are displayed by the tool on a decision grid, and it is up to the expert to find the best and optimal solution based on the client's needs. Those choices are placed in the different recovery scenarios.

The PETRA tool allows the comparison between the current state of the property and the renovation strategies generated with the new proposals of retrofit interventions, highlighting conservative, economic, energy and environmental aspects to increase the value of the property. PETRA is based on a previously developed inductive analysis method, namely EPIQR+ (Energy Performance Indoor Environment Quality Retrofit). It also supports the decision-making process of intervention measures, provides support to performs diagnosis, and uses economic evaluation concepts based on the INVESTIMMO (Franco G., 2020) model, for determining the best investment strategy in energy refurbishment. The methodology relies on a database containing the key dimensional coefficients compared to the intervention costs for all building types. It allows to make a diagnosis of both physical and functional conservative status through a systematic and coded diagnosis to determine the energy balance as function of energy aspects related with costs analyses, certification buildings labels and SIA and EU Codes. Results are compatible with local energy efficiency labels (e.g., Cantonal energy certificate for buildings CECE® and the Swiss construction standard MINERGIE®)

In the **HISTool**, specific renovation measures are predefined for each of the 40 predefined elements. The library contains a thorough collection of measures, e.g., to improve thermal resistance, to reduce thermal bridges, etc.

Every renovation measure is defined with its technical characteristics, thermal qualities (U-values), lifetime and costs, which compose data sets that are stored in a database. All data sets consist of a detailed description of the individual components, the cost of every component and the technical parameters. The result of the calculation procedure is a comparison of the life-cycle costs of different renovation variants, which reflect different thermal-energetic qualities. The detailed results contain the respective energy performance indicators, CO2 emissions and a summary of all arising costs per variant structured in cost categories, the present value, the accumulated present value and so on.

In the **RIBuild tool** (beta version) the user gets a list of relevant solutions, based on their input. The more detailed the inputs are, the shorter the list of solutions returned. It might happen that no solutions are suggested as the tool at present does not cover all combinations of location, orientation, wall type and thickness, etc., used as variables in the simulations. This is explained in the disclaimer of the tool.

The **DEMI MORE** visual decision tool provides a guidance and systematic overview for the user of the whole conservation process of a building. For the selection of specific measures, it refers to the legislation, guidelines and tools used locally, such as the assessment frameworks for specific refurbishment measures developed by the regional authority (www.onroerenderfgoed.be/gespecialiseerd-advies). The **DEMI MORE** visual decision tool gives the user an overview of the way the steps in the EN 16883 are followed and the specific systems, standards and technical references used to come to the selection of measures. The DEMI MORE visual decision tool has no fixed assessment system but asks the user to refer specific to the system(s) that are used.

3 EN 16883:2017: the application of support tool in the planning process to define renovation strategies

Decision-making is a complex process of identifying, evaluating, and choosing alternatives based on the values, preferences, and beliefs of the decision-maker. In the context of built heritage projects, this complexity is amplified as the decision makers should consider, in addition to economic resources, environmental impact, or legislative constrains, the analysis of historical and artistic values of the building.

The choices made in a specific case, among all available options, depend heavily on the initial goal setting: each goal might be directly linked to one or more criteria, possibly quantifiable by indicators, to support the evaluation of alternatives [5]. The complex nature of the problem is linked to the variety of stakeholders involved in the process, as well as other factors influencing the choice of the 'optimal' combination of solutions ('strategies'). In order to reach decisions that balance all aspects of sustainability, a more structured decision-making process is needed that bridges the gap between rigorous, universal standards and ad hoc decision-making processes [6].

To fill the gap between theory and practice, the EN 16883:2017 - 'Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings' was published. This European Standard provides guidelines for sustainably improving the energy performance of historic buildings, while respecting their heritage significance. The use of this standard applies to historic buildings of all types and ages and is not limited to buildings with statutory heritage designation.

EN 16883 presents a normative working procedure for selecting measures to improve energy performance, based on an investigation, analysis and documentation of the building including its heritage significance. The procedure assesses the impact of those measures from both energy and conservation point of view. As indicated in the procedure of the EN 16883, we can recognize seven steps in the decision-making process:

1. **Identification of objectives**: to make a decision, you must first identify the problem you need to solve or the question you need to answer.
2. **Collection of relevant information**: relevant and accurate information is needed for building characterization and energy evaluation. Special attention should be paid in analysing peculiar features of the historic environment, understanding the changes of its use, of its constructive characteristics and its material restrictions.
3. **Identification the alternatives**: identify possible solutions to your problem. There is usually more than one option to consider when trying to meet a goal. This balance requires a comprehensive understanding of historical architecture and technical know-how.
4. **Assessment of solutions and strategies**: implies carefully weighing the different possible alternatives (single solution or a combination of retrofit scenarios), with the support of tools for evaluation, energy simulation, financial assessment, risk assessment, etc. Once you have identified multiple alternatives, it is necessary to weigh the evidence for or against said alternatives. The single solutions are considered, as well as the combination in scenarios ("strategies").
5. **Choose among alternatives**: here is the part of the decision-making process where the actors involved in make the decision.
6. **Implementation of solutions**: the best scenario has been chosen. The solutions are defined.
7. **Check of the decision**: after a predetermined amount of time, it is necessary to take a look back at your decision. Did you solve the problem? Did you answer the question? Did you meet your goals?

The identification of solutions cannot be separated from the analysis of the building and its requirements. Often the identification concerns only the verification of single retrofit options, not necessarily taking possible interference between different alternatives into consideration. Further, the quality of decision-making in historic buildings interventions is a compromise between the costs and benefits of the specific project, not simply a technical practice, but also a socio-cultural activity, considering historical, cultural, economic, and social factors simultaneously.

In addition to that, some practical variables can then be linked in the assessment, for example, to the timing of the project, others to the economic feasibility of the interventions, reversibility and reliability of selected measures, comfort improvement, energy savings, environmental effects, etc [7]. Moreover, additional quantitative (for example, the conservation conditions of an historic building) and qualitative information (for example, the people's behaviour towards implementing retrofit actions) can be incorporated in the process [8, 9].

This balance requires a comprehensive understanding of historical architecture and technical know-how in the assessment of solutions. Therefore, in addition to the capacity of 'reading' the building, the assessment of solutions has also to evaluate the pros and cons of choices in a multidisciplinary and integrated way. The European guidelines propose for this reason a risk assessment matrix, focusing the attention on (i) heritage significance preservation; (ii) technical compatibility; (iii) economic viability; (iv) energy efficiency; (v) environmental impact; (vi) indoor environmental quality; (vii) aspects of use. The set of these criteria encompasses what are the principles for a good integrated energy retrofit project of a historical building.

The guidelines, however, do not give solutions neither specifies how to identify the best solutions / strategies for a single case, as its scope is to provide a generalised iterative planning process that is adaptable in different contexts. Each case requires a tailored analysis of the existing resources and a dedicated assessment of the different scenarios. This process is thought to be carried out by a multidisciplinary team, although the proper balance of that team is not always verified. Multiple actors are involved in the decision-making process, and sometimes with conflicting objectives. This includes stakeholders such as public government representatives, architects, architectural historians, developers, and owners.

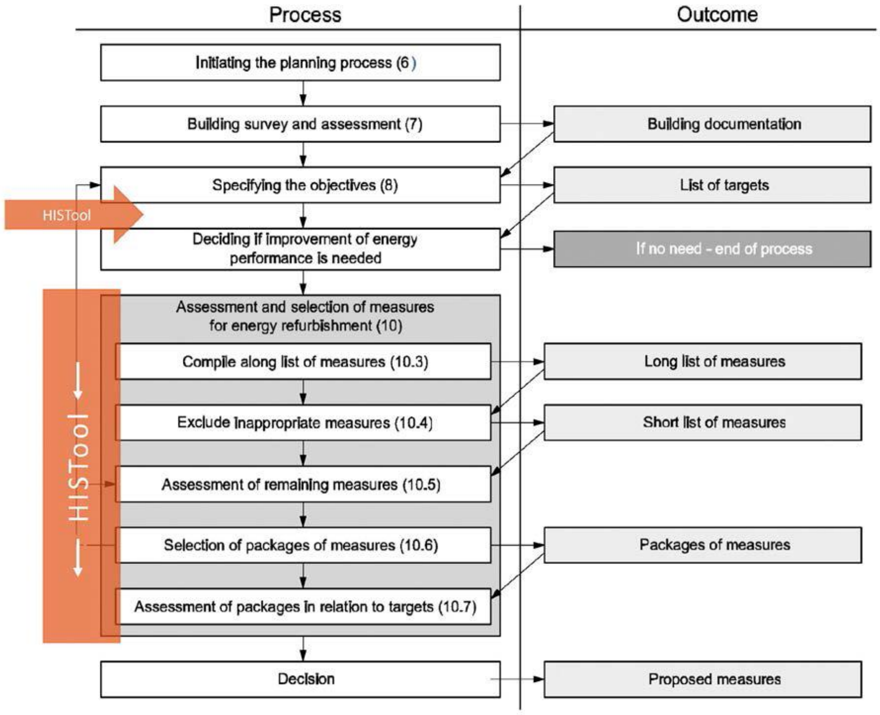

Figure 1. Flow chart showing the proposed procedure in EN 16883:2017 and application of HISTool (Source: Hüttler et al., 2018)

Hence, it is still necessary to investigate how the steps of identification (step 3), assessment (step 4) and choice of alternatives (step 5) can be supported with additional tools and resources. Some partial analyses have already been done looking at the application of certain tools in the context of the guidelines (e.g., HISTool Figure 1), but it would be necessary to understand how all the already available tools presented here could be applied within the procedure proposed in the EN 16883:2017 guidelines. That would eventually lead to a more robust decision-making process where complementary tools could be connected for the identification of the most suitable renovation strategy.

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