

Article

A Methodology for Integrated Refurbishment Actions in School Buildings

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Abstract: Educational buildings could play leading roles in increasing high-performance building refurbishments across Europe. The city of Vienna has substantially modernized its schools in the last decade, however mostly single refurbishment measures have been undertaken. This is missing the potential of comprehensive and more energy-efficient actions as well as functional adaptations, which become ever more important as school and learning systems are changing. Institutional framework conditions, budget constraints as well as the lack of a coherent methodology have been identified as the main barriers in this context. The research question addresses how qualitative aspects, such as architecture and function, as well as quantitative aspects, such as energy consumption, could be combined in a methodology that can be easily applied by relevant stakeholders. What would a methodology that actively supports stakeholders in their decision-making process for more comprehensive school refurbishments look like? This paper describes a potential approach and its application in a case study. The proposed methodology supports the development of energy- and functionally optimized refurbishment concepts, with a focus on the synergies between energy-related optimizations and state-of-the-art functional room concepts in order to do justice to the changing learning requirements in schools.

Keywords: educational buildings; school buildings; energy efficiency; energy concepts; building refurbishment; functional refurbishment; integrated refurbishment actions

1. Introduction

In a factsheet regarding the assessment of progress towards reaching the 20% energy efficiency target for 2020 and beyond by the European Commission, it is cited that the European Union (EU) renovation rate is about 1% per year [1]. This would, consequently, mean that renovating the EU building stock would take about 100 years. In Austria, the renovation rate similarly is about 1% [2], even though the government has cited numerous times that this should be increased to 3% or even 5% [3]. Motivating the private sector to increase refurbishment actions would necessitate incentives and regulatory measures, but it also means that the public sector must step up and set best-practice examples. With 17% of all non-residential buildings in the EU being educational buildings [4], in the majority under public control, national governments have significant leverage to provide best-practice examples on buildings that are highly visible to the public.

In Austria, the government invests several million euros in the maintenance and upkeep of public schools every year in order to adapt outdated building stock to the current state of the art in terms of fire regulations, accessibility, energy usage and changes in the functional room requirements. The city of Vienna alone developed, within the framework of a large-school refurbishment package [5], a plan for the refurbishment of all Viennese schools until 2017 in which altogether 570 million euros were foreseen for basic maintenance and adaptation measures in 242 compulsory schools. This plan has

now been extended with an increased budget to last until 2022 [5]. Based on these refurbishment actions, there is a significant potential for creating synergies: holistic refurbishment actions could reduce greenhouse-gas emissions by increasing energy efficiency as well as adding energy-generation potential by the development of plus-energy buildings.

1.1. New Functional Requirements for Schools

Refurbishing educational buildings also requires a holistic view of the school building stock: new types of schools necessitate an adequate learning environment to challenge and encourage pupils in their development. Requirements for the shapes of learning spaces can and should be derived from the teaching form, noting that not every form of teaching also needs a separate space. Different forms of group work, face-to-face lessons and talks should be facilitated by the room, as already documented by Budde [6] and Kentner [7]. New requirements on the space arise primarily from new school forms. The traditional school outside the Anglo-Saxon world still separates lessons (morning) and leisure (afternoon). However, the increased need for afternoon care also brings new requirements for eating, learning, seclusion, movement, sport and games. New school concepts building on the integration of community activities, leisure activities and educational activities [8] have become ever more popular in Austria and other European countries, and are moving away from the separation of learning and leisure time. For the transformation of the school building stock, this means that school and leisure design are no longer strictly separated in different areas (inside/outside) or different times (morning/afternoon). From an architectural viewpoint, there is thus a need for a variety of alternative space concepts that provide flexible and differentiated learning environments.

Teaching staff and pupils as the main stakeholders in schools play an important role in the acceptance of educational concepts and systems. Similarly, new room concepts must also be approved by these stakeholders. In a study dealing with requirements for alternative teaching environments commissioned by the Austrian Federal Ministry of Education, the responses of more than 1000 headmasters have been analyzed [9]. The desire for adapted space programs and differentiated learning situations was very evident, as shown in Figure 1. In general, more than 80% of respondents expressed the need for the various alternative learning environments whereas half, or in some instances less than half, of the respondents confirmed that these spaces were already available to them.

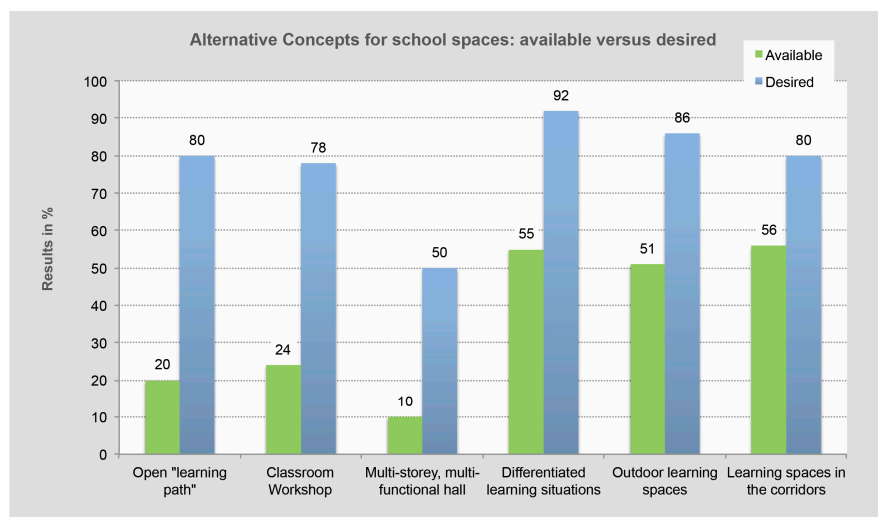


Figure 1. Alternative concepts for school spaces: available versus desired; data translated from [9].

In an essay for *Austria 2050—fit for the future*, a researcher in the field of educational systems described her vision for the school of the future as follows: "... in 2050 the school is a place where pupils are happy but at the same time a place where learning is encouraged. There is a place for retreat

to work quietly by oneself, there is the possibility for group work and walls can be moved for large group gatherings or for celebrating together . . . ", translated from [10]. In an essay about educational buildings and based on the famous quote ("form follows function") by Louis Sullivan, the quote "Form follows kids fiction" [11] has been suggested to describe the goal of designing for future schools.

Following this vision, in the framework of the SchulRen+ project [12] for the Austrian Ministry of Transport, Innovation and Technology the functional requirements noted below have been defined for the adaptation of architectural spaces:

- space for self-teaching, testing, exploratory work, reading, writing, researching as well as simulating, constructing and memorizing on digital devices;
- space for undisturbed self-reflection;
- space for individual lessons, defined by the ratio of teachers/students;
- space for group conversations (6 to 12 students);
- space for demonstration by watching, listening to lectures, presentations, films, experimental work or concerts.

All this must be translated into contemporary architecture to create inspiring learning environments. Currently, however, this potential is not fully exploited as school refurbishment focuses mostly on single measures in respect of maintenance and adaptation of the building structure. Energy-efficiency measures are considered only selectively, and functional changes in terms of adapted room functionalities are mostly implemented in annexes to buildings (which can essentially be considered as new buildings) but rarely in existing buildings. The reasons for the few numbers of truly holistic school refurbishment projects can be found in limited budgets, political and institutional framework conditions, as well as the lack of a coherent methodology to address innovative and holistic building-refurbishment concepts [12]. In another study by the European Commission, the lack of technical knowledge among decision-makers was cited together with a lack of financial support as the main obstacles to the implementation of energy-saving measures in schools [13]. This was especially so since the older building stock of the school buildings in central Europe shows a similar structure and layout, and the repeatability of concepts could be used based on a series of similarities. Only in the last two to three decades can a stronger differentiation be seen in the architecture of more contemporary school buildings.

1.2. Regulatory Framework Conditions

Building regulations and accompanying norms provide a series of requirements when buildings are undergoing minor or major renovation actions. For schools, there is a particular focus on fire regulation and accessibility for the disabled, as many educational buildings are in need of necessary updates in this respect. The school refurbishment package of the Municipality of Vienna [5] has already placed a strong priority on urgent and immediately necessary measures, which focus on the safety and accessibility of the buildings. Aspects related to energy efficiency and integration of renewable energy are, likewise, governed by the building regulations. In Austria, the Guideline No. 6 of the Austrian Institute of Construction Engineering [14], which follows the guidelines of the latest Energy Performance of Buildings Directive (EPBD) [15], is one of the main documents in this respect.

Building-certification schemes go above and beyond the regulatory norms and standards and are completely voluntary. The certification schemes offer a certain methodology to support the planning process and can have an impact on the energy concept if the client wants to reach a certain certificate. In the commercial sector, these certificates offer a market advantage and thus an incentive to create a more energy-efficient and sustainable building, as the schemes noted below go far beyond energy-related measures. They also include, for example, aspects such as lifecycle costs of materials, land use or water management. For school buildings, these schemes could in theory also support a sustainable design process in the planning phase. Building-certification schemes such as Leadership in Energy and Environmental Design (LEED) [16], Building Research Establishment Environmental Assessment Method (BREEAM) [17] or the German 'Deutsche

Gesellschaft für Nachhaltige Immobilienwirtschaft' (DGNB) [18] each offer specific assessments for schools. In Austria, there are two certification schemes, the 'Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft' (ÖGNI) [19], which is based on the DGNB and the 'Österreichische Gesellschaft für Nachhaltiges Bauen' (ÖGNB) [20], which has been developed from another certification scheme. However, for public buildings and particular educational buildings these schemes are not widely applied. As of 2017, there were only two school buildings certified under ÖGNI and five under ÖGNB [19,20]. Therefore, it can be concluded that voluntary certification schemes do not play a significant role for the relevant stakeholders in the development of school refurbishment concepts. In summary, there are a series of regulations, norms and standards in place that govern educational refurbishment processes. Voluntary certification schemes can provide additional guidance, however neither of these supports the stakeholders with a coherent methodology.

1.3. Methodologies for Refurbishment

Methodological approaches addressing refurbishment in general have been elaborated in Ma et al. [21]. Here, a general overview of key elements affecting building retrofits as well as comprehensive strategies has been discussed in a theoretical framework. Kaklauskas et al. have developed another theoretical approach by applying a multi-criteria analysis [22]. Various factors related to e.g., price, reliability, longevity or payback period have been defined as needs for the definition of quantitative and qualitative criteria. With more than 100,000 alternative versions developed for one case study, the calculations highlight better or weaker versions. The focus of the methodology was on energy saving and CO₂ emission reduction. A more practical take has been described in a paper by Ouyand et al. [23] with a methodology for an energy-efficient renovation for a case study of residential buildings. Following a similar approach, Passer et al. [24] describe in their assessment of refurbishment strategies towards plus-energy buildings how different scenarios (no refurbishment, minimum refurbishment, and high-quality refurbishment) affect the overall lifecycle energy demand based on a lifecycle assessment approach.

Whilst these approaches offer a sound theoretical framework, they are difficult to apply by non-experts. Stakeholders in the decision-making process of school refurbishment projects will probably have little or no access to these theoretical frameworks. In addition, factors of space, architecture and functional requirements need to be considered.

In a study focusing on the potential of school refurbishment and exchange of information throughout central Europe, the findings were summarized in an "Energy Concepts Advisor" aimed at creating a new planning tool for decision-makers in the field of schools [25,26]. The tool is based on 25 case studies and provides guidelines for energy-optimized refurbishments including energy efficiency and investment costs. A more recent article based on four case studies in the UK outlines in more detail energy and lifecycle costs of energy-efficient refurbishment measures in typical 20th-century UK school buildings [27]. The approach is based on a regression model to indicate which measures show the biggest effect. The conclusion stresses, that the modeling of combination of measures is critical to " ... determine the impact that a series of interventions may have on the energy consumption of a building and on the lifecycle cost of the package of measures as a whole ... ". This indicates the importance of a holistic view, rather than a single-measure approach. However, an approach that addresses the synergies and optimization potential of energy-related aspects together with functional requirements towards holistic refurbishment measures has not yet been considered.

1.4. Research Question

The aim of the project [12] and subsequent thesis [28] described in this paper was, therefore, to add to the understanding of the potential of energy-optimized and architecturally as well as functionally improved refurbishments in school buildings, and to provide relevant stakeholders with a methodology to make informed decisions about comprehensive and sustainable refurbishment actions. By summarizing the structural, functional and energy-relevant framework conditions, the synergetic potentials of comprehensive school refurbishments are highlighted.

The research question addressed in this paper thus focuses on if and how qualitative aspects, such as architecture and function, as well as quantitative aspects, such as energy consumption and lifecycle costs, could be combined in a methodology that can be easily applied by relevant stakeholders. That is, what would a methodology that actively supports the relevant stakeholders in their decision-making process in order to support the implementation of more comprehensive refurbishment actions in school buildings look like? The methodology developed in this work delivers a potential approach. The proposed methodology supports the development of energy- and functionally optimized refurbishment concepts with a focus on the synergies between energy-related optimizations with state-of-the-art functional room concepts in order to do justice to the changing learning requirements in schools. The methodology specifically addresses stakeholders in the decision-making process who are supported by relevant planning experts.

2. Proposed Methodology

The underlying goal of the methodology was to increase the rate of comprehensive school refurbishments, which combine structural, energy-related as well as functional measures. Based on the fact that the barriers to comprehensive refurbishments in this sector can be found more on the institutional rather than technical level, as outlined above, the focus was on delivering a methodology that can be used by a group of diverse stakeholders ranging from teachers, headmasters, pupils and parents but also experts from the municipality, architects and planners. One of the key elements of the methodology was to facilitate the decision-making process and to support the diverse stakeholders in turning their ideas and requirements into future proof, feasible and concrete actions. The methodology has been developed based on the following tasks:

1. Input given by relevant stakeholders during interviews and workshops held in the process of the project, which forms the basis of the study as described in [12].
2. A thorough literature research to assess the historical development of school buildings, the current state of the school building stock, and the architectural and functional requirements of current and future learning methods as described in depth in [28].
3. The adaptation of a general methodology as outlined in [28] for the development of building energy concepts to suit the specific needs of school buildings.

During workshops held in the framework of the study [12], several stakeholders have been consulted to provide feedback. The stakeholders included professionals from the construction industry, experts from project management, architects, experts from the Municipality of Vienna, and the Head of the Austrian institute for school and sport buildings (Österreichisches Institut für Schul- und Sportstättenbau ÖISS). The main conclusions that could be drawn from these assessments were that, in addition to a sound financing plan, participation of the involved stakeholders plays a key role in any school refurbishment process. This also coincides with findings undertaken in a comprehensive study on school construction, where the integration of stakeholders within a professionally moderated planning and building process was seen as an important factor [29]. Following the findings of point 1 and 2 above, the methodology was based on a general methodology that can form part of any design process for energy-efficient and sustainable buildings, as further described in Section 2.1 below.

2.1. General Methodology for the Development of Building Energy Concepts

A methodology for energy-efficient building refurbishment generally focuses on factors relating to energy-demand reduction, energy-efficient equipment, renewable-energy systems and human aspects. Ma et al. have identified these as the main categories related to building retrofit technologies [21]. Similarly, Xing et al. have highlighted in their assessment of zero-carbon building refurbishments that advanced technologies should be assessed in a “... consequential manner as a hierarchical pathway ...” [30]. They state the retrofitting of fabrics, more efficient equipment, and micro-generation as the hierarchical process towards zero-carbon refurbishments. These theoretical approaches are underlined

by practical examples undertaken within the framework of the German demonstration and research project “Eneff:Schule” [31], dealing with the retrofitting of schools towards plus-energy buildings. The measures addressed in the seven case studies include energy retrofitting of the envelope, technical building services, and the use of renewable energy [32].

Figure 2 below depicts a general methodology for building energy concepts following, in principle, a three-step approach. This methodology forms the basis for the development of building-energy concepts. In the first step, passive design measures should be exploited in order to reduce the overall energy demand by means of architecture and construction. Construction measures that have—in addition to their structural and architectural purpose—energy-relevant aspects also are considered within this first optimization process. The goal of the first step is mainly to minimize heating, cooling, ventilation and lighting loads by addressing the overall building architecture without the building-energy systems. This includes, for example, compactness, orientation, building envelope, as well as transparent elements of the building skin. Building according to the local climate and specific needs of the building users form the basis of this first step. In step two, the building-energy systems must be optimized to supply and distribute the required energy efficiently. Efficient ducting, control engineering and monitoring of the building systems form the relevant optimization aspects of this second step. Hybrid systems that work closely with passive measures form an intrinsic part of this optimization process. The focus of the third step lies in the efficient and architecturally sound integration of renewable-energy systems. The goal is to avoid regarding the renewable energy systems as additive technologies on the building structure, but as functionally and architecturally integrated systems, which form part of the overall design of the building.

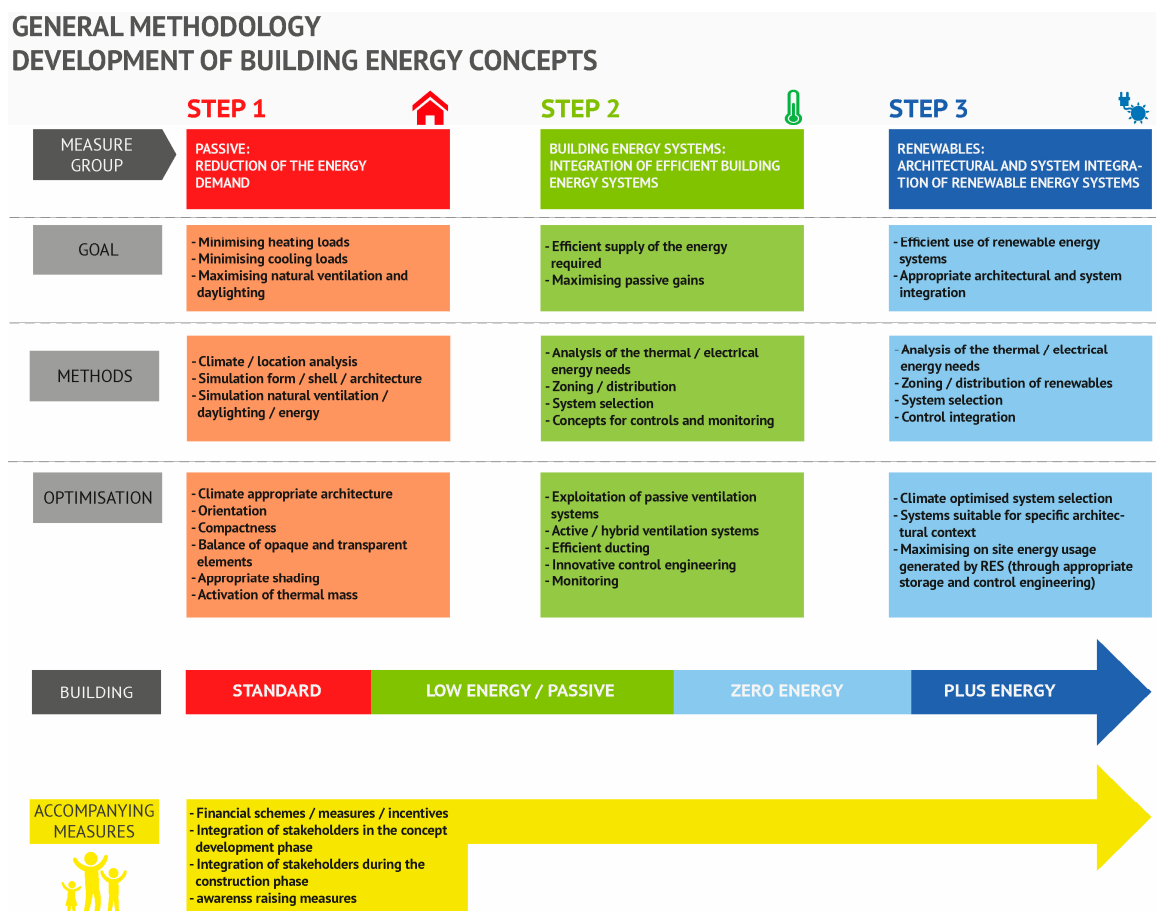


Figure 2. General methodology: development of building-energy concepts in a 3-step approach [28].

This approach should ensure that, before any active technology- and system-intense measures are considered, the passive measures are fully exploited. The architecture supporting energy efficiency is thus the underlying focus. This approach necessitates that demand-side measures are optimized before distribution and supply measures, which results in an efficient use of resources and technical or renewable building systems.

2.2. School Refurbishment Methodology for the Development of Building-Energy Concepts

Based on the results of interviews and workshops held as part of the project [12] as well as the literature research documented in [28], the above-described methodology (Figure 2) has subsequently been adapted into a school refurbishment-specific methodology and divided into modular sub-areas to suit the specific requirements of school refurbishment concepts. The focus of this adapted methodology, as shown in Figure 3, lies on the synergies and interactions between energy-related renovation measures and new functional space requirements in school buildings. The aim of the modular system is, on the one hand, to meet the varying complexity of different refurbishment projects and, on the other, to allow enough flexibility in order to apply the methodology to a wide range of projects. The individual measures are based on the 3-steps approach as outlined above (Section 2.1) and divided into the groups of measures: passive (1), building-energy systems (2), and renewables (3), and numbered from 1 to 3. Accompanying measures are in a separate set, as they should be seen as part of the overall process and not in a successive sequence (see below Section 2.4).

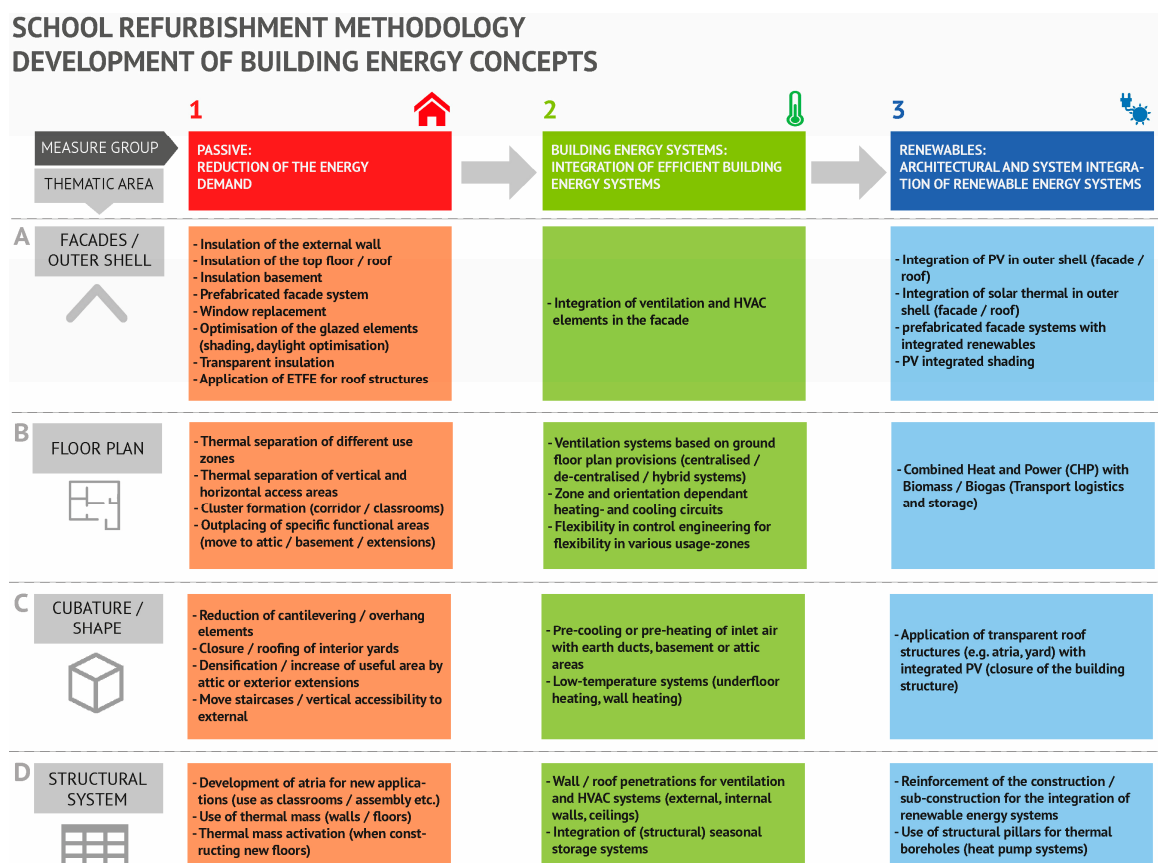


Figure 3. School refurbishment methodology: development of building-energy concepts in a 3-step approach adapted for measures in school refurbishments [28].

The measures in the three steps are bundled into the four thematic areas of façades/outer shell (A), floor plan (B), cubature/shape (C) and structural system (D). These four areas were chosen based

on the fact that refurbishment projects can range from measures that, for example, only deal with the insulation of the façade to measures that encompass the overall structure of the building, including removing or adding floors and walls. To allow for the possibility to specifically include or exclude a whole thematic area, this distinction into four groups has been made. The façades/outer shell (thematic area A) is the area most likely being addressed by any refurbishment, motivated on energy-efficiency needs or structural malfunctions of the façade. Maintenance aspects of the façade, such as changing the windows or adding external shading to the transparent areas, also fall into this thematic area. These can include minimal invasive actions, which can even be undertaken during the school year (e.g., if windows are changed from one class to the other, only one class has to move at a time during construction). Given the increased use of pre-fabrication systems, measures in this thematic area must not necessarily disrupt the everyday school life if properly planned. The thematic area B concerns itself with the floor plan. This is especially important if functional changes are being considered as part of the refurbishment. New school forms and changes to the curricula require also adequate learning environments. Measures that also affect the floor plan thus need to be viewed within the overall context of the school form and subsequent space requirements. The third thematic area, C, focuses on the cubature and shape aspects. This would already mean that adaptations to the outer shell are being considered. Measures could range from hardly invasive, such as closing an inner courtyard with a photovoltaic roof, to more invasive measures, such as extending the building by including annexes or additional floors. Making changes to the structural system (thematic area D) would implicate a “deep renovation” with substantial changes to the structure of the building. Measures in this area usually also mean, that the entire school would probably need to be relocated during the construction process.

This module-like design is intended to support the complexity and the required degree of innovation to suit a wide range of project types. Depending on the requirements and complexity of the project, the individual measures can be linked to bundles of measures to ensure the greatest possible flexibility for different types of buildings. They represent a selection and a basis that can be applied in principle to all school refurbishment projects, independent of external framework conditions (e.g., country, institutional context). Depending on the project, it might be useful to include or omit measures in the measures groups.

2.3. Detailed Description of Measures in Interaction with New Functional Requirements

Following the above logic of groups of measures (1 to 3) and thematic areas (A to D), potential impacts, interactions and synergies with new functional requirements are described for each measure group. This is of particular importance as it provides the key value of the methodology: the technical aspects of the measures are linked to the potential functional changes. For stakeholders from the educational field, this provides a translation into space and room concepts and should open up ideas and options of how specific measures could be exploited to improve the functional space. This is where the synergies between the structural, energy-related and functional changes are highlighted. Here, the methodology should provide relevant decision support for the stakeholders as they can select and assess various measures and review the impact of the measure on the architecture and space.

For each step of the three-step approach (1 to 3), the four measure groups for the four thematic areas (A to D) show the description of the interaction of the measure group with the new functional requirements. Each step (1 passive, 2 building energy systems and 3 renewables) is combined with each thematic area (A façades/outer shell, B floor plan, C cubature/shape and D structural system). In the following sub-chapters, the individual measures are discussed in more detail.

2.3.1. Measure Group 1 Passive: Reduction of Energy Demand

Figure 4 below provides the measure groups for step 1 (passive) in combination with thematic areas A to D. For example, measure group 1A describes passive measures (i.e., architecturally driven), which are being applied to the outer shell of the building. e.g., the application of transparent insulation substituting part of an opaque wall could create new interior spaces in areas that previously did not get enough

daylight. An increased wall thickness due to the external application of a new insulated façades system could provide additional window bays or window seats for pupils to rest or read. Following the same principle, a detailed assessment of the impact, interaction and synergies with new functional requirements has been made for the three remaining thematic areas of this first measure group (1B, 1C, 1D).

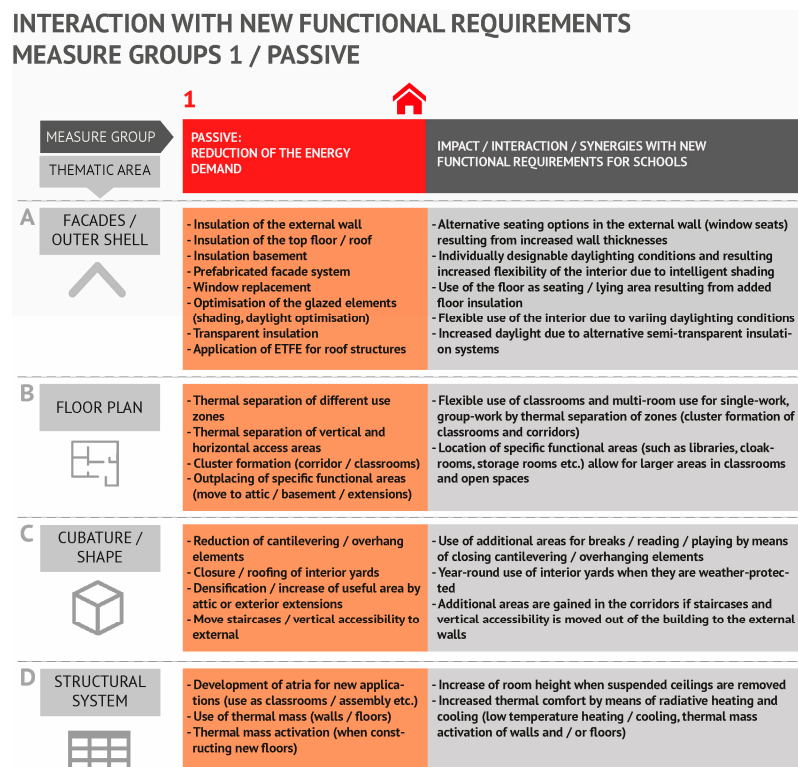


Figure 4. Measure group 1: Interaction of measures 1A, 1B, 1C and 1D with new functional requirements for schools [28].

2.3.2. Measure Group 2 Building-Energy Systems: Integration of Efficient Building-Energy Systems

For step 2 (building-energy systems), the interaction with thematic areas A, B, C and D is shown in Figure 5 above. As an example of the description of measure group 2B: when providing a new heating or ventilation system, which can be controlled based on occupancy and room size, then flexible partitions and room-joining or room-separation becomes possible as part of the floor-plan concept. This shows a typical interaction of a technical system-related measure with the room concept. Similarly, the three other thematic areas in this group (2A, 2C and 2D) are described in detail under the synergies heading of Figure 5.

2.3.3. Measure Group 3 Renewables: Architectural and System Integration of Renewable-Energy Systems

For step 3, the four respective measure groups are shown below in Figure 6. For example, in measure group 3C a combination of step 3 (renewable-energy systems) and thematic area C (cubature/shape) is described. As an example, the application of photovoltaic elements to enclose whole or parts of courtyards could create additional protected spaces for outdoor classrooms or leisure activities for the pupils. Renewable-energy systems could in this instance serve a double purpose of adding valuable environments to the schools, creating awareness by displaying these systems, and providing energy to the building. The interactions with the three remaining thematic areas (3A, 3B and 3D) are part of Figure 6.

INTERACTION WITH NEW FUNCTIONAL REQUIREMENTS MEASURE GROUPS 2 / BUILDING ENERGY SYSTEMS





MEASURE GROUP		2	
THEMATIC AREA		BUILDING ENERGY SYSTEMS: INTEGRATION OF EFFICIENT BUILDING ENERGY SYSTEMS	IMPACT / INTERACTION / SYNERGIES WITH NEW FUNCTIONAL REQUIREMENTS FOR SCHOOLS
A	FACADES / OUTER SHELL 	<ul style="list-style-type: none"> - Integration of ventilation and HVAC elements in the facade 	<ul style="list-style-type: none"> - Acoustic requirements must be considered when integrating HVAC systems into the facade (especially ventilation systems) - The opening of windows should be possible in addition to the mechanical ventilation system (hybrid system); the ventilation rate will be controlled depending on the indoor air quality
B	FLOOR PLAN 	<ul style="list-style-type: none"> - Ventilation systems based on ground floor plan provisions (centralised / de-centralised / hybrid systems) - Zone and orientation dependant heating- and cooling circuits - Flexibility in control engineering for flexibility in various usage-zones 	<ul style="list-style-type: none"> - Control circuits for heating, cooling and ventilation (centralised, decentralised, hybride) must be able to support the flexibility in room uses - Control systems must be able to be adjusted based on the specific room use at a given time (to allow for joining / separating spaces and varying occupancy rates) - For thermally activated slabs the systems must be able to control pre-cooling or pre-heating of the spaces based on the actual room use at a given time (occupancy and time dependant conditioning)
C	CUBATURE / SHAPE 	<ul style="list-style-type: none"> - Pre-cooling and / or pre-heating of inlet air by means of earth ducts / basements / attics - Low-temperature systems (underfloor heating, wall heating) 	<ul style="list-style-type: none"> - Additional use of the floor as seating / playing area by means of underfloor heating - Control circuits for heating / ventilation systems must be flexible enough to adjust to various room uses (e.g. use for group-work, use for reading, use for light exercise or play etc.)
D	STRUCTURAL SYSTEM 	<ul style="list-style-type: none"> - Wall / roof penetrations for ventilation and HVAC systems (external, internal walls, ceilings) - Integration of (structural) seasonal storage systems 	<ul style="list-style-type: none"> - Acoustic requirements must be considered at all times, especially when catering for multi-functional room requirements (e.g. flexible connection of corridor and classroom must consider acoustic aspects of the connection of the ventilation system of the corridor and classroom)

Figure 5. Measure group 2: interaction of measures 2A, 2B, 2C and 2D with new functional requirements for schools [28].

INTERACTION WITH NEW FUNCTIONAL REQUIREMENTS MEASURE GROUPS 3 / RENEWABLES





MEASURE GROUP		3	
THEMATIC AREA		RENEWABLES: ARCHITECTURAL AND SYSTEM INTEGRA- TION OF RENEWABLE ENERGY SYSTEMS	IMPACT / INTERACTION / SYNERGIES WITH NEW FUNCTIONAL REQUIREMENTS FOR SCHOOLS
A	FACADES / OUTER SHELL 	<ul style="list-style-type: none"> - Integration of PV in outer shell (facade / roof) - Integration of solar thermal in outer shell (facade / roof) - prefabricated facade systems with integrated renewables - PV integrated shading 	<ul style="list-style-type: none"> - Semi-transparent elements in the facade create various light-patterns in the interior and thus varying indoor-lighting qualities - Semi-transparent elements can be applied when daylight but no direct view to the outside is required - Adaptable (PV)-shading allows for a flexible use of the interior by means of intelligent shading (e.g. brighter daylight conditions for reading and dimmed daylight conditions for screen applications)
B	FLOOR PLAN 	<ul style="list-style-type: none"> - Combined Heat and Power (CHP) with Biomass / Biogas (Transport logistics and storage) 	<ul style="list-style-type: none"> - Logistical aspects must be considered when using biomass (e.g. delivery of biomass and maintenance of systems must be possible outside school hours and with limited noise interference)
C	CUBATURE / SHAPE 	<ul style="list-style-type: none"> - Application of transparent roof structures (e.g. atria, yard) with integrated PV (closure of the building structure) 	<ul style="list-style-type: none"> - Creation of additional protected open spaces by means of semi-transparent roofing (e.g. open or inner courtyards, window bays, light wells) - Semi-transparent elements create various lighting patterns and subsequently adapted interior room and space qualities
D	STRUCTURAL SYSTEM 	<ul style="list-style-type: none"> - Reinforcement of the construction / sub-construction for the integration of renewable energy systems - Use of structural pillars for thermal boreholes (heat pump systems) 	<ul style="list-style-type: none"> - If small wind turbines are integrated into existing buildings, specific care must be taken to avoid any noise and / or vibration caused by the turbines (e.g. structural separation of turbines and roof)

Figure 6. Measure group 3: interaction of measures 3A, 3B, 3C and 3D with new functional requirements for schools [28].

The description of these measure groups should provide the basic idea of the methodology in increasing the importance of the functional improvements to the typical technical measures undertaken in refurbishment projects.

2.4. Accompanying Measures

“Accompanying measures” in this context are defined as measures that do not directly result in structural or technical optimizations, but support the entire construction process as an accompaniment. These include forms of financing, the involvement of stakeholders in concept development, support for stakeholders during the construction phase, and awareness-raising measures. These measures form an essential aspect of the successful implementation of a school refurbishment project, but they are difficult to quantify both in energy- as well as cost-related terms. Financing forms are particularly relevant if financing cannot be provided from one source or if certain measures can only be implemented if additional funds can be acquired. The involvement of the relevant stakeholders throughout the whole development plays another important role in ensuring a high acceptance of the overall process. In refurbishment projects especially, the stakeholders can be faced with severe changes to their familiar working or learning environment. If a relocation of the school during construction is not possible, they are also confronted with the negative effects of the building process such as noise or dirt. Involvement and “ownership” of the changes that are undertaken in the schools by those who are most affected (i.e., the pupils and teachers) are therefore vital for delivering a successful project. In a study developed by Zundel and Stieß, aspects beyond the profitability of energy-saving measures were analyzed in order to assess attitudes towards energy savings [33]. Even if the results focus on private homeowners and can thus not directly be linked to public buildings, one can derive from the conclusions that a broad range of aspects are important when it comes to energy efficiency. These relate, for example, to comfort, convenience and belonging, factors that are equally important when addressing energy-saving measures in schools. Awareness-raising measures also contribute to the acceptance and energy-efficient operation of the building after the construction phase. To support this, information about energy consumption can be displayed via digital media, at the same time pointing out energy-saving measures or specific workshops on the energy-efficient use of the building.

3. Results

3.1. Application of Methodology in a Case Study

As part of the project [12], a case study that represents a typical Viennese “Gründerzeit” school building, constructed in 1898, has been selected. With over 30% of the Viennese school building stock being erected before 1900, this building represents a “typical” Viennese school building. The building is located in the 21st district in a rather dense urban area with the shape of almost two identical building blocks to the north and south, which originally hosted the boys-only and girls-only sections of the school. The school comprises three full floors and an attic, which was unused at the time the study was undertaken. The total gross floor area is roughly 6900 m² [28,34]. Figure 7 below shows the ground floor plan and section of the school.



Figure 7. Ground floor plan (a) and section (b) of the case-study school [12,28].

Within the project, the goal was to quantitatively (energy and lifecycle costs) and qualitatively (architecture, functional requirements) assess which refurbishment measures were most suitable for the specific building and use. In order to provide a transparent methodology, whereby stakeholders are included, the process was divided into four subsequent actions:

- ☐ Action 1: Analysis of the existing building.
- ☐ Action 2: Goal development with stakeholders.
- ☐ Action 3: Selection of refurbishment concepts.
- ☐ Action 4: Quantitative assessment of refurbishment concept.

The analysis of the existing building (action 1) included a thorough assessment of the building structure, architecture and systems in addition to energy-consumption data obtained from the building managers. In the following action (action 2), the stakeholders were consulted in order to arrive at a common understanding of the overall goals. Within action 3, the methodology as developed in the project has been applied and subsequently refined to arrive at the methodology described in this paper. This step has been facilitated by the measures, which have been selected and grouped based on the tasks as described at the beginning of Section 2 above. The case study and methodology, therefore, jointly provided an iterative way of improvement: the first draft of the methodology with selected measure groups was developed purely on a theoretical approach following the basic principles of building energy concepts (Figure 2). In workshops and discussions with the relevant stakeholders of the case-study school, the measure groups were elaborated and the functional requirements and synergies have been added. The resulting methodology was then again tested on the case study for a final revision.

3.2. Selection of Measures and Concept Development

Based on the feedback from the stakeholders, the methodology also supports the application of varying degrees of innovation. During the process of selecting the various measures for the case studies, it became evident that it would be important for the stakeholders to arrive at concepts and designs which allow for different (more or less) innovative actions.

In the process of the development, the stakeholders could select different concept bundles. This enables a project to be combined with measures for e.g., “standard refurbishment”, “standard+ refurbishment” and “innovative refurbishment”. This could be of particular importance if, for example, different funding opportunities are used in school refurbishment projects. As outlined at the beginning of this paper, in Vienna refurbishments for compulsory schools are currently funded by the City of Vienna [5]. However this does not apply to additional measures (e.g., the changing of the heating system or integration of renewable energy). Thus, the stakeholders could select three different bundles of measures, e.g., the “standard” bundle for measures that will be financed by the local municipality,

the “standard+” bundle for measures that could be afforded, if additional structural funds are made available, and the “innovative” bundle for the wish-list of measures if e.g., infrastructure funds would be granted. For each bundle, individual measures could be selected.

In Figure 8, three-selected concept bundles for measure group 1 passive are shown for the case study. It can be seen that for each bundle (standard, standard+ and innovative), different individual measures have been selected. Together with the two other measure groups (group 2 building-energy systems and group 3 renewables) the selection can provide a description of three concepts with varying degrees of innovation. This is intended to support the planners and stakeholders in designing different innovative concepts for their schooling project based on one common methodology, which subsequently can be planned and priced accordingly. Passer et al. [24] have also highlighted in their conclusions that high-quality refurbishments (as opposed to standard refurbishments) can result in greater acceptance by the building’s users. Addressing varying degrees of innovation can thus support the decision-making process by assessing the different cost vs. value options.

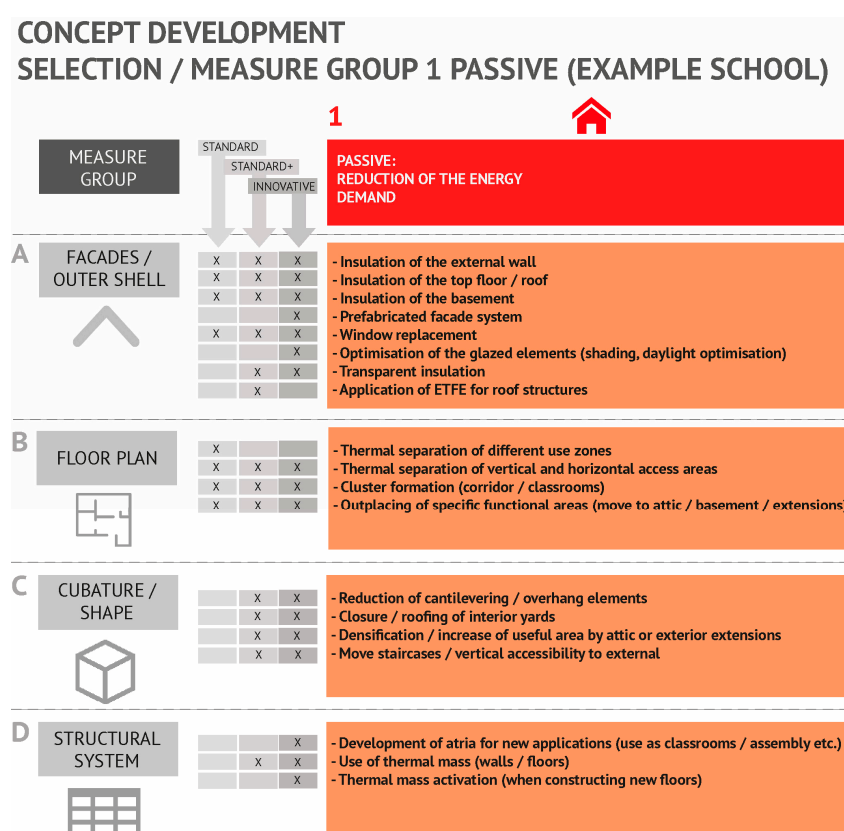


Figure 8. Concept development: selection in measure group 1 (passive) for the case-study school [28].

3.3. Evaluation of Concepts

In the last action (action 4), the concepts can be evaluated and compared in terms of energy performance (e.g., reduction of heating-energy demand) and budgetary allowance (e.g., lifecycle analysis) and planned accordingly. Once the selection has taken place, various options can be assessed and compared. Figure 9 shows an example of one of the resulting analyses of the energy performance for combined measures. Here, various measures and measure groups, which previously have been selected as part of action 3, have been quantitatively compared for the case study by means of thermal-dynamic simulations. In the same way measures have also been simulated individually to assess their potential impact. E.g., one of the measures relates to clustering the classrooms in different zones (thermally and from a fire regulation point of view), thus closing off the vertical access (staircase)

from the corridors (Measure Group 1B, see Figure 4 above). This created additional floor spaces (the corridors function as part of the classrooms) and at the same time, the vertical access is thermally separated with lower room temperatures. The analysis showed, that this refurbishment measure would result in a heating energy demand reduction of 12,5%. Similarly other functionally relevant measures have been simulated in various scenarios.

The detailed results of the energy and lifecycle assessments have already been documented in separate proceedings [34], therefore these evaluations have been added for explanatory purposes.

The results of the energy and life-cycle assessment as carried out in action 4 should, in an iterative approach, feed back to the selection of measures. Based on the quantitative results, changes can be made to the selection. The quantitative results thus support the decision-making process. The overall process should ensure a high level of transparency and involvement of all relevant stakeholders concerned, in order to arrive at a project concept that has been both jointly developed and thoroughly assessed to ensure sound concept development with a high acceptance rate.

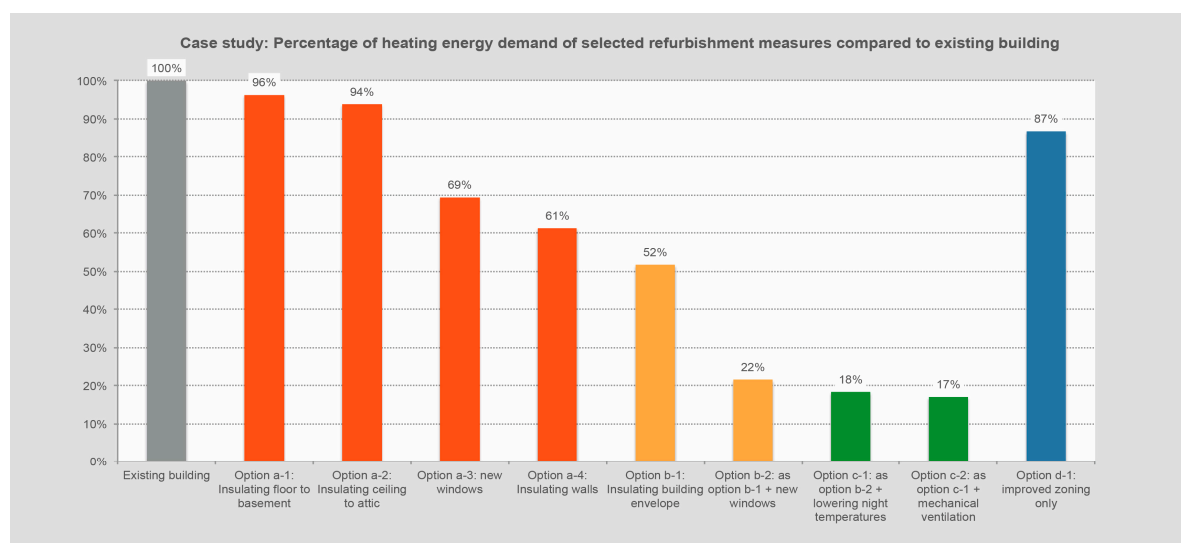


Figure 9. Analysis for the case-study school: percentage of heating-energy demand of selected refurbishment measures compared to the existing building [12,28,34].

4. Discussion

From the analysis of the requirements that new teaching and learning methods have of the spaces of school buildings, it becomes evident that these new functional requirements must be taken into account when addressing school refurbishment projects. Only focusing on the new technical, construction-related and building regulatory aspects would leave out the key factor of how educational spaces must be adapted to suit state-of-the-art learning concepts. The refurbished buildings must be suitable for future generations, thus it is important that functional changes are addressed in a joint effort if refurbishment actions are undertaken.

The goal is to provide the relevant stakeholders with a basis for decision-making and to support the overall process of the development of sustainable-refurbishment concepts with a thorough, but at the same time easy-to-use, methodology. It must also be noted that any comprehensive refurbishment process involving a series of stakeholders should be professionally accompanied and moderated. Professionals in this respect can be planners with additional expertise in moderation and mediation techniques, or coaches specializing in group-moderation and process management with a focus on architectural and planning projects. The methodology can provide guidance in this process and supports an understanding of the linkages between the technical measures and the functional room requirements. This must, however, be applied within the context of a planning team, which can assess

the requirements of the school to be refurbished and carry out the required adaptations and designs for refurbishment actions.

Replication of the methodology under varying framework conditions (e.g., different climate zones, different countries, different institutional context, and specific functional learning-space requirements) is desired but has not yet been undertaken. A next potential step could be the digitalization of the methodology in an online platform in order to provide an openly available tool for stakeholder processes in this field. By means of open access, the methodology could be further developed and additional measures added based on the feedback provided by those who apply the methodology to their projects. An open-access methodology would also enable relevant planning stakeholders and local authorities involved in the building regulatory process to review and assess different variations of measures. It would facilitate the sharing and comparing of different viewpoints, as selected scenarios could be compared and subsequently assessed by the relevant planning experts.

5. Conclusions

A lack of a coherent methodology has, together with budgetary constraints, been identified as one of the main barriers to comprehensive school refurbishment actions. The proposed methodology can serve as a potential solution. It offers a more qualitative rather than a solely quantitative approach, which has been cited as more appropriate when dealing with a very diverse group of stakeholders most of whom might not have a technical or planning background.

The application of the developed methodology in an exemplary case study has shown that the process of selecting appropriate measures for sustainable refurbishment actions can be facilitated by the developed methodology. Highlighting the synergies between energy related refurbishment measures and functional adaptations greatly helped in the communication with the stakeholders and to arrive at a result in a short period of time. Stakeholders dealing with the actual refurbishment actions would mostly be interested in the costs and technical aspects. On the other hand, stakeholders from the school would mostly be interested in the functional improvements they would get from the planned refurbishment. With the proposed approach, the refurbishment actions could be planned jointly, with a higher acceptance of all stakeholders involved. The measures were found to be comprehensive, as most aspects of individual refurbishment actions have been covered by the measures and measure bundles. Nevertheless, it might be necessary to add or omit measures based on specific project needs. Additional measures should, however, be included in the main groups of measures and should follow the same principles of integrating the technical aspects with the functional requirements.

Connecting the individual measures with functional requirements provides a crucial step forward in addressing qualitative aspects of space and architecture. The main benefit of the methodology thus lies in these synergies: supporting the stakeholders in the development of resource- and energy-efficiency but also functionally and architecturally improved schools with a methodology that can be easily applied to any school refurbishment project.

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