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A new decision guidance tool for the adoption of energy retrofit solutions in historic buildings

Alexander Rieser[1,3], Eleonora Leonardi[2], Franziska Haas[2] and Rainer Pfluger[1]

[1] Department of Energy-Efficient Buildings, University of Innsbruck, 6020 Innsbruck, Austria;
[2] Institute for Renewable Energy, Eurac Research, 39100 Bolzano, Italy;
[3] Corresponding author, alexander.rieser@uibk.ac.at

Abstract. Energy retrofit of historic buildings often represents a challenge for owners and practitioners due to the lack of knowledge and access to suitable solutions. The growth of awareness and interest in sustainability has caused an increase in the number of solutions available for improvement of historic buildings' energy performance. What it is still missing is their dissemination across the involved stakeholders. This will improve practitioners' trust on these solutions and the adoption by owners in the building renovation. In the framework of IEA SHC Task 59 and the Interreg project ATLAS, experts have collected well established and innovative solutions for historic building renovation presented in an online decision guidance tool. The set of solutions is structured in four groups: wall insulation, window solutions, solar systems and HVAC systems. For each group a decision tree was developed to guide the end-user with questions to the appropriate solutions for their building. The tool aims to inspire and motivate technicians and owners with a large number of possible solutions, which serve as a basis for further investigation and planning. With more than 130 documented solutions it is already a comprehensive tool that can be used as basis and extended in future.

Keywords – Decision guidance tool, historic buildings, energy retrofit solutions, refurbishment

1. Introduction

The renovation of historic buildings is a complex task, as standard solution packages 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.

However, numerous realized energy renovations of historic buildings demonstrate, that the preservation of the building´s character and associated historic attributes is not contradictory to the improvement of energy efficiency. Several such exemplary projects are shown in the Historic Building Energy Retrofit ATLAS HiBERATLAS (www.hiberatlas.com). The presentation 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 a key issue to make the technical information and the know-how behind accessible. The topic of viable solutions for energy refurbishment is of course nothing new and has been dealt with in many 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 almost completely missing, however, is the technically detailed presentation of solutions that have already been implemented.

Nevertheless, this does not mean that the solutions presented in this way are simply transferable. 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.

2. Methods

The development of the new decision guidance tool is based on two main pillars: the collection of technical solutions for the application in historic buildings and the establishment of a query structure that intuitively leads to the appropriate solution. Finally, the compilation is presented in a well-structured online guidance tool to building owners and technicians.

From the beginning, the collection of technical solutions pursued the documentation of realised and tested solutions down to the technical detail, as well as the evaluation of these solutions for their applicability in the historical context. So far, such in-depth descriptions have been found mainly in separate publications and mostly focused on a limited number of solutions. The value of such a compilation therefore is less the presentation of technical innovations and more the synopsis of the state of the art.

In the collaborative project IEA-SHC Task59 [3] and the Interreg Alpine Space project ATLAS [4], it was possible to include the knowledge of a widely based group of international experts in the compilation of suitable solutions. The different experiences of the partners from research and practice as well as the geographical distribution across Europe guaranteed a broad and scientifically sound data set.

The basic aspects that had to be fulfilled for each documentation of a solution were: (1) the energetic improvement of the considered element, (2) the technical functionality as well as (3) the consideration of the compatibility with historic structures. Thus, in order to achieve a coherent and comparable documentation, for every single solution a set of questions was answered under the aforementioned aspects:

- What is the solution?
- Why does it work? (compatibility with conservation, technical function, energy improvement)
- Description of the context (What is special about the building and its surroundings?)
- Pros and Cons of the solution
- Additional Information (Publications, Links to further information)

The written documentation is visually supported by drawings and photos. The main value of the collection, however, is that most of the solutions presented are used in practice. Many of the solutions can be linked to the documentation of the overall renovation project in the HiBERATLAS. Through this reference, one can better understand the considerations that led to the decision for the specific solution and gets a more comprehensive insight.

Furthermore, some of the documented solutions have been studied in detail by means of numerical simulation and/or in-situ monitoring as part of research projects. All of these data provide useful information in the appraisal of the solutions. A few of them are innovative solutions that are still not commercialized but provide an insight on future development.

Another important step is the presentation and communication of the solutions for the end user. Each catalogue needs a table of contents in order to locate the relevant information quickly and conveniently. In the course of the project, decision trees were defined for the respective elements to lead the user to appropriate solutions and exclude irrelevant possibilities. The query mostly relates to two points: (1) what stock is to be assumed and (2) what options are available with regard to historical values. These question trees are presented by an online tool, the so-called Historic Building Energy Retrofit Tool - HiBERtool (link will be provided soon at www.hiberatlas.com). The purpose of this tool is to ensure that the solutions finally identified in this way can be downloaded as a PDF and for most cases contain the link to the respective best practice example on the Hiberatlas.

3. Results

Three types of results could be achieved: first the documentation of the different solutions for the various building elements; second the developed query which is the basis for the third and thus the final result, the online tool HiBERtool.

3.1. Documentation of Solutions

As already mentioned, the solutions are assigned to the building elements Walls, Windows, Heating, Ventilation and Solar. In the following, the currently available documentation results are summarized and explained with an example.

3.1.1. Walls:

In the group of wall solutions, a total of 39 solutions were documented. The solutions can be assigned to the categories: internal insulation, external insulation, external insulation combined with internal insulation, frame infill insulation, cavity insulation, reversible systems and innovative solutions. Especially when renovating historic buildings, the external appearance is in many cases of heritage significance. It is therefore not surprising that a large proportion, namely 18 of the 39 solutions, are assigned to the category "internal insulation". But interesting renovation approaches for filling existing cavities were also documented. Innovative reversible systems show a completely different approach in preserving existing building fabric and unusual insulation materials such as aerogel, hemp concrete or reed mats show a range of possibilities for energetic improvement.

Figure 1: *left*: installation of internal insulation (Perlite) at Villa Castelli © Eurac; *middle*: Blowing on the wet cellulose insulation material © HES; *right*: installation of wood fibre © Eurac

3.1.2. Windows

The window solutions were also divided into different groups. The first distinction was made on the basis of the historic window type: (1) single window, (2) coupled window, (3) box type window and (4) single window with winter windows. With the classification according to the type of window to be retrofitted, the possible impact of the refurbishment on the historic appearance and character of the building as well as on the window itself was defined in a second level. The higher the possible impact, the higher the energy efficiency that can be achieved.

In total, 16 solutions were documented. Solutions for (i) interventions with low impact are measures such as repairing the window, installing additional seals on the frame, additional foils on the glass or repairing the shutters. These solutions have no impact on the visual appearance and material and also no spatial impact on the building. In the case of solutions with (ii) impact on the internal appearance of the window, the glass or the inner sash of e.g. box-type windows are replaced. Furthermore, solutions of additional modern windows on the inside of the original window are also documented (Figure 7, right). In total, 6 solutions were documented for this category. The next level of impact of the intervention is an (iii)additional change of the exterior view. Changing the external glass can result in an important change of appearance, as the reflection of new modern glass is different from the historical glazing. The last category (vi) affects the whole historic window. In this group solutions such as replacing the existing window with a replica are included.

Figure 2:

left: insert sealing at Dante School Bolzano © EURAC;

right: new added window layer on the inside at the "Giatlahaus" in Innervillgraten ©UIBK

3.1.3. Heating and Ventilation

In the course of documenting the ventilation solutions, the focus was on different topics. A total of 18 solutions were documented, including some general descriptions of solutions that cannot be assigned to a best practice example. Three solutions about airtightness were integrated which deal with the planning and execution of airtight levels using practical examples. Three fact sheets for cascade ventilation, extended cascade ventilation and active overflow systems were created with regard to low invasivity of air distribution and planning. Another documentation includes the use of existing chimneys or shafts for the distribution of the ventilation pipes. The remaining 11 solutions refer to the location of the ventilation unit (central, decentral) as well as to the possible distribution in the floor, ceiling and façade based on best practice examples.

Figure 3:

left: supply air opening in a farm house in Tyrol © Michael Flach,

right Ventilation pipes in the floor at Doragno Castle in Switzerland © *L. Carugo*

The documentation of solutions (totally 25 solutions) for heating can be divided into two groups. The heating production and distribution. Especially in historic buildings, the question of heat distribution is typically more difficult to answer than the production itself. Various practical solutions for floor heating, wall heating and normal radiators are described in the documentation. Alternative distributions such as radiators with visible piping, air heating and infrared heating panels are included as general descriptions. Since most of the documentation is related to a practical best practice example, many of the documents contain a description of the distribution and the associated production (local stoves, heat pumps, pellet boiler, wood chip boiler, cogeneration plant, district heating and biogas).

3.1.4. Solar

The solar energy solutions documented mainly concerned solar thermal collectors and photovoltaic systems compatible with historic buildings. Totally, 37 solutions are documented up to now. They are divided in the following categories: plants attached to the roof, roof integrated, attached to the wall, façade integrated and free-standing solar plants and solution for the integration into the landscape.

Additionally, in order to give an alternative for extreme cases and have a comprehensive documentation, some solutions for local sharing of renewables and models for sharing the renewables energy via power-network are documented. The case studies documented demonstrate that most solutions used to date in historic buildings are roof-integrated systems (22 solutions out of 37).

Figure 4: *left*: colour modules terracotta of PV © Solaragentur Prix Solaire Suisse 2018, Maison rurale Galley, 1730 Ecuvillens/FR; *middle*: solar thermal units on ten protected blocks of flats in the City of Edinburgh. © HES; *right*: side view of the House Breuer (Austria) with non-reflecting PV modules with a dark background ©FG Marcello Girardelli

In some case studies, the solar thermal and photovoltaic systems have the same colours as the roof and therefore well camouflaged. In other cases, these systems are not visible from the street and sometimes they are just part of the architectural concept.

3.2. Decision trees

As already mentioned in chapter 2, decision trees were developed for the respective elements. These decision trees allow a simple and quick pre-selection of the previously described categories of the respective elements. Since the exact assignment of a solution is very complex, especially in the case of historic buildings, the questions are formulated in very general terms and in a way that is simple to understand.

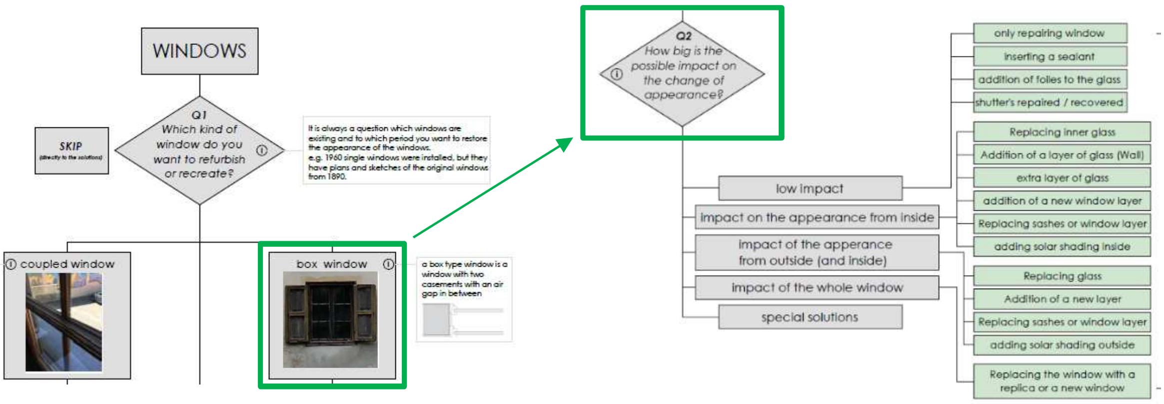

Figure 5: decision tree of windows: Q1 about the type of the windows, Q2 about the possible impact on the appearance. The resulting categories refer to the documented solutions.

Basically, the decision trees follow a basic structure. The first questions should provide information about the existing building or the situation to be renovated. In the case of walls, the question is obviously directed to the type of the wall to be retrofitted. In the case of windows, it is the window type. For ventilation, information about the airtightness of the building, the room height and the availability of existing chimneys and shafts must be requested. For heating, the current heat distribution situation is interesting. In the case of solar & photovoltaic solutions, it is important to know where an integration of modules is possible at all (roof, façade or neighboring properties). Depending on the answers to these questions, the user is led to suitable categories containing the various solutions.

A further subdivision is provided by the question of the historical context or elements worthy of preservation. In the case of walls, this can concern the façade, or in the case of windows, the possible influence on the appearance of the windows and the building as already described above. An example of the window decision tree can be seen in figure 5.

3.3. Hibertool

After explaining the structure and classification of the solutions, the final result is presented: The Hibertool. Based on the decision trees, the tool presents the online mask and actual interfaces for the user. On the website, the respective element can be selected. The questions of the decision trees lead then to the final output, a PDF describing the appropriate solution that can be downloaded and the link to the best practice example.

Figure 6: Website *HiBERtool*: (1) Choosing the element, (2) Answer the questions, (3) final result: Download of the PDF Documentation of the Solution and the Link to the best practice example of the *Hiberatlas.*

As an example, solutions are requested for the refurbishment of the walls of a farmhouse in solid timber construction. Starting from the structure of the tool, the question tree for the element "Walls" is started. Figure 7 illustrates the course of the questioning and leads to the result category "internal insulation".

For internal insulation, a wide variety of practically implemented solutions are given as results (perlite / aerogel for stone walls, calcium silicate for brick masonry, dense wood fibre for stone masonry, etc.). After reviewing the solutions, these are relevant for the above described farm: Cellulose for log walls - farm "Neuhäusl" as well as sheep wool with vapour control layer - Giatlahaus.

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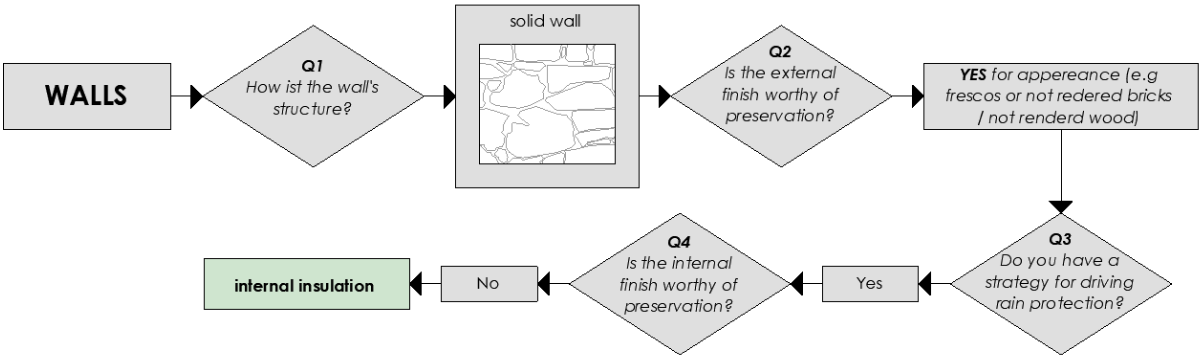

Figure 7: example of a decision path of a historic farmhouse with log walls

The example should illustrate the discussion on the benefits of the documentations, the decision trees and the tool. The basic structure and the type of documentation have been determined and provide the necessary transparency of practically implemented examples where not only the technical function of the solution is examined but also consideration has been given to the context of the building and it´s heritage significance. Of course, the current scope is only a start to answering this issue, because to stay with the example described above, the output of 20 solutions with associated best practice documentation would be of far greater benefit.

Figure 8: *left:* Black wind paper and the frame construction for the OSB panels in “Hof Neuhäusl” © DI Hans Peter Gruber; *right*: New block wall on the inside of the “Giatlashaus”. The space between the old log wall and new log wall was insulated with sheep wool. ©Benjamin Schaller

4. Discussion

The documented solutions and the tool structure aim to offer to the user a basis, inspiration and source of information for further planning. Of course, the tool does not want to substitute the technician in his job and makes this clear in the solutions’ documentation. Each historic building has to be analysed and retrofitted with targeted solutions that must be evaluated by an expert case by case.

Regarding the tool structure, a classification according to building types and regions was discussed in the course of the research projects. The existing HiBERtool currently contains about 130 solutions. For a building-specific classification as envisaged in the beginning, however, many more solutions would be necessary. Other elements such as the roof and the floor are not yet included in the tool. However, the tool is designed in such a way that further elements can be added in future projects and further subdivisions can be made. The current result is the basis for a comprehensive catalogue for the energetic renovation of historic buildings. This will become more comprehensive and relevant with each additional documentation.

5. Conclusion

Practical examples are important references in many areas of civil engineering. Also, in the renovation of historic buildings, already realised solutions and examples are of enormous importance as one can assess and evaluate the final result. The complexity of such a renovation is enormous, because besides the technical function, the history of the construction has to be considered. The documentation and evaluation of such solutions requires comprehensive know-how in the fields of building physics, historical and modern building techniques as well as the preservation of historic monuments. In the collaborative project IEA-SHC Task59 [3] and the Interreg Alpine Space project ATLAS [4], this broad knowledge was used with the help of various partners to create an online tool, the so-called Historic Building Energy Retrofit Tool - HiBERtool (www.hiberatlas.com), for the renovation of different elements of historic buildings. The combination of the documentation of individual measures in the HiBERtool and in many cases the reference to complete building documentation in the Historic Building Energy Retrofit ATLAS HiBERATLAS (www.hiberatlas.com) represents a fundamental source of information for the renovation of such buildings. This tool aims to give inspiration and impulses for identifying retrofit solutions. The number of 130 documented solutions represents a good basis to publish the tool. A future increase and an extension to roof and basement retrofit solutions is desired and important to make the tool comprehensive.

6. References

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[4] ATLAS Interreg Alpine Space project Advanced Tools for Low-carbon, high value development of historic architecture in the Alpine Space (https://www.alpine-space.eu/projects/atlas/en/home)

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