ATLAS-FeliCity: Supporting Energy Retrofit of the Heritage Building Stock Through a Simplified Digital Twin

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Abstract

Retrofitting the heritage buildings (listed or not) is a complex task due to legal, financial and technical barriers. The decision makers often lack a holistic view about the condition of the existing building stock in their jurisdiction, possible renovation options and the impact of the renovation actions on the overall sustainability performance of the building stock. Within the ATLAS research project, the ATLAS-FeliCity online tool was developed. The tool provides a simplified digital twin version of the built environment and allows the user to conduct an energy performance analysis at various spatial scales (single, or portfolio of buildings). The developed tool was tested in different demo sites in the Alpine Space area characterized by similar building types and specially focused on the historic building stock. The tool is designed to be used as basis for the decision-making at municipality level. Municipalities will be supported in developing optimized renovation strategies in terms of reducing the ecological footprint and carbon emissions as well as increasing building´s energy efficiency. This paper presents a summary of the main features of the FeliCity-ATLAS tool and the results achieved during two-demo site testing: Madruzzo/Calavino (Italy) and Locarno (Switzerland).

Keywords: Renovation of building stock, energy retrofit, heritage buildings, digital twin, 3D digital-tool

1. Introduction

Over a quarter of the European building stock is classified as “historic” with vast majority of it concentrated in the rural areas (Troi, 2011). The traditional architecture in the Alps is a key enabler for sustainable development in the social, ecological and economic spheres. In this context, improving the sustainability of the historic buildings can lead to several positive effects on the sustainability of the whole Alpine area. It would promote the use of the existing infrastructure and the local economy thus, limiting the land use changes and the rural depopulation. Moreover, the energy renovating of the traditional historic architecture extend their service life and reduce the ecological footprint and have an overarching socioeconomic impact that goes beyond the environmental or economic benefits (Khoja et al., 2021a)

The retrofitting of historic buildings is a complex task. Very often in the case of historic buildings (HB) specific constraints and restrictions may limit the architects and designers in the application and selection of retrofitting solutions during the design phase (e.g., buildings protected by cultural heritage, legal constraints, technical constraints or financial constraints, etc.). In order to achieve the most effective results, all involved stakeholders must cooperate in a well-coordinated and structured way. This requires a thoughtful methodology that guides the stakeholders through the different phases of the retrofitting project. Local guidelines and the EU standards EN 16883 - 2017-0899 Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings can give certain recommendations to be followed, but there is a lack of specific tools at operational level to help with this task (Buda et al., 2022). Hence, Within the ATLAS research project (https://www.alpine-space.org/projects/atlas/en/home), a digital twin decision support online tool named ATLAS-FeliCity was developed (Khoja et al., 2021b). The tool is designed to support a holistic energy retrofit of the heritage building stock. The tool supports planners in the complex task of improving the sustainability of the built environment through providing a simplified digital twin of buildings, neighborhoods or cities, which is connected to several analysis and optimization functions (e.g. energy, carbon emissions, renewables, etc.). Moreover, the tool offers a highly flexible and easy to

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use plug and play approach, useful for non-expert users to get a quick start in the applications of the tool. During the development, the tool was tested at different municipalities in Italy, Switzerland, Slovenia and Germany. The developed tool is a key enabler of the novel ATLAS integrated decision support methodology (DS-Toolkit) which guides the stakeholder throughout the renovation work of historical buildings in five sequential phases, starting at the initiation phase up to the in-use phase. (Figure 1).

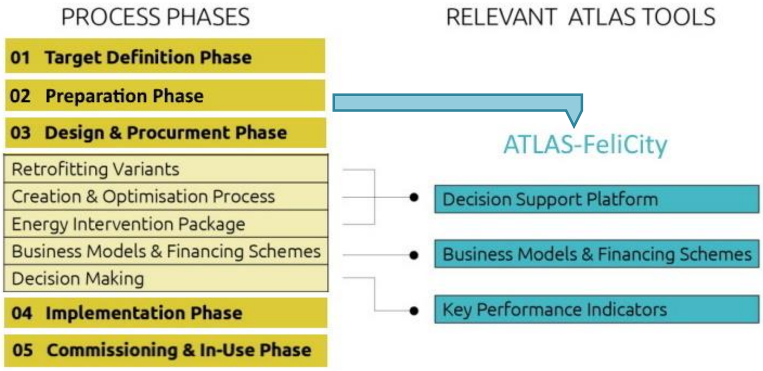


Fig. 1: Main phases in the ATLAS integrated decision support methodology (IDS) to support energy renovation of Historical Buildings (HB). Preparation phase (02) serves as input data for the tool. Source: Khoja et al., 2020a.

2. ATLAS- FeliCity Tool architecture and requirements

The effectiveness of building retrofitting can be increased significantly through district wide, multi scale renovation of the building stock (Khoja et al., 2019). This multi scale renovation enables the planners to exploit energy synergies between the existing buildings, utilize district energy systems and take advantage of the economics of scale (Khoja et al., 2019). However, working beside an own isolated project on multiple scales faces major challenges as the complexity of planning grows exponentially and traditional planning methods and tools do not support such multi scale consideration. Modern digital twin tools can help the sector overcome this barrier by providing the planner with multi scale consideration of their interventions. ATLAS-FeliCity is one of the few advanced planning software tools that are able to address this holistic, multi-layered approach.

ATLAS-Felicity bundles a comprehensive 3D building database with open-source GIS data and connect external webservices. These open sources serve as an extendible basis for real-time hourly thermal simulation and data visualisation. Thus, the user is able via the cloud to import and activate information directly objects from the built environment (building models, streets, landscape objects, public transport stops, etc.) in the tool web-interface without any pre-processing or uploading of data (e.g. GIS). A core part of the default dataset in ATLAS-FeliCity is the building construction database, which includes default parameters for various building types (e.g., residential, school, offices, retail, etc.), several construction periods (since about 1850, until 1900 and after 2010) and heritage protection status (e.g., listed, buildings protected as part of a conservation area, building with historic values but not listed, and without historical values). The database holds all the needed information and parameters to run a single zone hourly energy simulation using the ISO 13790 calculation method. To support the design team in assessing the impact of different renovation scenarios on the heritage buildings, ATLAS-FeliCity provides an advanced Simulation and Design Hub (SDH) which is a convergence of Dynamic Simulation Modelling, Geographic Information Systems (GIS), cloud data storage & analysis supported by key performance indicators (KPIs) and valuable analysis tools. The SDH allows performing various analyses like energy demand, carbon emissions, share of renewables, and payback period of the selected interventions. The objective therefore is to create and optimise the selected intervention measures in terms of energy, heritage compatibility, cost efficiency as well as the overall sustainability.

2.1. The ATLAS-FeliCity Decision Support (DS) Process in the preparation phase

When dealing with retrofitting projects, understanding the current energy performance of the building and its potential for energy demand reduction is an important step in the early decision-making process of the project to set the targets to be achieved during the project (01 Target definition phase, Fig.1). During the preparation phase (phase 02, Fig.1), various stakeholders gather information about the building and its surrounding serving as input for the FeliCity tool. Thus, within the preparation phase, the following three processes take place:

a) *Populating the building model*: intensive data collection to perform a qualified energy assessment of the as-it-state of the building, the effect of the retrofitting project as well as for its interaction with the environment and local grids. To help the designer in this complex task, the ATLAS DS-Toolkit provides a list of minimum data, which is required to populate the building model. According to this list, also default data are included in the ATLAS-FeliCity tool which can replace unknow values based on the building age class. This allows for having a fairly acceptable result of the energy performance in short modelling time;

b) *Identification of the building weak points*: during the diagnosis the designer need to specify the building components (i.e. envelop, systems, etc.) that are causing the highest amount of energy consumption and can/shall be improved. The ATLAS-FeliCity provide a detailed ranking list of the different energy performance weaknesses of the building. This serves as a basis for selecting and prioritising the most efficient retrofitting solutions and for creating a package of interventions for the building in the next steps;

c) *Identification of the potential solutions*: A core element of the ATLAS project was the collection of good examples on very different levels from historic building typologies and existing guidelines for energy retrofitting, to the use of renewable energy sources (RES) in a regional Alpine Space context documented in Atlas Deliverable D.T3.2.1 (Polo López, et al. 2020, 2021). ATLAS research gathered best-practice examples of how historic buildings can be renovated to achieve high levels of energy efficiency while respecting and protecting its heritage significance. A database of best practice building renovations is available with the HiBERatlas (www.hiberatlas.com) (Haas et al. 2021) and accordingly for technical solutions for energy retrofit with the HiBERtool (www.tool.hiberatlas.com) (Rieser et al., 2021). These tools developed within the Interreg AS ATLAS are strategic elements aiming at establishing transnationally integrated low carbon policy instruments. They are useful information to stakeholders involved in the renovation process of historic buildings, as the ATLAS holistic decision-support (DS) methodology and toolkit, Atlas Deliverable D.T3.4.1 (Khoja et al. 2020a) and Deliverable D.T3.5.1 (Khoja et al. 2021)).

2.2. Design and Procurement phase (phase 03, in Fig.1),

A retrofitting design variant in ATLAS-FeliCity DS is a package of different retrofitting interventions applied on single buildings or a group of buildings, in the whole neighbourhood and its energy related infrastructure, like heat networks or power plants. Thus, each concept may contain several different design variants that on the one hand need to reach the set targets and as well must be in line with the identified constraints and restrictions determined in the Target definition phase (phase 01, Fig. 1). Therefore, all valid variants would then be later assessed in the decision-making step to choose the concept to be developed. In the later decision-making step, the developed design variants within a concept are compared against each other thanks to a Multiple Criteria Decision Analysis (MCDA) value assessment. Retrofitting design variants can include one package of interventions which has been applied to relevant objects (i.e., building or group of buildings) or in urban environments (i.e., energy infrastructure, neighbourhood objects). For example, to promote multi scale renovation approaches as roof sharing strategies, smart grids or energy storage for the neighbourhood. The objective therefore is to create and optimise the selected intervention measures in terms of energy, heritage compatibility, cost efficiency as well as the overall sustainability. The following in figure 1 represent the sequence of applying retrofitting interventions in the iteration steps of the DS that is to be adopted by the "Planners team":

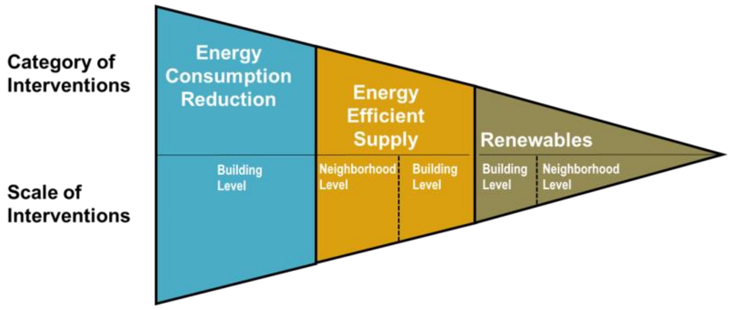


Fig. 2: Sequence of applying retrofitting interventions in the iteration steps of the DS. Source: Khoja et al., 2020a.

While creating a design variant the "Planners team" must consider several aspects like the determined targets, constraints, and restrictions as well as different interactions between the applied interventions and the buildings in the neighbourhood or its energy infrastructure. Moreover, the "Planners team" also needs to involve all relevant project stakeholders like "Managers/Coordinators", "End-Users", "Client/Owners" and others in the design process of variants. To make all these challenges manageable, the ATLAS DS process in the Concept phase contains the following main steps to create design variants which need to be followed by the "Planners team":

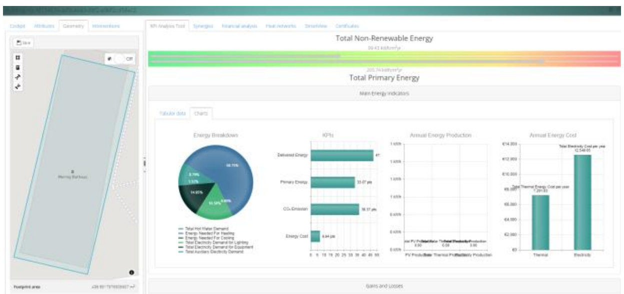
1. *Selection and optimisation of energy interventions* on building and neighbourhood level;
2. Addition of *non-simulated interventions*;
3. Inclusion of *business models and financing schemes*;
4. *Approval of design variant*.

First step in the *selection and optimisation of the intervention package* is to identify and exclude all interventions, which may not be suitable to be applied for the building or neighbourhood due to the previously defined constraints, or restrictions. For example, if cultural heritage protection laws restrict the works on the façade of the building the “Planners team” needs to filter out all interventions which cannot be applied. Then, based on the identified weak-points in the preparation phase, “Planners team” can assess the potential for improvements and therefore select most useful retrofitting interventions from the ATLAS-FeliCity technology library datasheet.

Secondly, there may also be *non-quantifiable or non-simulated interventions* on objects which have not been defined in the ATLAS technology library. Such non-quantifiable interventions are introduced in a qualitative way (written text) in a design variant and considered in the design phase by the “Planners”. Such non-quantifiable interventions cannot be simulated or calculated with ATLAS tools but can be quantified by the ATLAS KPIs. The ATLAS project has developed based on the CESBA (Common European Sustainable Built Environment Assessment) Alps key performance indicators KPIs, the ATLAS KPIs. The ATLAS KPI are specific for heritage buildings and should help guide the “Planning Team” in establishing the renovation targets in terms of energy, CO_2 savings and payback periods (Khoja et al., 2020b). These KPIs are partially incorporated within the ATLAS-FeliCity tool to aid the decision-making process and monitor the target achievements after renovation works are concluded.

The third step then provides for the *incorporation of business models and financing schemes*. Depending on the site of the project the “Planners Team” must search for the current financing schemes and their specific conditions in the region or site of the project. The results of the ATLAS Task 3.3, Deliverable D3.1/3.3 (Khoja et al. 2020 c) can be used a preliminary starting point for this search. However, due to dynamic nature of national and regional funding schemes, up-to-date research by the “Planners Team” must be done. The ATLAS-FeliCity tool provides an initial estimation of the area and cost of each intervention, however, the specification of the investment cost data for each applied intervention needs to be done based on local price indexes or other external software tools to get accurate investment estimation. Only with having an estimation of the expected total investment costs, it is possible to select useful financing mechanism and business models for the variant. If direct cost benefits from incentives like grants are available, the “Planners Team” needs to calculate the benefits based on the specific conditions of each financing mechanism and intervention. Hence, the final investment cost for the applied interventions may reduce by applying these financing mechanisms depending on the availability in the related country or region of the project. After collecting data on investment costs and all financing mechanisms for the variants, the “Planners Team” can calculate the ROI (Return on Investment) and PP (Payback Period) of the interventions.

At last, fourth step, it is necessary *to approve the design variant*. The design variant finally needs to be matched with the set targets defined in the definition phase and to compare the results of the design variant against the KPIs targets (e.g. Figure 3). Depending on the kind of set targets (Benchmarks) the KPIs can be compared with the current state results in a quantitative way by checking the absolute values of the results (e.g. kWh m^{-2} per year) or using the relative results (20% reduction). “Planners Team” needs to check after each iteration if the targets already have been reached or not by the selected package of measures. All KPIs can be calculated for different variants on each scale of application and are aggregated or averaged. Hence, these comparisons and checks already should have been done for several times after each iteration step. Final matching between the variant results and the set targets is the last step in the optimisation and creation process. If the optimisation is finished and the targets have been reached by the variant, the iteration loops stops and the variant is ready for a presentation and an approval by the relevant project stakeholders (e.g. “Client/Owner” and the “Manager/Coordinator”) and the implementation phase can start.



The KPIs available in FeliCity are as follows:

- Delivered and Primary Energy Demand
- Carbon Emissions
- Operational Energy Cost
- Share of renewables on-site
- Self-Sufficiency rate from electricity grid
- Share of own consumption from renewables
- Investment cost for maintenance, repair and retrofitting works
- Return on Investment ROI and Life cycle cost (LCC)

Fig. 3: A screenshot of the ATLAS DS tool showing the KPIs value.

ATLAS-FeliCity DS Tool main features applied to case studies

The ATLAS-FeliCity fully supports the Pareto principle, which allows achieving accuracy in energy and cost results of at least 80 % by only providing around 20% of input data. Hence, minimizing the data collection time and cost effort by the users. ATLAS-FeliCity Data Collection process is based on gathering digital building data, city data and data for the surrounding infrastructure on multiple scales via a simple to use Data Collection wizard. The collected data is stored in a cloud-based webserver for subsequent use through the whole conception and refurbishment process that uses two modes methodology for data capturing on different building data in a multi-scale environment (basic and advanced). This enables working on urban larger scales and multiple buildings (e.g. large building stock portfolios) in an efficient and precise way.

The building construction default dataset in ATLAS-FeliCity includes typical building construction for various building types and construction periods, and also historical status characteristics of the building or urban area. The database holds all the needed information and parameters to run an energy simulation. ATLAS-FeliCity will then be able to set up an energy model of the building by combining the default database with the geometric data from the geometry database. Afterwards, the planning team can start applying various renovation interventions using the ATLAS-FeliCity intervention catalogue. The ATLAS-FeliCity renovation catalogue provides over 300 different kind of retrofitting measures which can be simulated on different scales of application. For each selectable measure the effect in terms of energy efficiency and further KPIs can be simulated and the investment cost of the intervention can be estimated as well as the reduction in the running costs. To run simulations, ATLAS-FeliCity includes the U.S. Department of Energy's DOE dataset of hourly-based climate data, which are automatically assigned by the simulation and planning hub based on the GIS location of the project. All input data from the default database can be displayed and overwritten step-by-step by the user in case more detailed information has been collected. This enables the user to overwrite and input all needed data for the creation of the geometry information model, modelling of building components or systems (HVAC, pipes, etc.), thermal and energy simulation models, and further related models like financial and life-cycle analysis models.

A novelty of the ATLAS-FeliCity tool is its capability to allow planners working with the built environment on a multi-scale level in a flexible and intuitive way by activated on a virtual map and selecting the scale on which the user intends to work. Thus, it is possible to flexibly switch between the scales from the highest level of detail to a lower level of detail on a larger scale, depending on the projects scope and objectives. Enlarging the scale of application implies add further buildings (Figure 4) which it turns allows upscaling to a neighbourhood or even a city scale (Figure 5). FeliCity in this case calculates depending on the metric of interest a weighted average of the required values (e.g. primary energy demand or carbon emissions per m² and year). The cost of each intervention as well as the bill of quantities is estimated based on the 3D building geometries (e.g. wall area, roof area, windows area, floor area, etc.) and statistical methods. Using the estimated bill of quantity, the average cost of the intervention per reference unit and country stored in the FeliCity backend database are applied to estimate the rough renovation cost. Based on the investment cost and savings in operational cost a return of investment and payback period of all applied renovation measures considering the real building geometries, actual climate data and construction costs at the present location is conducted by the tool.

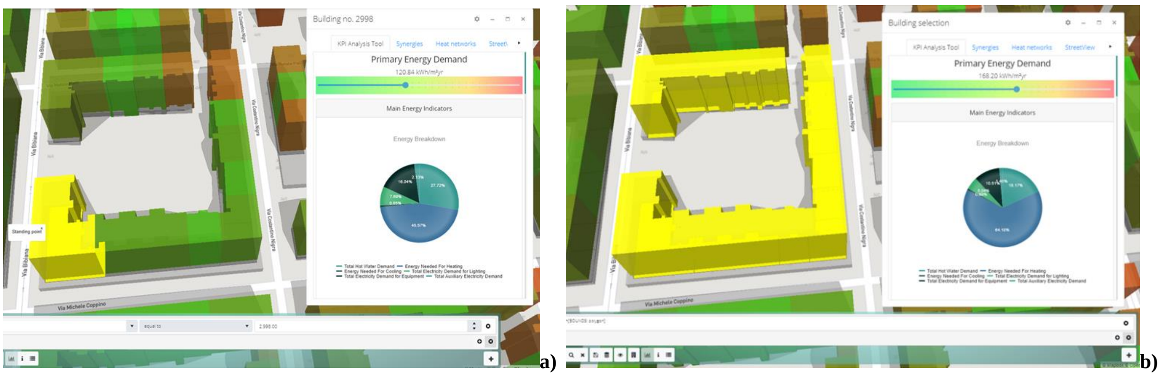


Fig. 4: ATLAS-FeliCity example of upscaling from the primary energy demand on a single building (a) to aggregated primary energy demand at building block scale (b,12 buildings). Source: Khoja et al., 2020a.

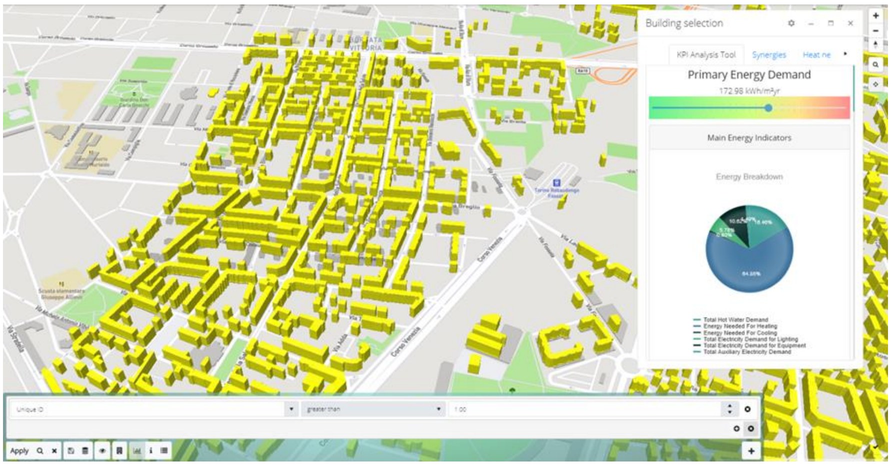


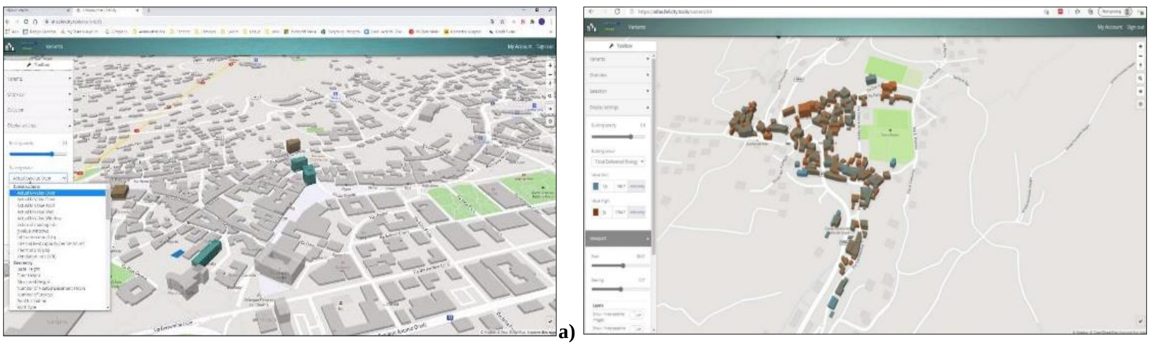
Fig. 5: Aggregated primary energy demand and energy breakdown's on a city scale (3000 buildings). Source: Khoja et al., 2020a.

2.4. Implementing and commissioning & end-use phases

In these phases (04 and 05 phases) as any construction activity whether it is a newly built project or a retrofitting one, the goal is to create a set of drawings, documents and detailed specifications that would allow for implementing the developed retrofitting design on the ground. Depending on the complexity of the project, it might be necessary to engage consultants and moreover, in this phase it is important to engage the local knowledge in the final development of the project. The developed project must reflect the "End User's "requirements defined in concept phase. Furthermore, "planners' team" in cooperation with "Manager/ Coordinator" need to develop a detailed breakdown of the project budget that reflects the project cost estimations and to make sure that the developed design is within the project performance targets previously defined. The 'Planners Team', in coordination with the 'Manager/Coordinator' and 'Builder', must develop methods and strategies to be used in the handover, commissioning and utilisation phase. These could include monitoring and optimisation of energy performance as well as continuous post-occupancy investigation to avoid sub-optimal utilisation, which is indeed crucial in the long-term sustainability of successful retrofit projects.

3. ATLAS-FeliCity Decision Support Tool: Beta testing in Alpine municipalities

Within the ATLAS project, a beta-version of ATLAS-FeliCity Decision Support DS Tool has been tested in four demo sites (Madruzzo/Calavino (Italy), Locarno o Lugano (Switzerland), Tolmin (Slovenia) and Mering (Germany). This paper will discuss the results of the demo site testing for two cases namely (Figure 6): Locarno (Switzerland) and Madruzzo/Calavino (Italy), dicussing the main features of the ATLAS-FeliCity- and its usability and limitation for guiding the decision-makers in renovating their existing stock.



a) b)

Fig. 6: ATLAS-FeliCity Decision Support Tool application to Locarno municipality (Switzerland) and Calavino center (Italy).

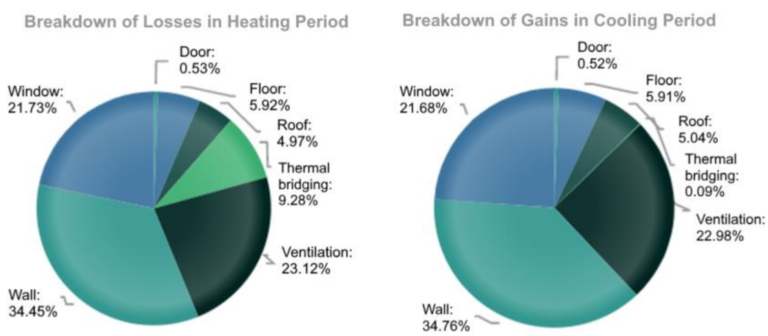
3.1 ATLAS-FeliCity DS Tool: Case Study Locarno (Canton of Ticino, Switzerland)

The existing real estate portfolio in Switzerland, but also in Canton of Ticino, consists mainly of "old buildings" (i.e. 45% of the buildings were built before 1960, and almost 70% before 1980.) characterized by high heating consumption due to poor energy efficiency of the building envelope and systems. The technical age of their constructive elements is for the most part higher than their useful life span due to lack of renewal cycles and a lack of renovation strategy. This situation, in addition to the continued loss of property value, is a serious obstacle to the achievement of the Confederation Energy Strategy 2050 (BFE, 2017; Boulouchos, et al., 2022). In 2019, the City of Locarno commissioned the University of Applied Sciences and Arts of Southern Switzerland, SUPSI to analyse and plan the rehabilitation of its real estate portfolio (Branca et al., 2019). The work has been aimed to find a concrete solution to the management and rehabilitation needs of the building stock of the city of Locarno. The study aimed to allow the property owner, in this case Locarno municipality, planning the interventions at the scale of the real estate portfolio by identifying priorities and sustainability. The real estate park City of Locarno consists of 21 buildings with different uses, mainly composed of school buildings and offices (i.e. 9 schools, 10 offices and 2 apartments, all built before the 1980s, with almost 50% of structures built before 1960). A first diagnosis of each single building was carried out with the PETRA tool, a Web Platform for Energetic and Technological Retrofit in Architecture (Buda et al., 2022; Branca et al., 2012). The tool developed by SUPSI in collaboration with the Swiss Federal Institute of Technology Lausanne (EPFL) and three private companies makes use of a database on sustainable building renovation with constantly updated information taking into account Swiss regulations. Ten historic buildings within the real estate portfolio of Locarno City have been used in the Beta Test of ATLAS-FeliCity tool (Figure 7).

Building City of Locarno	Building Use	Construction Data
01 Palazzo Marcacci	Office	1897
11 P.tta Capitani	Office	1900
30 Casorella	Office	1890
32 Casa rusca	Office	1890
33 Morettini	Office	1900
21 SE Solduno	School	1958
25 SI San Francesco	School	1890
51 Centro Diurno	Apartments	1901
87 Casa Bastoria	Office	1890
91 Casa Cristina	School	1920

Fig. 7: List of 10 historic buildings of Locarno Municipality (CH) and geolocation in ATLAS-FeliCity (e.g. 01. Palazzo Marcacci). Source: SUPSI

The current energy status scenario was defined for the calculation of the heat balance to get a picture of the theoretical energy consumption at historic buildings current state in the city of Locarno real estate park. In order to assess the differences between the initial state in the City of Locarno's building stock in energy terms and the final state, various retrofit intervention scenarios have been defined. First analysis of the distribution of losses and gains, expressed in percentages, for individual building elements during the heating period and the cooling period respectively before energy retrofit measures, shown that walls and windows of buildings are the main dispersing elements on which an effective retrofit strategy would need to be implemented. After identifying the theoretical energy consumption (quantified by 1,993,543 kWh/yr.), a comparison with the results obtained with regard the actual consumption collected in 2019 were possible (total energy consumption of 2,432,347 kWh/yr.). A difference between the actual consumption and theoretical with ATLAS-FeliCity of about 22% is observed (Figure 8). This margin of error is acceptable (+/- 20%) because it allowed evaluating with some precision the savings achieved in the new renovation scenarios simulated after.



CURRENT ENERGY STATUS SCENARIO

Label	Value	Unit
Total Delivered Energy	138.70	kWh/m²yr
Total Delivered Thermal Energy	105.58	kWh/m²yr
Total Delivered Electricity	33.12	kWh/m²yr
Total Primary Energy	196.27	kWh/m²yr
Total Primary Thermal Energy	113.47	kWh/m²yr
Total Primary Electricity	82.79	kWh/m²yr
Total Delivered Energy	1,993,542.80	kWh/yr
Real consumption	2,432,347.00	kWh/yr
Difference between real and theoretical consumption	438,804.20 ---------> 22 %	kWh/yr

Fig. 8: Gains and losses during the heating and cooling period before energy retrofits. Difference between actual and theoretical energy consumption calculated by the ATLAS-FeliCity DS tool for the total buildings analysed.

Based on the results of the current state, five different renovation scenarios were defined and the theoretical energy saving for each retrofit estimated. For each scenario a single renovation measure has been considered. In a second step, the individual scenarios were merged to see how much existing (theoretical) power consumption would be affected when multiple modernization measures are implemented at the same time and the cost of the intervention.

The simulated and assessed scenarios were:

- S1, Roof / Type of intervention: Rehabilitation of 6 roofs;
- S2, Window / Type of intervention: Refurbishment of 6 buildings with new windows;
- S3, Wall / Type of intervention: Façade insulation works on 8 buildings;
- S4, District Heating Network (DHN) / Type of intervention: 10 buildings connected to DHN;
- S5, Photovoltaic (PV) / Type of intervention: Installation of 10 PV plants in buildings.

Based on the results of the status-quo analysis, these five renovation scenarios were defined and the theoretical energy saving and investment need for each renovation were estimated. As the buildings are not listed under the heritage protection law, but on the protected city core ISOS (Federal Inventory of Swiss heritage sites of national importance), the building renovation must adhere, as much as possible, to thermal values defined in the Cantons Regulation on the use of energy (RUEn, 2008). Hence, the follow renovation measures have been assessed (Table 1):

Tab. 1: Case study Locarno (CH) – results of energy savings obtained by combining the individual scenarios.

Scenario, Building element	Status quo	Renovation target	Measures applied	Energy savings	Cost foreseen
S1, Roof	Current U-value of the roofs varies between 0.40 $Wm^{-2} K^{-1}$ and 0.61 $Wm^{-2} K^{-1}$	U value ≤ 0.23 $W m^{-2} K^{-1}$ to achieve an improvement of about 42% to 61%	Greater insulation to reduce the U-value of 6 roofs (restoration scenario applied only to buildings under a threshold U-value > 0.30 $W m^{-2} K^{-1}$).	52,600 kWh per year (ca. 3% of current total primary energy consumption)	232’600 €
S2, Window	Current U-value of the windows varies between 3.59 $Wm^{-2}K^{-1}$ and 2.50 $Wm^{-2} K^{-1}$	U value ≤ 0.80 $W m^{-2} K^{-1}$	New windows have been planned for 6 buildings. A limit U-value of 2.00 $Wm^{-2} K^{-1}$ was considered, as for historic buildings it already assumes a good energy performance.	184,000 kWh per year (ca. 9% of current total primary energy consumption)	93’256 €
S3, Wall	There are 8 buildings with not optimum wall insulation performances (U-value > 0.70 $Wm^{-2}K^{-1}$)	U-value ≤ 0.65 $Wm^{-2} K^{-1}$ with an improvement of about 30% to 57%	A thinner internal insulation layer (i.e. 10 cm internal insulation) was applied to the historic building.	264,000 kWh per year (ca. 13% of total primary energy consumption)	124’197 €
S4, DHN	Locarno City is planning to have a District Heating Network (DHN)	Non-invasive measures to improve the energy performance	The whole real estate park of buildings studied were selected to be connected to DHN.	341,000 kWh per year (ca. 8.5% of current total primary energy consumption)	- Cost cannot be calculated
S5, PV Plants	Under current regulations, PV systems may also be installed in historic buildings (*)	Implementation of renewable energy sources RES (PV). Total nominal power installed: 10 kWp	Installation of PV systems in the roof of all buildings studied. Self-sufficiency rate of about 4%, own consumption rate of about 87%. Total PV energy production is about 70,709.79 kWh per year.	70,700 kWh per year (ca. 14% of energy demand for auxiliary energy, lighting, and equipment; 2% of current primary energy consumption)	301,000 € (ca. 30,000 € each)

(*) Note: Only federal or cantonal listed buildings required the authorisation from the cultural heritage and landscape protection commissions.

As a result of the analysis, and combining the individual scenarios (Table 2), it was possible to observe that by intervening only on the building envelope – energy measures on roofs (S1), plus windows (S2) and walls (S3) – an energy savings of around 25% could be achieved. Through the S1+S2+S3 scenarios, approximately 500,000 kWh per year could be saved. If the connection to a district heating network for all buildings is considered an energy reduction of about 42% could be achieved (842,313 kWh per year). The best retrofit scenario, where scenarios S1+S2+S3+S4+S5 are combined, it is possible to see that the energy reduction is even greater. This result is achieved when a photovoltaic system is implemented on the roofs together with all previous measures that would further reduce the energy consumption of Locarno's building stock until the 46% (912,022 kWh per year).

Tab. 1: Case study Locarno (CH) – results of energy savings obtained by combining the individual scenarios.

	Actual energy status	**S1+S2**	**S1+S2+S3**	**S1+S2+S3+S4**	**S1+S2+S3+S4+S5**
Energy saved (kWh/yr.)		236,507	500,191	841,313	912,022
Total delivered energy (kWh/yr.)	1,993,543	1,757,036	1,493,352	1,152,230	1,081,521
Energy saving rate (%)		**12%**	**25%**	**42%**	**46%**

3.2 ATLAS-FeliCity DS Tool: Case Study Calavino, Madruzzo (Italy)

Calavino, one of the five fractions of the municipality of Madruzzo, is a historical village situated in the Valle dei Laghi in the Province of Trento (Italy). Is characterized by a historic city center with a rather homogeneous appearance, with traditional residential buildings whereof a large majority was built before 1860. Calavino has a high rate of vacant houses and as well as a high rate of non-refurbished buildings. A building stock analysis were already done in a preliminary project (Lucchi, 2018) where a specific datasheet for 220 private and public buildings gathered relevant information (e.g. location; construction period and constructive elements; typological aspects or building use and type, ownership; heritage value and legislation framework; conservation state; energy aspects, etc.). The data were then transferred and integrated into a GIS model software using two digital models (both derived from Light Detection and Ranging, LiDAR data), which were gathered from the GeoBrowser of the Province of Trento. The testing in the ATLAS-FeliCity tool included 216 buildings or building units of the historic centre. Of the buildings included are 84% built before 1860, 79% residential buildings; 75% not subject to conservation related regulations (only 5.7% are listed buildings, 17.2% have historical elements to be preserved); 16% abandoned or not used.

The study with the ATLAS-Feli-City tool aimed to identify these measures for retrofit and to investigate the energy savings potential of the historic building stock of Calavino. A further aspect was to compare the values of the baseline scenario of the FeliCity tool with those of the previous study. The preliminary study serves to input accuracy data on ATLAS-Felicity tool and only a few parameters were filled in automatically with default values. Thus, two baseline models in the Felicity tool were created: Calavino (with default U-values from ATLAS-FeliCity) and Calavino measured (with U-values from the preliminary study) with 216 buildings or building units. When doing a building stock analysis, it were useful to divide the building stock into different building groups or "archetypes" that share similar characteristics or according different attributes (e.g. listed buildings, in a conservation area, not listed, etc.). In case of Calavino the building stock is quite similar in terms of construction method, building age and building use, etc. It was useful distinguish the historic building stock between different intervention categories, in order to be able to tailor interventions to the heritage and conservation requirements (Figure 9). In that way different building groups (archetypes) were created: (I) historic buildings of the inner village of Calavino, (II) all buildings without historic value, (III) all listed historic buildings, (IV) all buildings with historic value and (V) buildings from 1860 and (VI) apartments from 1860. Additionally, a series of single buildings was studied more in detail.

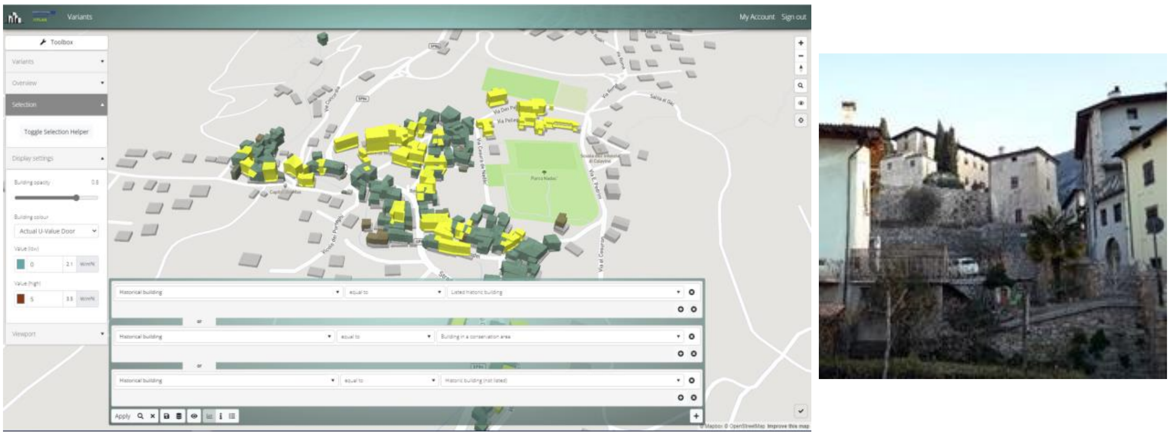
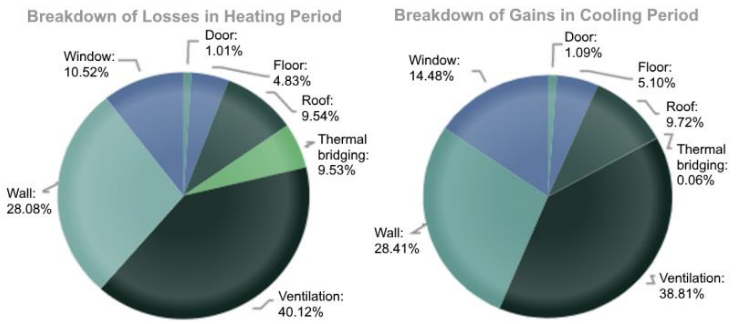


Fig. 9: Screenshot of ATLAS-FeliCity tool of Calavino´s historic center and view of the historical town of Calavino. Source: EURAC.

Figure 10 shows besides the "Absolute Energy Demand Breakdowns" also the share of losses and gains during the heating and cooling period per construction element before energy retrofit (all buildings studied, baseline scenario for 217 buildings). According to these results, the retrofit of the façades, but also of the windows, would have the greatest impact. Additionally, both would improve the airtightness and thus reduce the high ventilation losses. With regard the building services, the installation of a controlled ventilation system with heat recovery would decrease the ventilation losses even more.



CURRENT ENERGY STATUS SCENARIO

Label	Value	Unit
Total Delivered Energy	389.24	kWh/m²yr
Total Delivered Thermal Energy	365.88	kWh/m²yr
Total Delivered Electricity	23.36	kWh/m²yr
Total Primary Energy	445.94	kWh/m²yr
Total Primary Thermal Energy	387.55	kWh/m²yr
Total Primary Electricity	58.40	kWh/m²yr
Total Delivered Energy	24,372,829.60	kWh/yr
Thermal energy demand (149 buildings)	329.84	kWh/yr
Real primary thermal demand	229.45	kWh/yr
Difference (149 buildings)	---------> 32%	

Fig. 10: Gains and losses during the heating and cooling period before energy retrofits. Difference between actual and theoretical thermal primary energy demand calculated by the ATLAS-FeliCity DS tool for 149 buildings analysed.

Furthermore, the heating energy demand was assessed for 149 selected residential buildings belonging to the biggest building group with the most common characteristics in terms of constructive techniques and materials. For this a stationary calculation method was elaborated using the software Passive House Planning Package (PHPP) version 9. From this calculation, from the 220 total number of buildings, were excluded all non-residential buildings, buildings built after 1860 and a few highly damaged buildings. Then, the energy demand for heating on building level calculated with the beta version of ATLAS-FeliCity, in kWh m^{-2} per year, has been compared with the results from the PHPP calculation for 149 buildings (329.84 kWh m^{-2} per year). The big difference of the preliminary staudy of the Calavina building stock based on PHPP and the results derived from FeliCity (initially 100.21 kWh m^{-2} per year) were assessed. Tendentially the results for energy demand calculated in PHPP are lower.An iterative process was used to identify and reconcile differences in the corresponding input data, for example, weather datasets. The aim was not to produce equivalent absolute values, but to have as sound database enabling the estimation of savings effects for the various measures. With the help of the in-depth analysis and the comparison of the two studies, the FeliCity tool could be significantly improved, especially for the application in the historic building stock.

4. Conclusions, remarks, and lessons learned

Energy Efficiency of Buildings as one of the key actions for the sustainable growth and the historic architecture of the Alpine region is a key factor for sustainable development in the social, ecological and economic sense. FeliCity-ATLAS Decision-Support (DS) tool has been developed and tested for some municipalities within the Interreg Alp ine Space ATLAS research project. That's include capitalizing and optimizing existing best practice solutions for building refurbishment and regional development to increase number of high value renovations –considering historic and energetic aspects. The FeliCity-ATLAS DS-Toolkit provides a simplified digital twin version of the built environment to perform energy analysis at various spatial scales, that work as a hub for information from other activities developed during the project and will work as interlocking system, empowering municipalities to set the right course for building renovation strategies, balancing ecological, economic and social factors. The toolkit has been applied as pilot offline version to the ATLAS model regions (beta demo version applied to four municipalities), but will serve interface to later web-based 3D and BIM approaches as an offline tool with interface for later online web-based 3D and BIM approaches. This paper has shown results obtained for two demo sites, two historical city cores in the Alpine region: Locarno municipality (Canton Ticino, Switzerland) and Calavino (Madruzzo, Italy). The ATLAS-FeliCity tool has been proved to be very interesting and functional, as well as, easy to handle, in determining the possible renovation scenarios to be applied to the real estate parks studied. Within the tool it was possible to appreciate several very interesting functions such as the geo-localisation of the buildings within a map, or the possibility of filtering the different buildings by entering specific "attributes" (year of construction, U value, etc.) or by "archetypes" that share similar characteristics. Results obtained for the two locations were compared with previously in-depth studies and were possible to verify differences on calculations done with ATLAS-FeliCity DS tool in terms of actual consumption and theoretical delivered energy calculated (total delivered energy for Locarno building stock analysed or thermal primary energy demand, in the case study of Calavino). In the case study of Locarno municipality, it was possible to verify that the calculation of the energy balance in its initial state (before interventions) calculated by ATLAS-FeliCity tool is in line (+/- 20%) with the real energy consumption data (data from 2019) provided by the City of Locarno, which is very interesting. Different scenarios of retrofit at different scales (building or neighbourhood) can be simulated at the same time and key performance indicators (KPIs) were designed to enable the decision maker to assess the impact of the renovation interventions on the sustainability performance of historic buildings. ATLAS KPIs, implemented in ATLAS-FeliCity, that are specific for heritage buildings, shown if targets in terms of energy, CO_2 savings and payback periods are achieved.

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