*Research Paper*

# Digital Tools and Modular Design for Sustainable Energy-Efficient Refurbishment

## Demonstration Project, C-40 Abbiategrasso Social Housing Blocks in Milan

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Figure 1: Selected demonstration project: prefabricated modular concrete building, a prototypical residential building in urgent need of refurbishment, in Abbiategrasso, the southern periphery of Milan

## Abstract

Research Objective, Status Quo and Challenge, Problem Addressed: The building and construction sector is responsible for approx. 40% of global energy consumption and $CO_2$ emissions. Problems addressed are related to building design and construction.

The low percentage of building refurbishment in Europe, at only 1.5% per year, is associated with several significant problems in building design and construction:

- Energy Inefficiency: Many existing buildings in Europe were constructed without energy-efficient features and technologies. As a result, they have high energy consumption and contribute significantly to carbon emissions. The low rate of refurbishment means that a large portion of the building stock

continues to operate inefficiently, wasting energy and exacerbating environmental impacts.
- Lack of Sustainability: The low refurbishment rate hinders the transition to more sustainable and environmentally friendly buildings. Sustainable building design and construction practices, such as incorporating renewable energy sources, improving insulation, and optimizing energy performance, are not being implemented at the necessary scale. These are missed opportunities for reducing energy consumption, decreasing greenhouse gas emissions, and promoting sustainable living environments.
The building sector can best follow the principles of circular economy by prioritizing the refurbishment of existing buildings over further soil sealing and $CO_2$ emissions resulting from new construction. The transition to nZEB, net zero emissions buildings will succeed if, on one hand, safeguarding the existing structures is prioritized and the buildings are retrofitted and, on the other hand, future new construction generates zero emissions. Unique opportunities in refurbishment lie in rethinking, redesigning and modernizing existing buildings into more energy-efficient and less material-intensive ones. By adapting effective strategies and actions, the opportunity arises to not only improve the energy performance of buildings and increase the renovation rate of currently 1.5%, but also to ensure enhancing the quality of life in urban areas and support citizens' health and well-being. This would be particularly beneficial for less advantaged neighborhoods with older social housing blocks where a lack of funding for refurbishment hinders progress.
The transformation to renewable energy in existing cities depending on gas as the dominant energy source can only succeed if the energy inefficiency in the building sector is first reduced and existing buildings are refurbished to reduce thermal loss; i.e., the precondition for the transfer to low-temperature heating systems using renewable energy sources.
Energy modeling and simulation tools can be used to analyze building energy performance and identify areas for improvement. This data can inform the design of energy-efficient refurbishment measures and assess their potential impact. Energy-efficient refurbishment, energy transition and greening of existing buildings can create a holistic and sustainable approach to urban design that addresses some of the most pressing challenges facing cities where 80% of the buildings in 2040 (estimate Vienna) already exist today but only 1.5% is renovated per year. This abstract proposes a comprehensive approach to accelerate the refurbishment of social housing blocks built from prefabricated concrete using digital tools and modular design for replicability. The focus on large-scale, prefabricated residential buildings will be beneficial for the most vulnerable population living in high-density environments that are particularly affected by UHI. The inclusion of renewable energy sources and the greening of existing buildings emphasize the importance of sustainable urban design to create livable and environmentally friendly cities for present and future generations within the already built-up areas, especially those with fewer green spaces and an economically disadvantaged population. The adoption of circular design principles helps to reduce the carbon footprint of the refurbishment process and minimize the impact on the environment. By considering the entire life cycle of a building from design to demolition, circular economy principles can promote a more sustainable and responsible approach to building design and construction. Although digitalization is a prerequisite, data is hardly available for buildings older than 25 years.

**Keywords**
*$CO_2$ Neutrality, Energy Efficiency, Refurbishment, Social Housing ,UHI Effect, Modular Design*

## 0. Introduction

Most large cities worldwide have recently experienced the dramatic effects of the climate crisis. European cities face on top of that an unprecedented energy crisis with price explosions for gas and electricity which particularly affect lower-income households in older buildings. On the one hand, the population has increased in European cities due to better job opportunities, cultural networks and the location of social services. On the other hand, recent phenomena related to climate change and lately also to the war in Ukraine have been affecting the livability of human settlements and require mitigation and environmental solutions that have to be combined with the energy transition to renewables and the necessary refurbishment of existing buildings, especially all public buildings and the social housing stock.

Cities in southern and central Europe have been impacted by Urban Heat Islands (UHI) phenomena, which are particularly critical in densely populated residential districts. Climate change impacts all building types but social housing estates for low-income families experience higher indoor temperatures and are mostly not yet climate-resilient.

Missed Opportunities for Urban Renewal: Building refurbishment presents an opportunity for urban renewal and revitalization. Neglecting refurbishment means missing the chance to enhance the aesthetics, functionality, and livability of existing urban areas. This can hinder the regeneration of communities and the development of sustainable and vibrant cities. Modern tools of urban development, reconstruction and housing production after World War II have left a huge stock of energy-inefficient postwar housing, often located in vulnerable urban fabrics without adequate green open space. Contemporary standards for refurbishment have to aim at improving these environmental qualities while facilitating an acceleration of the process. Innovation in the transformation of the building stock, e.g., through modular design and prefabrication, can offer valuable contributions to providing more livable and sustainable spaces faster.

Following the principles of circular economy (CE) provides a chance to transform refurbishment and construction in a more sustainable way. The principles of reusing materials and building components have to become standard procedures and not the exception. Architectural design following circular economy principles can combine affordable design solutions with environmental goals. Targeting the refurbishment of the existing building stock is therefore essential to achieve the ambitious 1.5-degree goals while improving the living and working situation of the citizens.

## 1. Status Quo, Problem Definition and Research Question

### 1.1 Existing Buildings in the EU Will Constitute 85% of the Global Building Stock in 2050

The EU Commission realized the urgency of focusing on the existing buildings even before the current energy crisis, which particularly affects non-insulated buildings dependent on fossil energy. Under the presidency of Ursula von der Leyen, the EU has set ambitious goals to jumpstart the renovation wave and accelerate the rate of energy-efficient refurbishment.

*At least two-thirds of the buildings that will exist in 2040 are already built. In the EU, more than 220 million buildings, representing approximately 85% of the building stock, were built before 2001 and will mostly still be standing in 2050. They are also unprepared for the ongoing and future changes in our climate, such as increasing temperatures and extreme weather events. Buildings are responsible for about 40% of total energy consumption in the EU and 36% of greenhouse gas emissions from energy. Building renovation is crucial to tackling this energy use and emissions, to meeting the EU's 2030 emission reduction target and to becoming climate neutral by 2050, as well to increasing resilience to climate impacts.*

*Today, renovation reduces the energy consumption of the buildings by only 1% per year. Extensive renovations that improve the energy performance of a building by at least 60% are annually carried out only in 0.2% of the building stock and in only a fifth of the cases is energy efficiency significantly improved.*[1]

The building sector contributes to approx. 40% of all $CO_{-2}$ emissions worldwide. This includes new construction, as well as the operation of the existing buildings. When it comes to the emissions resulting from operating, especially heating and cooling, the older buildings fare much worse than the newer ones from the last decade, which were built after stricter energy consumption regulations had been implemented in 2012. The Energy Efficiency Directive 2012, especially the Energy Performance of Buildings Directive,[2] revised in 2018, will help reach the building and renovation goals set out in the European Green Deal.

### 1.2 Energy-efficient Refurbishment to Reach the 1.5-Degree Goal and $CO_2$ Neutrality

In order to sustainably improve the ecological footprint of the building sector, the focus has to lie on the refurbishment of the existing building stock. The planning and building regulations in place in most of Europe and worldwide do not yet consider the urgency of improving existing city quarters and individual buildings. Since the climate crisis is now accompanied by an energy crisis, the urgency has increased, as older buildings use considerably more energy, rarely use renewable energy sources and are more susceptible to overheating in summer since they are located in more densely built-up urban areas with less green space. In social housing, more family members share an apartment with fewer $m^2$ / person than the European average with 1.6 rooms per person, i.e., 35 $m^2$.[3] The average floor area per capita ranges depending on the country in the EU, with the northern and central European countries at the top of the list, e.g., Denmark leading with 77 $m^2$/capita, Austria in 6$^{th}$ place with 55 $m^2$/capita while Romania and Serbia, with only 20$m^2$/capita, stand at the other end of the spectrum.[4]

In order to accelerate the refurbishment rate, the worst performing buildings have to be prioritized based on established criteria as in the TABULA[5] report while the construction process has to become standardized and, where possible, use prefabrication and modular construction while integrating renewable energies in refurbishments. In this context, regulations can play key roles in reducing the dependency on fossil fuels and accelerating the transition towards $CO_2$ neutrality while reducing costs, as many building codes have been added over time, resulting in an over-regulated market. These have to be adapted to facilitate the combined refurbishment of existing buildings with energy-efficiency measures and a shift towards renewable energy sources.

### 1.3 Measure Embodied Carbon in Existing Buildings and Include Stored $CO_2$ in Calculations

When addressing these complex challenges, therefore, it is best to act on a city and community level in coalition with public and private building owners. Before considering the demolition of an existing building to replace it with a new one, e.g., with higher density, the embodied carbon has to be measured and considered in the approval process. Every building owner has to measure the embodied carbon of their existing buildings and the material manufacturers have to provide the numbers for it. Combined with a $CO_2$ tax, this will be an effective counter-strategy to the current practice in which tear down and build new predominate – in the EU and in countries outside the EU with more constrained budgets.

### 1.4 Economic Challenges Preventing Refurbishment

The low refurbishment rate in Europe can be attributed to various factors and challenges:

- Split Incentives: In multi-unit buildings, where different individuals own or occupy separate units, building owners often hesitate to invest in energy-efficient renovations when the benefits of reduced energy consumption and cost savings primarily accrue to the occupants. This misalignment of incentives can hinder refurbishment efforts.
- Regulatory Barriers: Regulatory frameworks and policies can influence building owners' decision-making regarding refurbishment. Complex regulations, lengthy permit processes and unclear guidelines, coupled with inadequate support from local authorities, create barriers to energy-efficient refurbishment and discourage building owners from initiating renovation projects.
- Limited Access to Financing: The lack of affordable loans, grants, or incentives specifically tailored to energy-efficient refurbishments can deter owners from investing in energy-saving renovations.

- Disruption to Occupants: Building refurbishment often requires temporary relocation or disruption to occupants, particularly in multi-unit buildings. The logistical challenges and potential inconvenience for occupants discourage building owners from pursuing refurbishment projects.

Addressing these challenges requires a multi-faceted approach, including financial incentives, streamlined regulations, increased awareness campaigns and access to financing options.

## 2. The Path to a Circular Economy and Energy-efficient Refurbishment

### 2.1 Application of Circular Economy Principles to Buildings and Renovation

Sustainable building design and construction align with circular economy principles because they promote the efficient use of resources, minimize waste, and reduce environmental impacts throughout the building's life cycle. By following circular economy principles, such as using recyclable materials, reusing and repurposing existing building components, and reducing energy consumption and carbon emissions, several advantages can be realized:

- Resource Efficiency: Circular economy principles prioritize resource efficiency by maximizing the use of materials already in circulation. By reusing and repurposing existing building components, the demand for new raw materials is reduced, conserving natural resources and minimizing extraction-related environmental impacts.
- Waste Reduction: Circular economy principles aim to minimize waste generation. By using recyclable materials and designing buildings for disassembly, materials can be recovered and reused at the end of a building's life, diverting waste from landfills and reducing the need for new production.
- Energy Conservation: Sustainable building design and construction focus on reducing energy consumption and carbon emissions. By optimizing building performance using energy-efficient systems, and incorporating renewable energy sources circular economy principles align with the goal of minimizing the energy required during the building's life cycle and decreasing its carbon footprint.
- Cost Savings: Circular economy principles can result in cost savings throughout the building's life cycle. Using recycled or salvaged materials can be more cost-effective than purchasing new materials. Additionally, energy-efficient design and reduced operational energy consumption can lead to lower energy bills and long-term cost savings for building owners and occupants.
- Environmental Benefits: By following circular economy principles, sustainable building design and construction contribute to environmental benefits, such as reduced carbon emissions, conservation of natural resources, and minimized waste generation. This helps mitigate climate change, preserve ecosystems, and promote overall environmental sustainability.

Overall, circular economy principles provide a framework for sustainable building design and construction that promotes resource efficiency, waste reduction, energy conservation, cost savings and environmental benefits. Buildings designed following these principles will become more sustainable, resilient and beneficial for both people and the planet.

The best and all-encompassing step towards a CE is to stop demolitions and instead reuse the existing buildings. The 10 Rs of circular economy describe perfectly how to deal with construction and their most effective implementation is the reuse of existing buildings.

The non-profit affordable housing production is already under economic pressure due to increased construction costs and interest rates. The scarcity of resources and building materials resulting from the COVID-19 crisis and, most recently, the dramatic increase in energy prices due to the Ukraine war have further raised costs in Europe.

The recommendations are therefore to strongly support and subsidize owners, often non-profit or public housing agencies with limited budgets, in refurbishment. Due to a lack of investment incentives in the past, social housing often has low energy-efficiency standards. In the current energy crisis, this leads to high costs for the renters and severe financial problems for them and their families.

For future refurbishment projects of buildings with high energy consumption and related $CO_2$ emissions, their insulation with cradle-to-cradle certified materials, recycled materials and an energy hierarchy to prioritize renewables will have to become mandatory and receive subsidies.

In addition, building regulations often hinder both ecological refurbishment and architectural innovation; especially the application of reused building components and materials is prevented by missing certifications and guarantees. If redrafted according to circular economy principles, they could stimulate sustainable developments and the integration of green measures.

### 2.2 Renovation Wave – The Role of Residential Buildings

In 2021, one lighthouse initiative to jumpstart this wave was the New European Bauhaus (NEB) initiative. When introducing this initiative, Ursula von der Leyen stated, “I want Next Generation EU to kickstart a European renovation wave and make the Union a leader in the circular economy.” The innovative aspect of this interdisciplinary initiative lies in its equally high environmental and economic ambitions while equally aspiring to become a new cultural project for Europe. At the same time it addresses the necessity of architectonic aesthetics, circularity and social aspects by being beautiful, sustainable and achieved together.[6]

The European policy framework[7] has already started to pay more attention to quality aspects by focusing on priority themes (such as the circular economy, climate adaptation, cultural heritage, the renovation wave, innovative public procurement, biodiversity and nature-based solutions) to improve the life conditions in urban areas set out in the Urban Agenda for the EU.

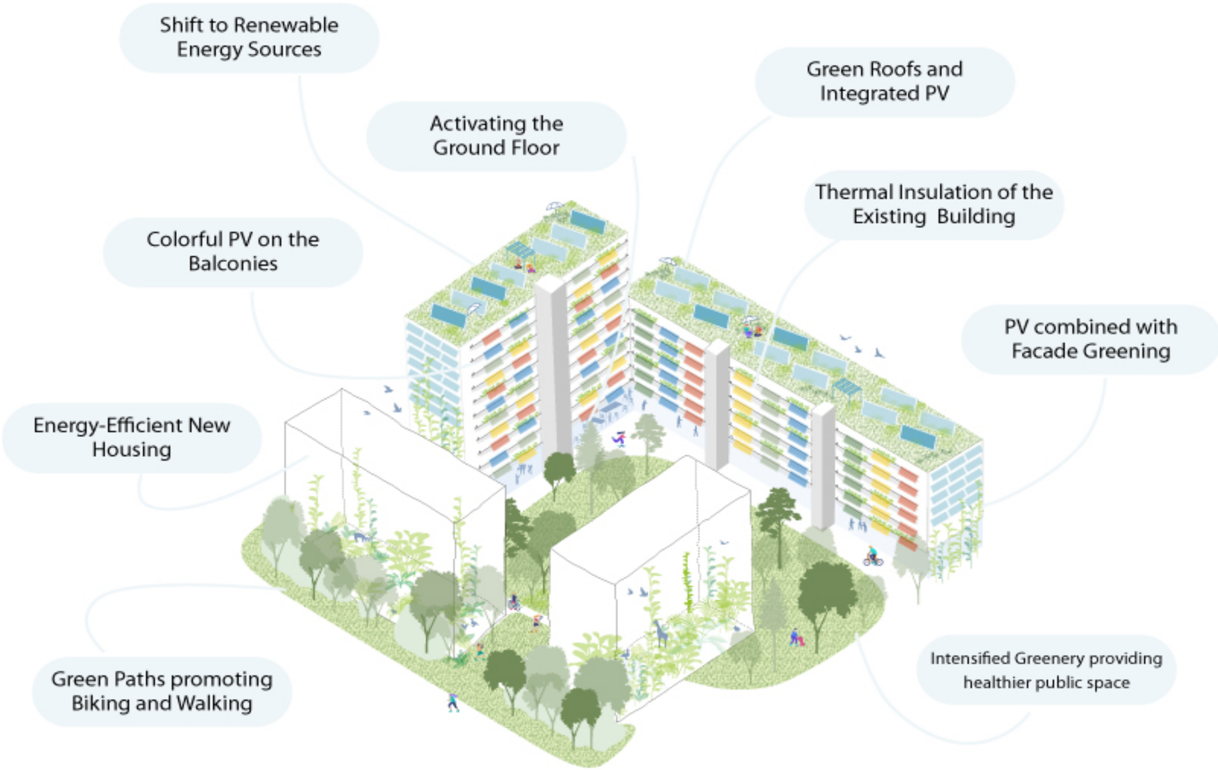
When focusing on construction and renovation, it becomes clear that a large positive impact can be generated by a renovation wave following the principles of circular economy. In the chapter “Leading the third industrial revolution,” the official website of the EU mentions that 35 million buildings could be renovated by 2030 and 160,000 new green jobs could be created in the construction sector by 2030.[8]

#### 2.2.1 Classification of the Residential Building Stock

In Austria, comparable to most European countries, the primary building category is residential. 80% of all existing buildings in Austria are residential and range from single-family house (SFH) to multi-family house (MFH) to large scale apartment-blocks (AB). To facilitate refurbishment strategies, a categorization of the different buildings was needed. The Austrian Federal Ministry of Economics, Family and Youth and the Austrian climate programme supported TABULA, a classification of the residential building stock in the research by IEE – Intelligent Energy Europe. The objective of the TABULA project is the development of a harmonized building typology for European countries. Each national building typology consists of a set of residential reference buildings with characteristic energy-related properties (envelope areas, U-values, supply system efficiencies). The data can be used by experts from all European countries for the assessment of national building stocks, for cross-country comparisons or for scenario calculations. The highest heating demand in $kWh/m^2/a$ is in all buildings (SFH, MFH, AB) dating from 1945–1960.[9] The next step based on this research will be to develop strategies for each category. In this paper, the focus lies on the AB in communal ownership because of the highest implementation potential and impact.

### 2.2.2 Demonstration Project

Starting from these environmental, social and economic challenges, the applied research "Comunità Solare" demonstration project investigates opportunities for refurbishment, innovation to improve green and environmental standards in building and renovation through CE, energy transition, and, ultimately, to enable better and more livable city quarters and residential buildings. A special focus lies on the shift of the energy sources towards renewables and the reduction of energy usage by thermally upgrading the buildings. The findings from the demonstration project will become replicable to modular buildings. The main findings will be collected in a case study project by the authors, a social housing estate in Abbiategrasso, on the periphery of Milan. The team participated successfully with Comunità Solare in the C-40 competition as one of several European case studies and demonstration projects for innovative refurbishment. The demonstration project for this paper best exemplifies a test case of an energy-inefficient building suitable for modular improvement measures to enhance energy efficiency as well




social sustainability, architecture and quality for the users and public space.

Figure 2: Demonstration Project for Modular Design in Refurbishment of Prefabricated Social Housing Blocks

The renovation will use renewable energies (solarthermics and photovoltaics, as well as geothermic probes and heat sources (e.g., environmental heat, ambient heat, waste heat or wastewater heat). For this purpose, a future-oriented building physics concept is developed with the aim of generating energy and absorbing $CO_2$ in order to boost the RE potential to increase overall energy efficiency and reduce energy consumption. A conscientious adaptation of use will relocate functions within the building based on the different thermal conditions within. The buildings can become energy self-sufficient and even supply buildings in the vicinity with electricity from the PV on the façades and roofs. The plan is to apply innovative refurbishment techniques and energy-efficiency measures, shift to renewable energy sources and at the same time consider and implement additional social and architectonical qualities for the users, as well as public space in the demonstration project to holistically address sustainability in the life cycle.

The documentation will support the application of the modular concept in other prefabricated social housing buildings in Europe.

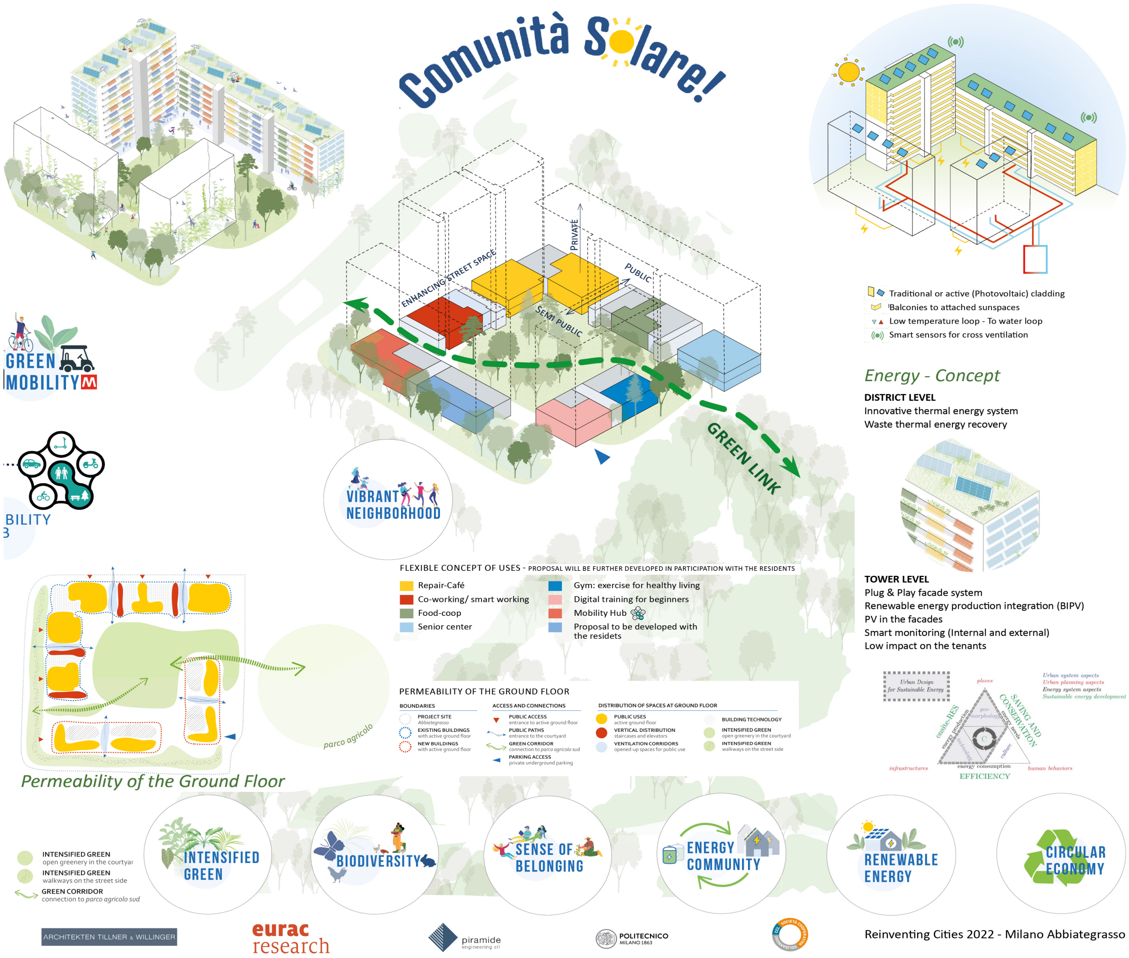



Figure 3: The Abbiategrasso demonstration project in Milan – combined measures to transform social housing from the 1980s into sustainable and $CO_2$-neutral, energy self-sufficient buildings, a successful contribution to the C-40 competition in 2022–2023

# 3. Modular Design

## 3.1 Modular Design in Refurbishment

The energy-efficient refurbishment of 20th-century social housing built from prefabricated concrete can be significantly accelerated and optimized by utilizing digital tools and modular design for replicability for the following reasons:

- Design Efficiency: Digital tools, such as Building Information Modeling (BIM) software, enable precise and efficient design processes. They allow architects and engineers to create detailed 3D models, simulate building performance and optimize energy efficiency strategies. This streamlines the design phase, reduces errors, and ensures the most effective energy-efficient solutions are incorporated.

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| - Iterative Design and Analysis: Digital tools facilitate iterative design and analysis, allowing for rapid testing and evaluation of different design options. By using energy simulation software, designers can assess the energy performance of various refurbishment strategies, enabling them to identify the most effective approaches quickly. This iterative process saves time and resources by avoiding the need for physical prototypes or trial-and-error modifications. |
| - Replicability and Standardization: Modular design enables the creation of standardized building components that can be replicated across multiple housing blocks. By developing a set of standardized modules that are designed for energy efficiency, the refurbishment process becomes more streamlined and scalable. This approach allows for faster implementation, reduced construction time, and consistent energy performance outcomes across different housing blocks.<br>- Prefabrication and Off-Site Construction: Digital tools facilitate the integration of modular design with prefabrication techniques. With precise 3D models, components can be prefabricated off-site in controlled environments, leading to improved quality control and faster construction. This off-site construction approach minimizes on-site disruptions, reduces construction time, and accelerates the energy-efficient refurbishment process.<br>- Data-Driven Decision-Making: Digital tools enable the collection and analysis of building performance data. By monitoring and analyzing real-time data from sensors and building management systems, energy inefficiencies or anomalies can be quickly identified and addressed. This data-driven approach helps optimize energy performance, enhances energy management strategies and supports continuous improvement in the energy efficiency of refurbished housing blocks. |
| The integration of digital tools and modular design for replicability accelerates the energy-efficient refurbishment of 20$^{th}$-century social housing blocks. It enables efficient design processes, iterative design and analysis, standardization, prefabrication, and data-driven decision-making. This results in faster implementation, improved energy efficiency and streamlined construction processes, ultimately contributing to a more sustainable and energy-efficient built environment. |

Therefore, several research projects funded in the Horizon 2020 program focused on the acceleration of the building renovation rate by developing a deep retrofit approach based on modular and industrialized solutions with the use of prefabricated multifunctional façades. This effective renovation method for existing buildings addresses both the envelope and the building systems, as well as structural rehabilitation. The method is being tested on several demonstration projects across Europe with 11 different partners on small to medium-scale buildings. The multi-functional new façade can be applied on the outside of the existing building envelope fixed to a modular prefabricated sub-structure with all the functional components needed for the retrofit (windows, energy generation and distribution systems, mechanical ventilation, etc., as well as additional qualities like balconies, greening, sight and wind protection, etc., to enhance quality for the users and create an attractive, lively public space that incentivizes communication)[10] To accomplish these objectives, the project develops two main technologies: building components and digital solutions.

- A modular envelope mesh, based on industrialized principles, enables fast assembly and interconnection of all components and energy/data networks, including technologies for energy harvesting, storage and distribution, as well as additional architectonical elements to improve the quality of usability and public space.
- A digital platform provides a framework to stakeholders with a clear structure and access to a wide range of technologies for deep renovation of buildings. It supports all stages of the renovation, from early decision-making and data acquisition to the manufacturing, construction, operation and maintenance of the implemented system. The platform makes use of digital modular tools closely linked to a digital model of the buildings, which in its final stage become a Digital Twin allowing real-time control, simulation and operation of all building components.

More sophisticated modular adaptable components can also be integrated within the system, including an active window for ventilation and heat recovery and solar harvesting devices. A cost-benefit analysis will be crucial for the final choice of a set of measures considering the affordability demand of social housing in most parts of the project. A low-tech approach will be favored.
A set of digital tools that will connect to the digital platform to support and accelerate all stages for a more efficient and automated renovation process: automated data acquisition, LCA/LCC analysis and decision support, digital BIM model building and computer-assisted manufacturing (CAM), and a smart building management system (sBMS) for optimized operation and maintenance.
A Digital Twin starts as a simplified digital model and increases in complexity and interaction potentialities as the project develops. At completion, the model becomes a Digital Twin of the renovated building allowing real-time monitorization, simulation and optimised operation of all building components, all collectors, PV and hybrid panels, heat pumps and energy batteries for load shifting.[11]

### 3.2 Comunità Solare – A Prototype for Modular Design in Refurbishment

Building upon and learning from the findings of others in the Build up Europe publication,[12] the renovation method for Comunità Solare in Abbiategrasso plans to apply methods to a larger scale, i.e., 13-story social housing blocks, and include the energy transformation embedded in a sustainable architectural and social concept for even longer validity in the life cycle.

The strategy for the refurbishment of prefabricated social housing blocks built in Europe between 1950 and 2000 may take advantage of the modularity of these buildings which used similar sizes and construction techniques. The selected demonstration project in Milan from the 1980s serves as a prototypical example for that building type. The modular Comunità Solare concept shall become a prototype for energy-efficient renovations and the creation of plus energy districts, as many issues relating to energy-saving renovations can be exemplarily addressed in these structures at least around Europe. Their renovation is to become a "case study" reference for this building typology and offer strategies for future projects, demonstrating scalability and replicability. The energy-efficient renovation of prefabricated residential buildings uses modular design for off-site fabricated façade elements to shorten the construction process and minimize the negative impact on residents up to enabling them to stay in their apartments during refurbishment. Costly scaffolding can thus also be foregone. Modular design would allow for the certification of entire façade elements rather than each individual component and therefore accelerate the process significantly. The façade elements will include thermal insulation, PV panels, greening, balconies, as well as sight and wind protection elements (see Figures 2 and 4).

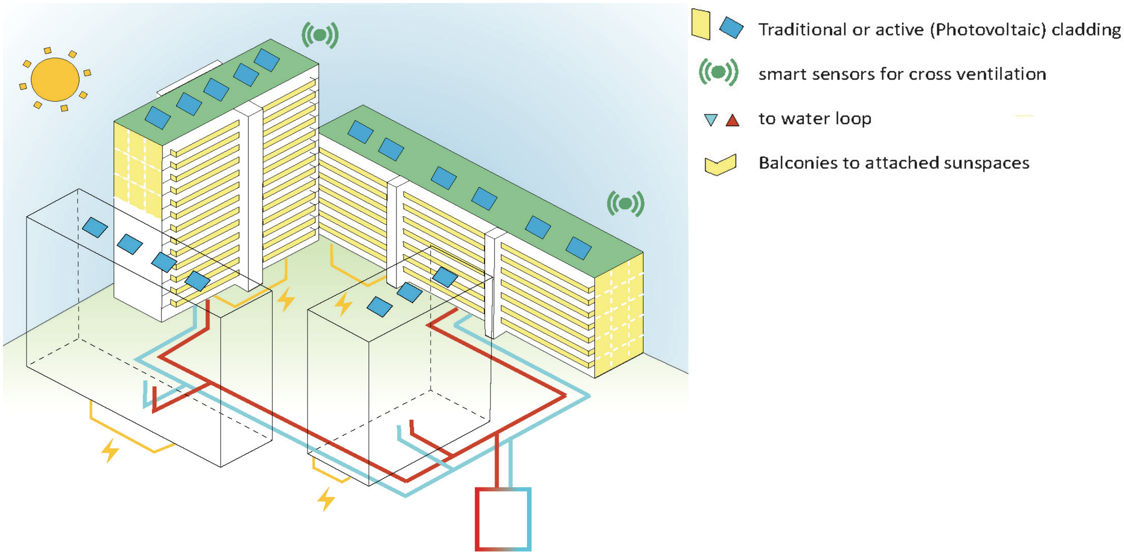


Figure 4 – Diagram for the energy system and the smart grid:
DISTRICT LEVEL Innovative thermal energy system, waste thermal energy recovery.
TOWER LEVEL: Plug & Play façade system, renewable energy production integration ( BIPV), smart monitoring (internal and external), low impact on the tenants

## 4. Energy Transition in Existing Buildings

The energy transition towards renewables has to include all existing buildings and use state-of-the-science technologies, i.e., green tech,[13] just as much as a responsible and considerate circular low-tech approach.

### 4.1 Energy Concept and Sources for the Use of Renewable Energies

The energy-efficient renovation will take place using renewable energies (e.g., solarthermics and photovoltaics, a geothermal probe field, as well as biomass/biomethane in a sustainably generated and available scope) and heat sources (e.g., environmental heat, ambient heat, waste heat or wastewater heat). For this purpose, a future-oriented building physics concept is developed with the aim of generating energy and absorbing $CO_2$ in order to boost RE potential to increase overall energy efficiency and reduce energy consumption and thus maintenance costs. The main goal is a transformation from the use of gas towards renewable energy sources. The research shows that geothermal probes are feasible and can be installed in the courtyard. Together with the brine/water heat pumps, this will be sufficient for the entire heating and cooling of the building.

The installation of photovoltaics is feasible on the roofs, as well as on the two south-facing façades. The total production of electricity was calculated to be 900,000 kWh/year. Combined with efficiency-enhancing measures, electricity use can be reduced and the excess electricity sold or integrated into an energy community with the residential buildings in the neighborhood.

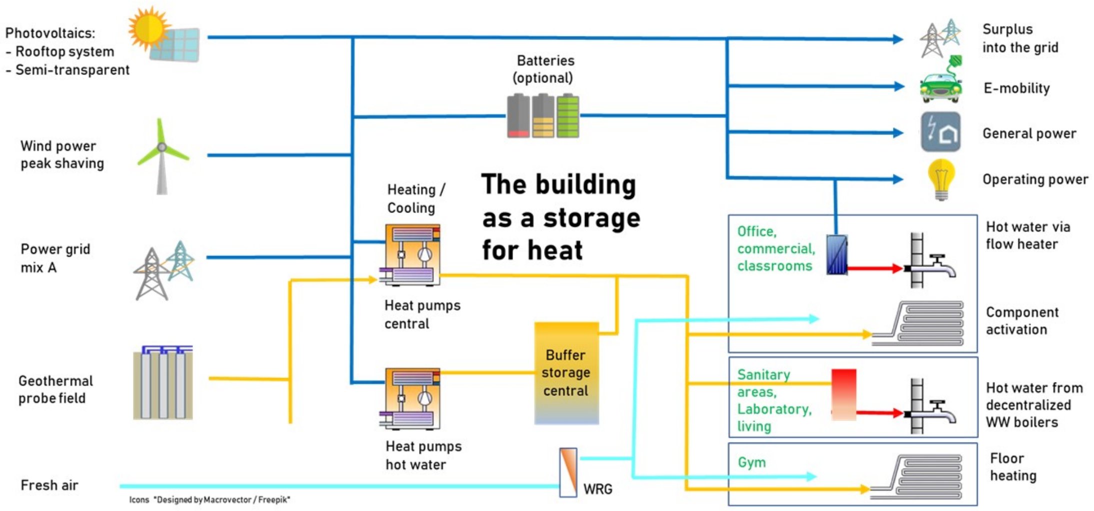

Figure 5: Diagram for potential renewable energy sources, geothermal probe field, PV, to create an energy district with the adjacent residential towers, the farm and the sports center.

**4.2 Measures for Increasing Energy Efficiency and the Use of Renewable Energies**

**4.3 Adaptation of Use**

Correct use poses a central question in energy-efficient renovation, as it leads to targeted, efficient construction measures. In the demonstration project, the moderate temperatures on the ground floor are now beneficial for the parked cars only. This is a waste of valuable space and a detriment to a lively street life with an active ground floor to enhance social sustainability and the quality of public space. **Greening,** as a synergy measure, plays a connecting role in this project.

## 5. Conclusions and Outlook

The paper has illustrated some of the challenges, trends and potential solutions for the success of the renovation wave. The first important conclusion is the necessity to apply modular solutions for standardized prefabricated residential buildings. In order to accelerate the refurbishment rate, the worst-performing buildings have to be prioritized based on established criteria as in the TABULA[14] report while the construction process has to become standardized and, where possible, use prefabrication and modular construction while integrating renewable energies in refurbishments. At the same time social and architectural sustainability aspects have to be considered. The awareness for life cycle impact analysis has to increase. The concepts have to follow the principles, now officially endorsed by the new EU regulations, of the circular economy, integrating the 10 Rs of CE in the refurbishment of the existing built stock. The focus was laid on a special challenge in this context – large social housing blocks from the last 70 years, because these buildings are in urgent need of renovation, their refurbishment using renewable energy is more difficult – with a need for demonstration projects.

## 6. Endnotes

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