# EEHB 2024

## The 5th International Conference on Energy Efficiency in Historic Buildings

7th – 8th October 2024

Singapore | Austria

University for Continuing Education Krems

ICOMOS SINGAPORE

# EEHB 2024 Singapore Proceedings

## The 5th International Conference on Energy Efficiency in Historic Buildings

7th and 8th October 2024
Austria | Singapore

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Publisher: ICOMOS Singapore
ISBN: 978-981-94-4168-6
Layout: EEHB 2024 Secretariat

# Forward to EEHB 2024

Good morning. I'm delighted to join you at the opening of the 5th International Conference on Energy Efficiency in Historic Buildings. For those who have travelled from abroad, I wish you a very warm welcome to Singapore. For those of you dialling in from abroad, I hope that you find a way to visit the sights in Singapore.

**Importance of protecting historic buildings and heritage to ensure sustainable development**

As an island city-state, Singapore faces a complex challenge to meet the needs of both a city and a country within our compact land area of only 735 square kilometres.

Even as we comprehensively plan and progressively redevelop our city to meet our needs, we also want to conserve and retain much of our history. Our built heritage can tell the story of our past and reflect the diverse experiences that have shaped our nation.

Thus far, we have conserved over 7,200 buildings and structures since our conservation programme started some 35 years ago.

**Ensuring a more sustainable built environment sector**

We retain our historic buildings to strengthen our sense of identity and history. But given the urgency to tackle climate change, we need to find ways to make these buildings more sustainable.

Decarbonising the built environment plays a critical role in our path to net zero emissions by 2050, given that buildings account for about 20% of our emissions.

Together with the industry, our Building and Construction Authority or BCA rolled out the latest edition of the Singapore Green Building Masterplan back in 2021, to accelerate our transition to a low-carbon built environment.

This is done through our various measures to achieve our three key targets of "80-80-80 in 2030". Firstly, we want to green 80% of our buildings by Gross Floor Area or GFA by 2030; Second, for 80% of our new developments by GFA to be Super Low Energy from 2030; and Third, to achieve an 80% improvement in energy efficiency compared to 2005 levels for best-in-class green buildings by 2030.

By retaining and adaptively reusing our historic buildings for contemporary uses, instead of demolishing them, we help support our green building efforts.

As such, BCA's Green Mark certification scheme, which rates a building's environmental impact and performance, recognises efforts to retain existing structures, including historic buildings, when assessing the carbon footprint of buildings.

Buildings with outstanding performance in this area are awarded the 'Whole Life Carbon' badge, on top of other requirements such as energy efficiency. However, just retaining buildings is not enough in our journey to net zero. We must also find ways to reduce their environmental footprint on an operational basis.

A key strategy would be to retrofit historic buildings so that they become more energy efficient. This can be a no regrets move for building owners as it reduces operating costs.

To facilitate this, we have the Green Mark Incentive Scheme which provides financial support towards energy efficient retrofits for private buildings.

We also continually review our conservation guidelines. This is to ensure that they strike a balance between providing flexibility to retrofit historic buildings with the latest energy efficient features, materials and designs on the one hand, and ensuring they still respect the historical context on the other hand.

For example, we updated our conservation guidelines in 2023 to allow greater flexibility in incorporating solar panels on conserved shophouses.

All these paved the way for building owners and built environment professionals to make our historic buildings more sustainable.

By reducing operating costs, energy efficiency retrofits also make the adaptive reuse of historic buildings more attractive. This encourages the creation of more distinctive spaces in our cities that are functional, sustainable and sensitive to the history and memory of our historic buildings.

**National Gallery Singapore**

Let me talk about the building we are in today, the National Gallery. It is housed across two national monuments, the former Supreme Court and City Hall.

It sensitively combines the neoclassical architectural elements of the original buildings, with contemporary elements such as an enclosed link between the buildings that opened in 2015.

Since then, the buildings have been adaptatively reused as Singapore's largest museum.

A multi-disciplinary team including engineers, architects and conservation experts worked closely to conserve the architecture, while making the building suitable as a museum and gallery.

This includes leaving no stone unturned to ensure energy efficiency. For example, vertical green walls keep the interiors of the Gallery cool, while solar panels installed sensitively on the Gallery's roof generate 70,000 kilowatts of clean energy annually.

**141 Neil Road and the role of industry**

We also need to increase the energy efficiency of smaller historic buildings as they form most of our conserved building stock. An outstanding example is the historic townhouse at 141 Neil Road.

The townhouse was built in the 1880s and is a rare survivor of this old type of a once-typical local residential terrace house. The building comprises traditional materials and natural elements such as lime plaster on walls in place of cement to keep the building naturally cooler; and open front and back yards and airwells to encourage natural cross ventilation.

With these measures, indoor daytime temperatures are up to four degrees Celsius lower than outdoors, reducing energy consumption. It serves as a reminder that our past can still offer green solutions for our future.

The impact of 141 Neil Road goes far beyond its four walls. It is home to the National University of Singapore's Architecture Conservation Laboratory, or ArClab. It is a dynamic living classroom for students taking graduate programmes and doctoral studies in built heritage management. This includes courses on net zero retrofit in historic buildings.

ArClab has also been developing solutions to make our historic buildings more energy efficient, using 141 Neil Road as a testbed. For example, improving materials to make the distinctive V-shaped unglazed clay roof tiles on our historic shophouses and townhouses perform better thermally; and optimising the location of ventilation openings.

ArClab is a testament to the important role that institutes of higher learning have in improving the energy efficiency of historic buildings. Their educational programmes and research findings will go a long way in shaping energy efficient solutions and building capabilities, to support Singapore's building management and conservation industry.

**Conclusion**

To conclude, energy efficient historic buildings serve as models of how we can achieve progress sustainably without sacrificing our past. Your support, your ideas and your expertise will be crucial in the greening of historic buildings, and our transition to a low carbon built environment.

I wish all of you a successful and fruitful conference, and I look forward to the learnings that will emerge both in Austria as well as in Singapore.

Mr Desmond Lee

Minister for National Development
Minister-in-Charge of Social Services Integration

# Secretariat EEHB2024

## Opening Address.

It is with great pleasure that we welcome you to the Fifth International Conference on Energy Efficiency in Historic Buildings, held this year in the vibrant city of Singapore.

This conference has been two years in the making, originating from discussions during the Fourth Conference in Germany in 2022. Recognizing that previous editions had largely been held in Europe, there was a strong desire to extend the conference's reach to a broader geographical region, including Asia. Singapore, with its rich architectural heritage and growing expertise in conservation, emerged as an ideal host.

Organizing a conference focused on energy efficiency in historic buildings presented unique challenges. Traditionally, energy efficiency initiatives have concentrated on large modernist structures and new developments. Historic buildings, however, pose distinct considerations requiring specialized approaches. Beyond the primary focus on energy efficiency, this conference also explores closely related fields such as photogrammetry, digitization, and simulation—areas that have seen growing momentum in Singapore, driven by technological advancement, a need for greater productivity, and the pressing requirement for thorough documentation of our heritage assets.

In selecting the venue, we were committed to hosting the conference in a historically significant building. After considering several iconic sites—including Tanjong Pagar Railway Station, Pasir Panjang Power Station, and the National Museum of Singapore—we are proud to gather at the National Gallery Singapore, itself a benchmark of adaptive reuse and conservation excellence.

A special feature of this year's event is the shared sessions with our counterparts in Austria, enabling participants to experience presentations from both locations. This transcontinental format allows for broader exchange and collaboration, enriching the conference experience. Bringing this conference to fruition involved many sleepless nights, tireless efforts in canvassing for sponsorship, securing speakers, and meticulous planning. The dedication and resilience of the organizing team have been truly remarkable. Their commitment has made this gathering not only possible but, we hope, profoundly meaningful.

As we come together over the next two days, we invite you to engage fully: share your insights, learn from diverse experiences, and forge new connections. It is our hope that this conference serves not only as a platform for dialogue on energy efficiency but also as a catalyst for broader conversations on sustainability and youth engagement in heritage conservation.

We are deeply honored by your participation and presence. Our heartfelt thanks go to the National Heritage Board, the National Gallery Singapore, the Urban Redevelopment Authority, and all our sponsors for their generous support.

Mr Wong Chung Wan

Technical Director, MAEK Consulting Pte Ltd
Secretariat, EEHB2024 Singapore

## ICOMOS Singapore

## Opening Address to EEHB 2024

Thank you very much. Good morning.

Our distinguished Guest of Honour, Minister Desmond Lee; our host, Mr. Chris Lee, Assistant CEO of NGS; our partners from the University of Krems; our esteemed visitors and participants; my dear ICOMOS colleagues; ladies and gentlemen —

It gives me great pleasure to welcome all of you to the Fifth International Conference on Energy Efficiency in Historic Buildings, jointly organized by the University for Continuing Education Krems (Donau University Krems) in Austria, and the Singapore Chapter of the International Council on Monuments and Sites (ICOMOS).

I'll say a little bit more about ICOMOS shortly, as some of you may not be familiar with the organization.

This is the fifth in a series of conferences on energy efficiency that was first organized in Madrid, Spain, in 2014. Since then, this conference series has been hosted in Brussels (2016), Visby in Sweden (2018), and in Benediktbeuern, Germany (2022). Save for the interim during the COVID pandemic, which made travel and face-to-face meetings impossible in 2020, this conference has been held every two years.

The staging of the conference here in Singapore creates three significant precedents:

First, this is the very first time the conference is being organized outside of Europe, and the first time it is being held in Asia.

Second, it is the first time a national committee of ICOMOS is involved in organizing the conference.

Third—and most exciting for us—is the fact that papers are being presented at this conference in both Krems and Singapore, simultaneously.

If you look at your program, you'll notice that in the afternoon sessions, both today and tomorrow, there are shared sessions where papers will be presented in Singapore, and our friends in Krems will be zooming in. Likewise, we will also benefit from listening to papers presented over there.

Of course, this kind of cross-border real-time sharing was not commonly utilized before COVID. Perhaps that break has actually made the world a little smaller and enabled us to do these things.

As I said earlier, most people have never heard of ICOMOS, so please indulge me while I introduce my organization.

ICOMOS—the International Council on Monuments and Sites—was established as an international non-governmental body in Warsaw, Poland, in 1965, following the drafting and signing of the International Charter on the Conservation and Restoration of Monuments and Sites, more popularly known as the Venice Charter.

Today, ICOMOS International has a membership of over 10,000 cultural heritage professionals in over 100 countries, working to conserve and protect the world's monuments and sites. Members include historians like myself, architectural historians like my colleague Professor Yeo Kang Shua, technical specialists and engineers like Mr. Wong Chun Wan, who addressed you earlier—along with many others from various technical fields involved in conservation and protection of built heritage.

It is the only global NGO of its kind. ICOMOS is also an advisory body to UNESCO, acting as its technical arm in matters concerning the inscription of World Heritage Sites. It contributes actively to the World Heritage Committee and plays a key role in implementing the World Heritage Convention of 1972.

The Singapore Chapter of ICOMOS was established in 2014—the same year the first EB Conference was held.

Our organizational partners, the University for Continuing Education Krems, was established in 1995 and is the only public university for continuing education in the German-speaking world.

Now, I'm supposed to say something about the conference theme—energy efficiency. Unfortunately, as a legal and historical scholar, I know very little about it. But I do know that when buildings are built to be sensitive to their climate and environment, they don't require much energy to perform the two tasks that consume the most energy: heating/cooling, and lighting.

Unless you decide to use a historic building as a data farm—which is another issue altogether—you won't need excessive energy if the building is naturally adapted.

Of course, this is standard textbook knowledge for any environmentally conscious architect or designer. The challenge lies with buildings we inherit—the old, historic ones. How do we manage those?

Some of our early architects and builders understood these principles very well, on how to build buildings appropriate to our climate. About 15 years ago, I made my first trip to Spain—unfortunately, during the height of summer. I finally understood why siestas exist.

While avoiding the midday heat in Seville, I noticed how closely packed the buildings were in the region. The streets separating the buildings were barely wide enough for a horse cart or small car. The reason for this is, by packing the buildings closely, none of the walls are exposed to the full blast of the sun—except around noon. The rest of the time, they remain in shade. I thought this was quite innovative.

Later, I learned that this technique had been used by architects in ancient Rome for centuries. It's simple: don't let the building heat up, then you don't have to cool it down. That's energy efficiency in practice.

Another experience I had was in Taiping, Perak. There was a marvellous building—the Old Market on Jalan Jin. Built in 1884 and 1885, these are the oldest markets in Malaysia. Each building is about 80 meters long, 20 meters wide, and probably 20 meters high.

When I walked into the market from outside, I felt as if it was air-conditioned. Actually, it wasn't. But compared to the sweltering outside, the inside was noticeably cooler—about 5°C cooler, according to my architectural friends.

There was no mechanical cooling. Just natural design: a constant breeze, hot air rising to the huge jack roof, and cool air flowing in. This natural circulation created a self-sustaining system. No electricity was needed—just good design that worked with nature.

If you ever get a chance to visit Taiping, do experience this market. Although, I understand it's currently being rebuilt after structural issues last year. Let's hope it will be preserved.

Today, as we find new uses for our historic buildings, we find ourselves in the odd position of having to control the environments we inherit—rather than letting nature do its work. It's easy to plan for efficiency in a new building; it's harder with an old one. Still, we must find ways to harness our environment and work with nature as efficiently as possible.

I'm afraid I've not been very efficient with my speech—and I've probably gone on longer than I should. But if I've learned anything about heating and cooling, it's this: it's easy to get people hot under the collar; much harder to cool them down.

So, I shall stop here and express my deepest gratitude:

First, to our Guest of Honour, for taking time to be with us.

Second, to my colleagues at ICOMOS, for all their tremendous hard work in organizing this conference.

To our distinguished guests and participants, who travelled far to share their knowledge with us.

And to all of you—for being here and for sharing your time and ideas over the next two days.

Thank you very much.

Prof Kevin YL Tan

President, ICOMOS Singapore

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# *Table of Contents*

# Balancing Preservation and Innovation: A Case Study on Sustainable Deep-Energy Renovation of European Historical Buildings in Florence

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**Abstract –** The preservation of historical heritage in a sustainable manner (environmentally, socially and economically) and is becoming increasingly complex and critical. While incentives to speed deep-energy improvements are growing, a stalling economy presents significant hurdles to real estate owners. In addition to these challenges, structural stability, safety, and social well-being are directly jeopardizing our historical and cultural heritage. These consequences are amplified by increasingly frequent and extremely weather events.

In such a complex environment, property managers, owners, and local governments tasked with future-proofing old buildings are juggling numerous competing demands. On the one hand, there is a need to quickly implement and scale deep energy retrofit approaches at a reasonable cost. Architects and designers are consequently driven to develop one-size-fits-all, plug-and-play solutions and rapidly duplicate best practices across multiple structures. On the other hand, there is a need to strengthen local identities and restore cultural values through distinct architectural flavors that adhere to the original (building) traditions to improve the welfare of local communities.

Despite substantial investments in tackling this challenge over the past decade, the renovation rate is still too slow, and the solutions implemented are suboptimal.

Besides a few brilliant exceptions, many of the approaches adopted to this day often rely on a case-by-case trade-off that compromises one aspect (e.g., energy efficiency) over the other (e.g., preserving architectural identity, often for the sake of tourism). While all these efforts have been instrumental in advancing existing knowledge, historical buildings are far from meeting the needs of present and future generations. Simultaneously, building decay is affecting local communities in many ways, from endangering touristic attractions to disrupting building surroundings, leading to declining real estate values and capital loss, all while being far from meeting ambitious climate targets.

This paper, based on results of a European Commission-funded research project that was later developed by the Inception spin-off team at the University of Ferrara, will provide an account of the Florence (Italy) case study, including detailed mapping, modeling, and making descriptions. It will focus on economic valuation, building regulatory compliance, historical building document analysis, user preference definition, and building inspection phases. It will also cover the construction of BIM models and the technical design evaluation process, with a focus on energy efficiency gains and problems encountered. Finally, it will cover the building and monitoring phases, highlighting new solutions and their influence on energy efficiency and indoor environmental quality.

**Keywords** – Historical Buildings, Sustainability, Deep-Renovation, Plug-and-Play, Energy Efficiency.

# 1. INTRODUCTION

Across Europe, there has been a major drive for extensive deep renovation, especially in light of the European Union's ambitions to achieve climate neutrality by 2050. Numerous creative ideas have arisen as a result of recent EU-funded research programs targeted at improving the building sector. However, the problem remains in scaling up these technologies and securing their widespread adoption across various building typologies. This involves the creation of novel combinations, procedures, and supporting ICT tools that can effectively overcome the current barriers to adoption. One of the most significant concerns is a lack of empirical evidence that these novel solutions regularly achieve the desired results in terms of energy efficiency and financial viability.

To overcome these obstacles, it is critical to build a comprehensive supply-chain infrastructure capable of supporting large-scale commercial deployment and scalability of deep renovation solutions. These solutions must be adaptable, evidence-based, and relevant to a wide range of building types, including public, residential, and historic structures. The European experience emphasises the need of combining cutting-edge technology such as 3D scanning and printing with prefabricated solutions, building on the proven outcomes of prior EU and national research projects.

Other regions around the world are facing comparable difficulties, however their approaches and contexts may differ. In North America, for example, there is an increasing interest in deep renovations, which is motivated by both environmental concerns and the economic requirement to cut energy use in aging buildings. The United States, in particular, has seen a growth in public-private partnerships aimed at retrofitting commercial and residential buildings, spurred by federal incentives and state laws. Unlike Europe, where the emphasis is frequently on historic preservation and adaptation, North America prioritizes the modernization of mid-century buildings, reflecting its distinct architectural and urban development history.

In Asia, particularly in rapidly urbanizing countries such as China and India, thorough restoration is emerging as a vital technique for addressing the combined concerns of energy efficiency and urban housing shortage. The degree of urbanization in these countries brings unique issues when compared to Europe. The emphasis is frequently on the renovation of large-scale residential complexes and public infrastructure, with a concentration on incorporating renewable energy sources to reduce the environmental impact of rapid urban growth. These countries are increasingly looking to European examples for best practices in sustainable refurbishment, particularly in terms of policy frameworks and technology advances.

The EU Energy-Efficiency Directive defines 'deep renovation' as cost-effective refurbishments that lower energy usage by more than 60% relative to pre-renovation levels. Achieving such high levels of energy performance at the lowest feasible cost throughout a building's economic lifecycle is critical, with a focus on providing a quick return on investment through energy savings. This notion is especially important in the global environment, since the principles of cost-effectiveness and sustainability are globally applicable. In other places, such as Latin America and Africa, where energy efficiency is becoming increasingly essential, the European model of extensive renovation may provide useful insights for designing locally tailored methods.

Furthermore, the final success of deep renovation, both in Europe and globally, is assessed by the structures' long-term viability. Energy performance objectives must be consistent with the building's ability to meet functional and user needs throughout its lifecycle. This comprehensive strategy assures that buildings remain operationally, technically, and economically viable, particularly while shifting building typologies and functions during extensive renovations. In areas experiencing fast urbanization, such as Southeast Asia and Sub-Saharan Africa, ensuring that rebuilt structures can resist future demographic and environmental changes is crucial for long-term urban sustainability.

Economically, deep renovation presents substantial prospects, particularly in converting old public buildings into residential units. In Europe, the economic crisis that began in 2008 left a large number of public buildings unoccupied, including offices, public service facilities, commercial spaces, and historic structures, posing a financial strain on public authorities. This predicament is replicated in other parts of the world, including Asia and Latin America, where growing urbanization and economic upheavals have resulted in comparable issues. The conversion of existing structures into residential areas not only tackles housing needs, but also helps to save energy and decreases environmental effect.

While the European Union has made tremendous progress in formulating and implementing deep renovation schemes, these difficulties and opportunities are common worldwide. Energy Use Intensity (EUI) should be used to make rational decisions about comprehensive deep renovation, since it effectively measures a building's energy use in relation to its size or other factors. Public buildings often consume 50-100% more energy than residential buildings with the same floor space, making a compelling rationale for extensive refurbishment. The global push for extensive renovation—whether in Europe, North America, Asia, or elsewhere—is a critical step toward generating significant energy savings, lowering environmental consequences, and addressing housing shortages in a sustainable way.

## 2. THE P2ENDURE PROJECT

The P2Endure project was an innovative research and development initiative funded by the European Commission under the Horizon 2020 Program, specifically under the call H2020-EE-10- 2016-IA, which supported accelerated and cost-effective deep renovation of buildings through Public-Private Partnerships (EeB PPP). The project, titled "Plug-and-Play product and process innovation for Energy-efficient building deep renovation," was identified by the acronym P2Endure. The main goal of P2Endure was to develop scalable, adaptable, and ready-to-implement prefabricated Plug-and-Play (PnP) systems for the deep renovation of building envelopes, MEP (Mechanical Electrical Plumbing) components and HVAC (Heating Ventilation and Air Conditioning) systems, aimed at transforming non-functioning or sub-optimal public and historic buildings into dwellings.

P2Endure, which was conducted from 2016 to 2020, was structured around a consortium of 16 participants from various countries across Europe, including both SMEs and large industries, academic institutions, and public authorities.

The consortium was carefully assembled to cover all aspects of the innovation chain from research to market implementation, ensuring that the project outcomes were not only scientifically sound but also practically viable and commercially exploitable. The project team was composed of experts in building inspection, asset management, prefabrication, 3D printing, BIM (Building Information Modelling), and energy systems, reflecting the multidisciplinary nature required to tackle the challenges of deep renovation effectively.

### 2.1 Objectives

The P2Endure project was driven by a set of comprehensive and ambitious objectives, all focused on optimizing, demonstrating, and scaling up innovative PnP prefabricated solutions for deep renovation. These objectives were strategically designed to address the key challenges in the building renovation sector and to ensure the widespread adoption of advanced renovation technologies across Europe. The objectives can be categorized into five major areas, each addressing a critical aspect of the project's goals.

Product Innovation

One of the main focuses of P2Endure was to push the boundaries of product innovation within the deep renovation sector. The project aimed to refine, integrate, and validate state-of-the-art prototypes and commercially available packages of PnP prefabricated solutions. These solutions were intended to significantly improve the performance of building components, including essential systems like MEP-HVAC. By enhancing these components, the project sought to achieve a holistic approach to deep renovation, ensuring that every element of a building's structure contributed to energy efficiency and overall sustainability. A key aspect of this innovation was the reduction of embodied energy—an often-overlooked factor in building renovation. P2Endure placed strong emphasis on the reuse and recycling of components to lower the carbon footprint associated with renovation activities.

Process Innovation

Beyond the products themselves, P2Endure recognized the need for innovative processes that could make deep renovation more accessible and less disruptive. The project set out to demonstrate and promote cutting-edge on-site processes that would enable rapid renovation with minimal inconvenience to occupants. One of the core goals was to reduce both the time and cost associated with renovation projects by 50% compared to traditional methods. This ambitious target was to be achieved through the application of advanced technologies such as BIM and 3D printing. These technologies were not only intended to accelerate the design and construction phases but also to enhance the precision and quality of the renovation works. By integrating these modern tools, P2Endure aimed to set new standards in the industry, showing that deep renovation could be both quick and cost-effective without compromising on quality or sustainability.

To achieve concrete results, P2ENDURE adopted an innovative modular process called the 4M process, characterized by four main steps: Mapping, Modelling, Making, and Monitoring.

Validation and Monitoring

A critical component of the P2Endure project was the rigorous validation and monitoring of the innovations it introduced. To ensure that the new products and processes would deliver the promised benefits, the project included a comprehensive framework for measuring and validating their performance. This involved demonstration case, where the PnP prefab solutions were implemented in concrete scenarios, allowing for close monitoring of outcomes. Virtual simulations complemented these live projects, providing a controlled environment for testing and refining the technologies. The project success metrics were clearly defined, with targets including 60% reduction in energy use, a 15% reduction in overall costs, and a 50% reduction in on-site assembly time. Achieving these targets while maintaining or improving Indoor Environmental Quality (IEQ) was paramount, as P2Endure sought to prove that its solutions could meet the highest standards of both energy efficiency and occupant comfort.

Market Uptake and Scalability

Understanding that innovation alone is insufficient without market adoption, P2Endure placed a strong emphasis on demonstrating the scalability and market readiness of its solutions. The project aimed to generate solid empirical evidence of the performance and viability of its PnP prefab systems, ensuring that these solutions could be replicated across different regions within the European Union. This was crucial for encouraging widespread adoption and scaling up the impact of the project beyond the initial demonstration sites. P2Endure also worked to engage a broad range of stakeholders, including real-estate clients, policymakers, and industrial partners. By involving these key players from the outset, the project aimed to create a strong foundation for market uptake, ensuring that the innovations developed would be ready for commercialization and large-scale implementation by the project's conclusion.

Dissemination and Exploitation

Finally, the P2Endure project placed significant importance on the dissemination and exploitation of its findings and innovations. Recognizing the value of knowledge sharing, the project focused on spreading its results and methodologies across Europe and beyond. This was done through a variety of channels, including academic publications, industry workshops, and collaboration with other EU and national innovation activities. P2Endure also aimed to establish synergies with existing projects and initiatives to further amplify its impact. A key part of this effort was the promotion of standardization and certification for the products and tools developed during the project. By aligning with established standards and contributing to the development of new ones, P2Endure sought to ensure that its innovations could be seamlessly integrated into the broader market, facilitating their adoption and ensuring their long-term sustainability.

In summary, the P2Endure project was a multifaceted initiative with objectives that spanned product development, process innovation, validation, market readiness, and knowledge dissemination. Each of these areas was carefully designed to ensure that the project not only advanced the state of the art in deep renovation but also laid the groundwork for its solutions to be widely adopted and scaled up across Europe, ultimately contributing to the EU's energy efficiency and sustainability goals.

## 2.2 The background

P2Endure builds on the existing body of research and technological advancements in deep renovation, particularly those emerging from recent EU-funded projects. The state of the art in deep renovation at the project's inception included:

- Prefabricated systems: the use of mass-manufactured prefabricated components, including facade and roof elements with smart PnP connectors, was already gaining traction as a means to reduce the time and cost associated with deep renovation projects. The state-of-the-art systems also included modular prefabricated installation platforms for HVAC systems, which offered significant advantages in terms of installation speed and energy efficiency.
- 3D scanning and printing technologies: advanced 3D scanning and printing technologies were increasingly being integrated into renovation processes, offering high precision in the retrofitting process and enabling on-site customization of building components. These technologies also contributed to reducing material waste and labor costs, thereby enhancing the overall efficiency of renovation projects.
- BIM and ICT tools: the integration of BIM and other ICT tools into renovation processes was a significant advancement, allowing for more efficient lifecycle management of buildings. BIM facilitated better coordination among stakeholders and improved decision-making through real-time data sharing and simulation capabilities.
- Energy performance and Indoor Environmental Quality: prior to P2Endure, various projects had demonstrated the potential for achieving significant energy savings through deep renovation. However, there was still a need for empirical evidence to validate the long-term performance of these solutions, particularly in terms of maintaining high standards of IEQ while reducing energy consumption.

The P2Endure project sought to build on these advancements by integrating them into a comprehensive framework that could be applied across different building typologies and EU regions. The project's innovative approach was to combine these state-of-the-art technologies into a single, cohesive system that could be easily scaled and replicated across Europe.

## 2.3 Implementation

The P2Endure project was systematically organized into several Work Packages (WPs), each tailored to address a specific aspect of the research and innovation process. This structured approach ensured that the project's ambitious objectives were achieved in a coordinated and effective manner. The WPs covered a wide range of activities, from product development and process innovation to market uptake and dissemination of results. By dividing the project into these distinct WPs, P2Endure was able to focus expertise and resources where they were most needed, facilitating the successful execution of its goals.

The general structure of the WPs can be summarized as follows:

- Product and process innovation: this WP laid the foundation for the technical aspects of the project, focusing on the optimization and integration of PnP prefab solutions for deep renovation.
- Demonstration and validation: building on the innovations from the first WP, this package aimed to prove their effectiveness through real-world demonstrations across different European regions.
- BIM and ICT Integration: central to modernizing the renovation process, this WP integrated advanced digital tools, such as BIM, to support lifecycle management and enhance the scalability of the solutions developed.
- Market uptake and exploitation: this WP focused on ensuring that the innovations developed during the project were ready for market adoption, involving the development of business models, stakeholder engagement, and standardization efforts.
- Dissemination and communication: ensuring that the knowledge generated was shared widely, this WP was responsible for reaching out to various audiences and maximizing the impact of the project's findings.
- Project management: overseeing the entire project, this WP ensured that all activities were completed efficiently, within budget, and according to the project's timeline.

The structured approach of the WPs was designed not just to achieve immediate project goals but also to generate long-term impacts across the European construction and renovation sectors. The expected impacts of the P2Endure project included significant advancements in energy efficiency, with a targeted 60% reduction in energy use in renovated buildings. The project also aimed to reduce renovation costs by 15% and on-site assembly time by 50%, demonstrating that high-performance renovations could be achieved in a cost-effective and time-efficient manner. Moreover, the project sought to catalyze the market uptake of its innovations by providing robust empirical evidence of their performance. By demonstrating the scalability and adaptability of PnP prefab solutions across different geographies and building types, P2Endure aimed to facilitate their widespread adoption. This, in turn, was expected to contribute to the EU's broader energy efficiency goals and to promote the growth of European SMEs in the construction industry.

Furthermore, the project's emphasis on standardization and certification was intended to ensure that its innovations could be seamlessly integrated into the market, enhancing their replicability and long-term sustainability. By fostering collaborations with stakeholders across the value chain, P2Endure also aimed to build a strong foundation for future projects and innovations in the field of deep renovation.

### 2.4 Outcomes and results achieved

The P2Endure project, aimed to revolutionize deep renovation practices across Europe through innovative PnP prefabricated systems, achieved significant outcomes and results, reflecting the success of its systematic and well-coordinated approach.

Methodologies, procedures and tools were designed to be scalable, adaptable, and easy to implement, particularly in transforming non-functioning or sub-optimal public and historic buildings into energy-efficient dwellings. The project's outcomes were driven by rigorous research, development, and real-world demonstration across different European geoclusters, ensuring wide applicability and impact.

The results achieved have demonstrated the potential of its innovative solutions to transform the deep restructuring market in Europe. Some of the key outcomes and achievements include:

- Product innovation and integration, one of the primary achievements of P2Endure was the development and optimization of PnP prefabricated components. These innovations included advanced building envelope solutions, HVAC systems, and on-site 3D printing technologies.
- Process innovation and efficiency, P2Endure made substantial strides in process innovation, particularly in demonstrating and promoting rapid deep renovation techniques. By leveraging advanced BIM-based design, 3D printing technologies, and modular processes, the project was able to reduce both the time and cost associated with renovations by 50% compared to traditional methods. These innovations minimized disruptions for occupants during renovation works while significantly improving IEQ.
- Validation and Monitoring, the project's success was underpinned by a robust validation and monitoring framework that provided empirical evidence of the effectiveness of P2Endure solutions. This framework included live demonstration projects in nine real-world settings across different EU geoclusters and two virtual simulations. Additionally, the project developed and implemented the Comfort Eye system, an innovative tool for monitoring and optimizing IEQ. This system was deployed across several demonstration sites, providing critical data that validated the project's impact on improving occupant comfort and building performance.
- Market Uptake and Scalability, the Technology Commercialization Platform (TCP) developed as part of the project played a pivotal role in this process, providing a framework for scaling up the innovations across different regions and building types. P2Endure's emphasis on standardization and certification further ensured that its solutions were compatible with existing regulations and market needs, paving the way for widespread adoption.

## 3. THE FLORENCE DEMONSTRATION CASE

The Florence demonstration case is one of the key examples within the P2Endure project, showcasing the practical application of innovative deep renovation technologies in a historic urban environment.

The building, located in the historical downtown of Florence, Italy, was originally constructed between 1864 and 1871.

Today is situated at the confluence of Via della Fornace and Via Ser Ventura Monachi, occupying a prominent corner position. It was initially designed with a multifunctional purpose, hosting commercial and craft activities on the ground floor and residential units on the upper levels. The building consists of four main floors, including an underground level used for storage and three above-ground levels that housed residential spaces.

*Figure 1. Pictures of the pre-intervention state of the historic building*

### 3.1 Pre-renovation condition

Before the renovation, the building had been vacant for several decades, leading to significant deterioration. The aging process, combined with a lack of maintenance, left the building in poor condition. The building envelope, including the external walls and roof, had a low thermal performance, characterized by poor U-values and outdated windows. The MEP systems were also severely outdated, with the heating system being particularly inefficient and unable to meet modern thermal comfort standards. Furthermore, the building lacked air conditioning systems, and the existing electrical installations were not compliant with current safety regulations. As a result, a comprehensive renovation was required to restore the building's functionality and improve its energy performance.

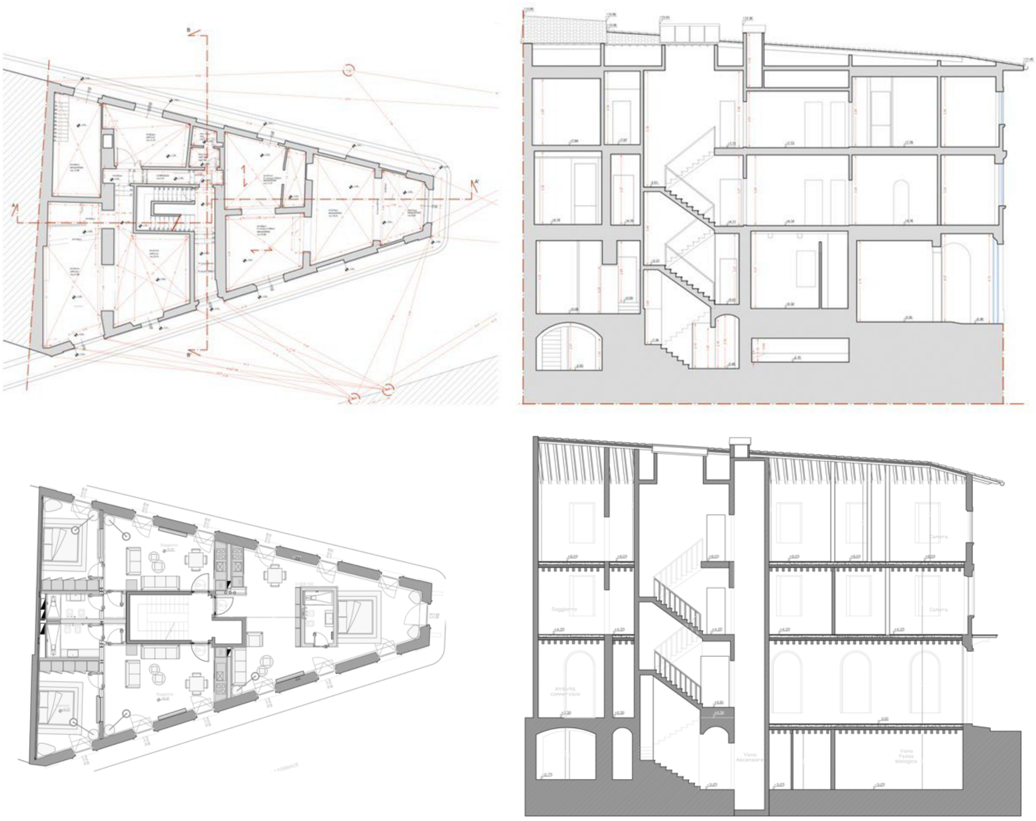

*Figure 2. Comparison between the pre-intervention state (plan and section model above) and the project state (plan and section model below).*

### 3.2 Objectives

The primary objective of the Florence demonstration case was to showcase how advanced retrofit solutions could be applied to a historic building to achieve significant energy savings while preserving its architectural heritage.

Specifically, the project aimed to:

- Improve energy efficiency: the renovation aimed to reduce the building's energy consumption, targeting a 60% reduction compared to its pre-renovation state. This involved the installation of advanced insulation materials, replacement of the existing windows with new high- performing, the integration of renewable energy sources, and the modernization of the building's HVAC systems.
- Enhance IEQ: the project sought to improve the thermal comfort, air quality, and overall indoor environment for future occupants. This was particularly challenging given the building's historical significance and the need to preserve its original features.
- Demonstrate the viability of PnP solutions: as part of the P2Endure project's broader goals, the Florence case aimed to demonstrate the feasibility of using PnP systems in a historical renovation context. This included testing the integration of these systems with modern BIM.

### 3.3 Renovation process and implementation

The renovation process in Florence was structured around the P2Endure project's 4M modular process: Mapping, Modelling, Making, and Monitoring. This approach ensured a comprehensive and systematic renovation, from the initial assessment of the building to the final evaluation of its performance.

- Step 1 - Mapping: the initial phase involved detailed technical and economic planning for the deep renovation. This included 3D laser scanning of the building to create an accurate as-built BIM model. The scanning helped identify the building's structural and energy inefficiencies, guiding the subsequent design and intervention strategies.
- Step 2 - Modelling: in the modelling phase, the data gathered during mapping was used to create a deep renovation design ready for execution. The design incorporated advanced energy calculations through a transition from the BIM to a Building Energy Model (BEM). The goal was to ensure that the renovation would achieve the targeted energy savings while respecting the building's historical architecture. This phase also involved validating the design through simulations, ensuring that the proposed solutions would meet the project's performance goals.
- Step 3 - Making: the making phase involved the actual execution of the deep renovation activities, both on-site and off-site. In Florence, this included the application of innovative prefabricated PnP solutions, which were customized to fit the building's specific needs. These solutions included advanced insulation panels, energy-efficient windows, and a modern HVAC system. Additionally, parts of the building structure were reinforced to comply with current seismic safety standards, a critical consideration given the building's age and historical value.
- Step 4 - Monitoring: after the renovation, the building's performance was continuously monitored to ensure that it met the project's objectives. This involved tracking energy consumption, IEQ, and overall occupant satisfaction. The monitoring phase provided valuable feedback that informed future projects within the P2Endure framework.

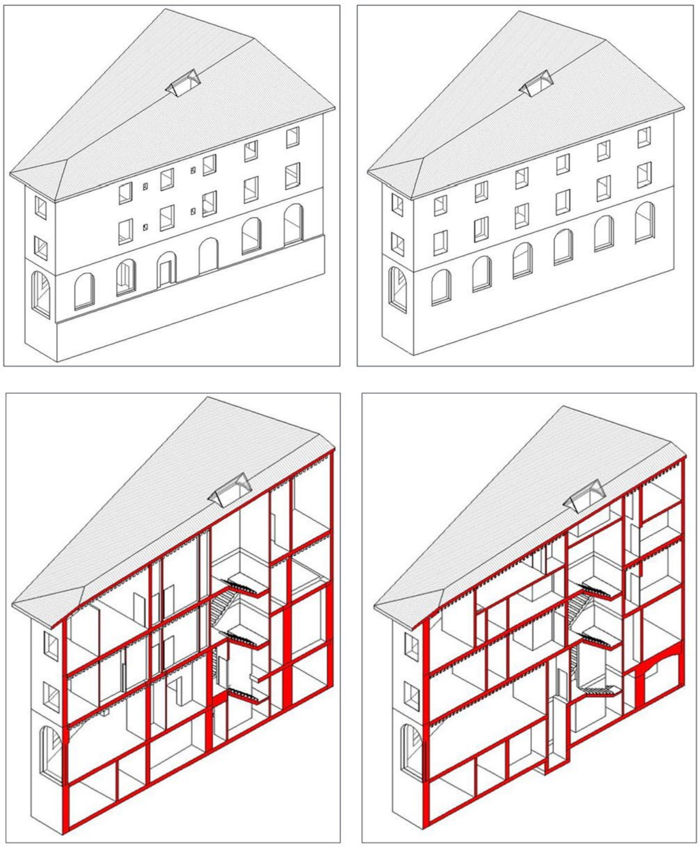

*Figure 3. Comparison between the BIM model of the pre-intervention state (left) and the BIM model of the project state (right).*

### 3.4 Challenges and Solutions

Renovating a historical building like the Florence demonstration case presented several unique challenges. One of the primary difficulties was balancing the need for modern energy efficiency with the preservation of the building's historical value. Strict regulations governing changes to historic buildings required careful planning and innovative solutions.

To address these challenges, the project team employed several strategies:

- Customized prefabricated solutions: the use of PnP systems allowed for significant customization, ensuring that new components could be seamlessly integrated with the building's existing structure without compromising its aesthetic or historical value.
- Advanced materials and technologies: the application of modern insulation materials and energy-efficient systems was tailored to enhance the building's performance while respecting its original design. For example, the existing wooden windows were replaced with high- performance units that replicated the original style but provided much better thermal insulation.
- Collaborative approach: the project involved close collaboration with local authorities, preservation experts, and stakeholders to ensure that all interventions met the necessary regulatory requirements and received the required approvals.

### 3.5 Results and Impacts

The renovation of the Florence building successfully demonstrated the potential of P2Endure's innovative solutions in a real-world context. The project achieved several key outcomes:

- Energy efficiency improvements: the renovation resulted in a substantial reduction in the building's energy consumption, exceeding the 60% target. The integration of renewable energy sources and the use of advanced insulation materials contributed to this success.
- Enhanced IEQ: the building now provides a much more comfortable and healthier indoor environment, with improved thermal comfort, better air quality, and modern amenities that meet contemporary standards.
- Preservation of historical integrity: despite the extensive renovations, the building's historical character was preserved. The use of customized PnP systems allowed the project team to maintain the building's original appearance while significantly improving its functionality and performance.
- Scalability and replicability: the Florence demonstration case provided valuable insights into the scalability and replicability of P2Endure solutions. The success of this project highlighted the potential for applying similar approaches to other historic buildings across Europe, contributing to the broader goals of the EU Horizon framework initiative.

*Figure 4. Replacement of old windows with new high-performance ones, while preserving the historic value*

*Figure 5. At the end of the deep renovation, the building achieved high energy performance preserving its historical aesthetic value, both in the facade and interior spaces.*

### 3.6 Lesson learned

The Florence demonstration case within the P2Endure project offered invaluable insights into deep renovation methodologies, particularly for historic buildings.

The project's success highlights how advanced renovation techniques can be harmonized with cultural heritage preservation, providing a model that can be adapted to diverse contexts across Europe and globally, including regions like Asia and South America.

A key takeaway from the Florence case was the necessity of detailed and accurate planning at the outset. The project's success was largely due to the thorough Mapping and Modelling phases, where advanced tools like 3D laser scanning and BIM were used to create a precise digital model of the building. This model was instrumental in identifying the building's structural deficiencies, inefficiencies, and outdated systems, allowing the renovation team to develop a tailored strategy. The precision and detail offered by these technologies ensured that the renovation could proceed smoothly, with fewer surprises and setbacks during construction. This approach is crucial in other contexts, especially in regions where original building documentation might be incomplete or outdated, such as in many historic areas in Asia. Accurate planning using advanced digital tools helps avoid unforeseen issues and ensures that the renovation is well-aligned with the building's specific needs and historical context.

Flexibility in design and implementation was another critical lesson from Florence. Historic buildings often present unexpected challenges, such as hidden structural issues or stringent heritage preservation regulations. In Florence, the ability to customize PnP prefabricated solutions was essential in addressing these challenges without compromising the building's historical integrity. The modular nature of these solutions allowed the renovation team to adapt quickly to on-site realities, ensuring that both modern energy efficiency standards and historical preservation requirements were met. This flexibility is particularly relevant in other regions with diverse climatic conditions and regulatory environments. For instance, in earthquake-prone areas like Japan or regions with extreme weather such as Southeast Asia, PnP systems can be adapted to enhance structural reinforcement or improve insulation and moisture resistance. This adaptability ensures that the P2Endure methodology can be applied across various building types and environmental contexts, making it a versatile solution for global renovation efforts.

The Florence project also underscored the importance of continuous stakeholder engagement. The success of the renovation was not just a matter of technical execution but also of effective collaboration with local authorities, preservation experts, and building owners. This engagement ensured that all interventions were appropriate, compliant with local regulations, and sensitive to the building's cultural significance. Involving stakeholders from the outset helped navigate the complexities of renovating a historic structure, ensuring that the project not only met energy efficiency goals but also respected and preserved the building's historical value. This approach is crucial when applying the P2Endure methodology in other countries, especially where cultural and historical sensitivities are paramount, such as in Asia and the Middle East. Early and continuous engagement with local stakeholders, including government agencies and community groups, can facilitate smoother project approvals and ensure that the renovation aligns with both technical standards and cultural expectations.

Another significant lesson from Florence was the integration of modern technology with historical preservation. The project successfully used advanced materials, like high-performance insulation and energy-efficient windows, while maintaining the building's original appearance and character. This balance between modern efficiency and historical preservation was achieved through the thoughtful application of PnP solutions, customized to fit the unique architectural features of the building. This approach is especially relevant in countries with rich architectural heritage, such as those in South America or Asia. By customizing PnP solutions to match the architectural styles and materials typical of these regions, similar energy savings and comfort improvements can be achieved without compromising the buildings' historical value.

Renovating cultural heritage buildings involves navigating a complex web of regulations and approval processes. The Florence case highlighted these challenges but also demonstrated that it is possible to modernize such buildings while respecting their historical significance. This experience is particularly relevant for countries with strict heritage preservation laws, such as France, Spain, and many Asian nations. The P2Endure approach, with its emphasis on collaboration and customization, can be adapted to meet the specific regulatory requirements of different countries. By working closely with heritage authorities and demonstrating the benefits of modern renovation techniques, project teams can gain approvals more smoothly and ensure that their interventions are both technically sound and culturally appropriate.

The Florence case also demonstrated that PnP solutions are not only effective in a specific context but also scalable and replicable across different building types and regions. The modular nature of these solutions means they can be adapted to various building configurations and climates, making them suitable for a wide range of applications. This scalability is particularly important for large-scale renovation programs, such as those funded by government initiatives or international organizations. Whether applied to residential, commercial, or public buildings, PnP solutions can be scaled up to meet broader renovation needs, such as in social housing estates or historic districts. The success of the Florence case provides a blueprint for expanding the use of PnP systems on a global scale, demonstrating their effectiveness in diverse contexts.

Finally, the Florence case emphasized the importance of not only improving energy efficiency but also enhancing IEQ. The renovation focused on upgrading the building's thermal comfort, air quality, and overall living conditions, making it a more comfortable and healthier environment for future occupants. This focus on IEQ is critical in renovation projects, particularly in regions with extreme climates or poor air quality, such as densely populated urban areas in Asia. Improving indoor air quality and thermal comfort can have significant public health benefits, making IEQ-focused renovations an important consideration in global renovation efforts.

## 4. CONCLUSION

The P2Endure project contributed to the EU's broader goals of enhancing energy efficiency and promoting sustainable building practices. Its innovations were designed to be scalable and replicable, ensuring their impact could extend across a wide range of building types and regions. The project demonstrated that it is possible to achieve a 60% reduction in net primary energy use compared to pre-renovation levels. In addition, the cost reductions achieved were significant, with a 15% decrease compared to typical renovations meeting current building regulations. Moreover, the project showed the potential to double the speed of renovation processes, a crucial factor in accelerating the rate of building upgrades across Europe.

The Florence demonstration case within the P2Endure project serves as a benchmark for how modern renovation technologies can be successfully applied to historic buildings. The project not only achieved significant energy efficiency improvements but also demonstrated that it is possible to modernize and preserve historical value using innovative, adaptable approaches.

The lessons learned from this case provide valuable guidance for applying the P2Endure methodology to other contexts and countries. Key takeaways include the importance of detailed planning, the need for flexibility in design and implementation, and the value of continuous stakeholder engagement. Additionally, the successful integration of modern technology with historical preservation and the scalability of PnP solutions offers a clear path forward for similar projects in diverse settings.

By adapting these lessons to different cultural, regulatory, and environmental contexts, the P2Endure approach can be effectively applied to renovation projects around the world. This methodology not only advances the goals of energy efficiency and sustainability but also ensures that the cultural and historical integrity of buildings is preserved for future generations.

The Florence case highlights the potential of the P2Endure approach to contribute to large-scale renovation efforts globally, providing a model for how historic buildings can be brought into the 21st century while maintaining their unique historical character. This approach is particularly

relevant as cities around the world seek to balance the demands of modern living with the need to preserve their cultural heritage. By leveraging the lessons learned from Florence, future projects can achieve similar success, making a significant impact on the global push for energy- efficient, sustainable, and culturally respectful building renovations.

In conclusion, the outcomes and results achieved by P2Endure reflect the project's success in advancing the state of the art in deep renovation. By combining innovative products, processes, and validation techniques with a strong focus on market adoption and scalability, P2Endure set a new benchmark for energy-efficient renovations in Europe.

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