Off-site construction

to simplify the energy transition in social housing

Practice Manual for Architects

A project by

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Practice Manual for Architects

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Abstract

The contemporary era is characterised by an increasing scarcity of resources in all forms, prompting a profound reflection on the way in which we live.

In light of the increasing necessity to reduce the environmental impact of the construction industry, European legislation is requiring the implementation of new environmentally-
friendly technologies and approaches to reduce the energy consumption and environmental impact of the building stock.
Furthermore, the progressive impoverishment of families and the scarce supply of affordable housing on the market have led to a real social emergency and crisis of living that is affecting numerous countries across Europe and beyond.
These phenomena are significantly influencing the construction sector, as the majority of European buildings must be renovated in the near future, particularly social housing due to its pervasive energy poverty.

Climate change and the housing crisis are two issues that are well-known, but how can architecture provide with innovative and sustainable responses?
The twofold reflection on the future of living and the ecological transition is encountered along this path, through a research project that analyses the potential of off-site architecture for collective housing retrofit and new construction.
The project proposes a turnaround to innovate the construction sector by establishing new professions, skills and roles to cope with a constant scarcity of resources and demographic issues such as the ageing population and the increasing life expectancy.

Mission & Vision

Looking at the ecological transition: the European context

The European legislation (2020 'Renovation Wave' and the newest 2023-24 European Performance of Buildings Directive) requires new environmentally-friendly technologies and approaches to reduce the environmental impact and energy consumption of buildings, also setting the goal of having zero-emission EU building stock by 2050. This will impact the construction sector, as the majority of European buildings must be renovated in the years to come, in particular social housing due to its widespread energy poverty.

The progressive impoverishment of families and the scarce supply of affordable housing on the market bring us to a real social emergency and crisis of living.
In addition, recent evidence has shown that low-income individuals and households tend to dedicate a larger share of their budget to fundamental goods such as energy and food, and they are the ones experiencing the highest rates of inflation with consequences in terms of poverty and inequality. Housing costs are part of this concern on the increasing cost of living. Expenditure on housing costs represents the highest share of household budgets in the vast majority of EU countries with an average 32.7% of total consumption expenditure.[7]
Moreover households account for 27% of final energy consumption in the EU and contribute to 21% of total greenhouse gas emissions.[8] Buildings are therefore the largest consumer of energy in Europe: heating, cooling and domestic hot water account for 80% of citizens' consumption.
The construction sector contributes significantly to global climate

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7 Eurostat, "Housing, food & transport: 61% of households' budgets". Data referring to 2020.

8 Eurostat, "Greenhouse gas emission statistics - air emissions accounts". Data referring to 2021.

change, accounting for about 23% of global greenhouse gas emissions and 37% of energy and process-related carbon dioxide (CO_2) emissions.

Off-site construction is the only technique that makes building projects' delivery faster, cheaper, safer and greener (less waste and emissions), delivering low-carbon prefabricated buildings and reducing the embodied energy of a building by up to 30%.
Promoting off-site since the first step of the construction chain is important to reverse this trend and create a network of skilled professionals that look at green and inclusive alternatives in architecture.

The increasing impoverishment of families and the scarcity of affordable housing on the market are creating a real social emergency and housing crisis. More and more households are exposed to energy poverty, especially low-income households living in energy-inefficient dwellings. This is compounded by other factors such as the loss of effectiveness of housing support policies due to a lack of public funding and inefficiencies in the management of existing assets.

One of the consequences of this is a progressive reduction in the supply of public housing, which has to contend with some critical factors such as the high percentage of owner-occupied homes that has always characterized the Italian property market.
However, the vast majority of houses, around 7 out of 10, are owner-occupied, which in Italy is considered a safe investment.
Nationally, public rental housing (Edilizia Residenziale Pubblica or ERP) is estimated to represent about 3.5% of the total housing stock in the country and is a permanent feature of our housing system.[9]

It includes about 900.000 units managed by public housing companies and municipalities. There is no centralized information on the energy performance of public housing, but the need to renovate public housing units is widespread - to the extent that an estimated 10% of the stock is currently vacant. In fact, more than half of the available EPCs are in classes F and G, indicating that the energy efficiency of housing in Italy is relatively low. [10]

Turin's social housing stock, most of which was built between the 1950s and 1980s (68% of the housing stock was built before 1981 and 14% after 1991), is spread over a large part of the urban

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9 Istat, Population and Housing Census 2021.

10 Sistema informativo sugli Attestati di Prestazione Energetica (SIAPE).

area, with varying densities. There are 17.435 housing units, 63% of which are owned by ATC, 34.4% by the Municipality of Turin and the rest by the State Property Office, the Local Health Authority and the Ministry of Justice.[11]
This data confirms that around 35% of EU buildings are over 50 years old and almost 75% of the building stock is energy inefficient.

In terms of the labour market, construction remains one of the most vulnerable sectors in Italy. In 2022, construction is the sector with the highest number of fatal accidents, with 110 fatalities. Even for non-fatal accidents, the sector remains one of the most exposed, as confirmed by Inail[12] data.

In this context, it is clear how an innovative process could control the risk associated with work phases, drastically reducing work-related injuries and fatalities.
Inevitably, the need for human resources, which are increasingly scarce in the sector, would be reduced or redesigned.

The Italian off-site project landscape is mainly developed on new construction projects (both single-family and multi-storey buildings). The most commonly used technologies are timber or hybrid timber-reinforced concrete-steel, while retrofit technologies are still almost unexplored. Off-site architecture offers various possibilities for innovation in the construction chain, which in Italy is currently static and rooted in traditional technologies and methods.

The green and digital transitions are an opportunity to address the shortcomings of the construction industry and make social housing projects more inclusive, effective, safer, faster and more environmentally friendly. What's more, off-site techniques, with their lower costs, can help to reduce the financial burden on the beneficiaries of social housing refurbishment, who typically cannot afford large investments.

In Poland, the construction industry is experiencing a gradual shift towards the use of prefabrication methods.
Prefabrication involves the manufacture of building components in a factory and then transporting these components to the construction site for assembly. One of the most promising developments in this area is modular construction. This

11 Città di Torino, Osservatorio Condizione Abitativa XIX Rapporto - anno 2022.

12 National Institute for Insurance against Accidents at Work.

innovative approach involves the production of entire modules of a building in a factory, which are then transported and assembled on site. The potential of modular construction in Poland is considerable, as it can lead to faster project completion, cost savings and a reduction in environmental impact. However, despite its potential, the widespread adoption of modular construction in Poland faces several challenges. One of the main obstacles is the existing regulatory framework, which has not been fully adapted to this modern construction method. Regulations often lag behind technological advances, creating hurdles in the approval process and increasing the complexity of compliance. In addition, traditional construction practices are deeply ingrained in the industry, making it difficult to move towards a more modular approach.

On the other hand, in Poland, factories have sprung up near Toruń and Kraków to produce modular housing elements from wood or steel. Although their production is mostly exported to other Western markets, their location could be seen as a beacon and driver for change. With the right attention, they could be brought more into the domestic market, where they are not as widely used as in other countries where their customers are located.

In Poland, the use of prefabrication in construction is still somewhat limited and most prefabricated buildings are based on concrete wall systems rather than fully modular components. Projects that typically involve the use of prefabricated concrete walls, which are assembled on site to form the structure of the building, are being used in various residential and commercial buildings across Poland.
Although these methods improve durability, efficiency and quality compared to traditional construction techniques, they fall short of the full potential of modular construction. Unfortunately, there are currently restrictions in the law and building regulations that are very much in line with what is considered good practice. These are mainly related to adequate fire protection and the need to build lower structures, for example in timber. This is set to change in the coming years, as the government has recently launched a wider debate on the subject.
In summary, while Poland is making progress in integrating prefabrication into its construction industry, there is still a long way to go before the full potential of modular construction is realised.

Project objectives

The main objective of the project is to engage a group of Polish and Italian architects to stimulate debate, deepen their knowledge and develop innovative project ideas for off-site construction to facilitate the energy transition in social housing and to enable architects to adapt their professional profile to the changing skills arising from the renovation wave in Europe.
The architects will improve their professional practices and pave the way for a widespread greening and digitalisation of their work, comparing and learning from the experiences of Poland and Italy within the framework of best practices in the European context.
Building knowledge of off-site techniques will support its use in the partner countries, contributing to a faster green transition in social housing, where decarbonization and energy efficiency are more urgent given the higher obsolescence of building stock.

Site and company visits will allow participants to discuss with policy makers, contractors and professionals the off-site solutions used in the renovation and new construction of social housing and their strategic contribution to achieving inclusiveness, aesthetics and sustainability.

Starting from the analysis of different good practices, the project will identify and design new transnational training content and professional tools to empower architects in off-site design for social housing. In this way, their work will respond to the environmental and social challenges of the social housing context, combining digital and collaborative technologies with innovative and high-performance materials. At the design stage, equal access to housing will be improved through cheaper and higher quality solutions that meet people's diverse needs. Off-site design will allow architects to escape conventional methods and adopt more flexible techniques. Buildings that respond to housing shortages can be adapted to different needs and the use of modular/prefabricated components can help reduce costs and materials.

Following these statements, the project aims to build a community of professionals who will able to:

- Exchange good practices on off-site architecture for social housing as a first step towards its wider adoption;
- Promote the use of off-site construction among European architects;
- Increase the digitalisation of the construction process thanks to a better use of digital tools (BIM, 3D printing, drones and robots) in off-site practices for social housing;
- Support the digital and green transition in the construction sector by promoting off-site construction as a sustainable and inclusive approach to the construction and the retrofit of social housing projects.

The programme is organised by macro areas and will cover the following topics:

- **Political and socio-cultural context**

In light of the European housing crisis, the debate aims to explore and propose public policy solutions for public heritage to be upgraded and renovated. It will also explore the potential of collective and shared housing as architectural typologies and the benefits they can bring to urban management;

- **Environmental and socio-cultural context**

It focuses on energy poverty in the social housing stock and analyses the new trend of energy retrofitting according to the rules of the recent European Green Deal. Special attention is given to circularity in construction processes, material reuse and bio-construction;

- **Off-site design & processes**

Starting from the current state of the art, we will explore innovative construction technologies, materials and processes in off-site architecture and site management in the context of European best practice;

- **Digital design and industrialization**

What is process innovation?
The topic covers the role of process industrialisation and how established and emerging technologies in off-site construction, such as BIM technologies, 3D printing and robotics, can help to rapidly innovate the system.

Project partners

"Off-site Construction to Simplify the Energy Transition in Social Housing" is a project by Fondazione per l'architettura / Torino and Stowarzyszenie Laboratory for Urban Research & Education, funded by the European Union within the framework of the Vocational Training Partnership KA210-VET (Erasmus+).

Fondazione per l'architettura / Torino

Fondazione per l'architettura / Torino was founded in 2002 on the initiative of the Association of Architects of Turin, and it promotes architecture as a discipline at the service of the quality of life.

The organisation promotes interdisciplinary relations and acts as a bridge between the worlds of design, construction, technology and culture. Its aim is to investigate current and future social needs, to study innovative responses and to implement concrete actions in the field, stimulating change and seeking tools to face the challenges of the future with awareness and responsibility.
The foundation works in various fields: vocational training, social projects, cultural projects and architectural competitions.

Fondazione per l'architettura / Torino is a member of the New European Bauhaus Community and of Torino Social Impact, the platform that aims to experiment, together with companies and institutions, a new development strategy with a high social impact and technological intensity.

Social media:
Sito web

Laboratory for Urban Research & Education

LURE is an urban think tank focused on research, education and development to provide answers to the challenges facing cities and the Green Deal agenda. Its team consists of architects and researchers working on innovative projects for cities.
The group focuses on promoting susta inable urban development through innovative architecture and interdisciplinary perspectives in all urban dimensions.

LURE has experience in unleashing a new wave of innovative buildings and urban infrastructure focused on sustainable building materials, renewable energy solutions and water challenges.
LURE is part of the New European Bauhaus and a supporter of the Covenant of Mayors for Climate and Energy and has offices in 4 countries (Poland, Belgium, Romania and Spain).

Social media:
Sito web

Calendar activities

18–19 October 2024	Vocational training with conferences, construction site visits and workshop scenario TURIN (ITALY)
21–22–23 February 2025	Vocational training with conferences, construction and factory visits, and workshop WARSAW AND TORUŃ (POLAND)
3 April 2025	Public dissemination event with local experts and stakeholders TURIN (ITALY)
30 May 2025	Public dissemination event with local experts and stakeholders WARSAW (POLAND)

Project impact

Over **350** architects empowered thanks to project events

2 major events featuring conferences and workshops

2 dissemination events for broader outreach

40 speeches from sector experts

10 public and private stakeholders actively engaged in the debate

20 partners, both technical and technological

3 media partners

Off-site Manual

Short historical tour on prefab architecture

The history of prefabrication has been neither linear nor rapid. While prefabricated buildings have existed since ancient times and became more defined during the colonial era — driven by global demand for rapid settlement — it wasn't until the 19th century that prefabrication began to gain widespread traction. The modern concept of prefabrication in Europe expanded significantly during the Industrial Revolution, driven by the introduction of new materials such as iron and steel, along with the rise of mass production techniques. This evolution can be broadly traced through six key phases: industrialization, standardization, mechanization, mass production, automation, and mass customization, each marking a significant step in the technological and process development of prefabrication methods[7].

Thanks to the development of prefabricated components — first in steel and iron, and later in reinforced concrete — the construction industry began to move toward rationalisation and industrialisation. Elements such as lintels, windows, columns, beams, and trusses could now be manufactured in foundries or factories and pre-assembled in workshops.
The prefabrication and standardisation of components allowed them to be used in infrastructure projects and the construction of large public buildings. A notable example from this period is the Crystal Palace, designed by Joseph Paxton for the Great Exhibition of 1851 in London.

7 Smith, Ryan E., "Prefab architecture. A guide to modular design and construction", New Jersey, USA, 2010.

During the 20th century, many architects were captivated by the potential of these emerging building methods. They explored them extensively and contributed significantly to their evolution. The Modern Movement, which developed between the 1920s and 1960s, saw the standardisation and industrialisation of construction, as well as technical progress, as a response to the needs of modern industrial society, offering new formal languages and construction methods. Architects were using steel frames, standardized panels, and glass walls, creating prefabricated structures that were both functional and visually striking. Their projects showcased how prefabrication could be a method for high-quality and innovative residential design expressing the potential of prefab construction in transforming housing design.

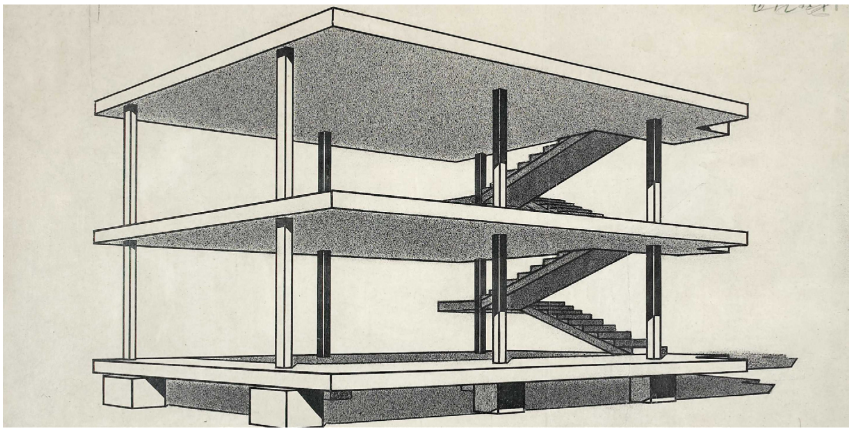

Image: Le Corbusier, Maison Dom-ino, 1914.
© Fondation Le Corbusier/ADAGP

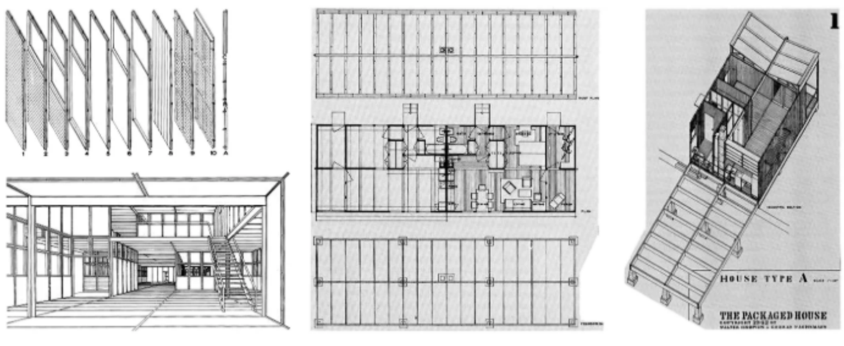

Image: Gropius and Wachsmann, Packaged House, standard house type A, 1942.
© MIT Press Open Architecture and Urban Studies

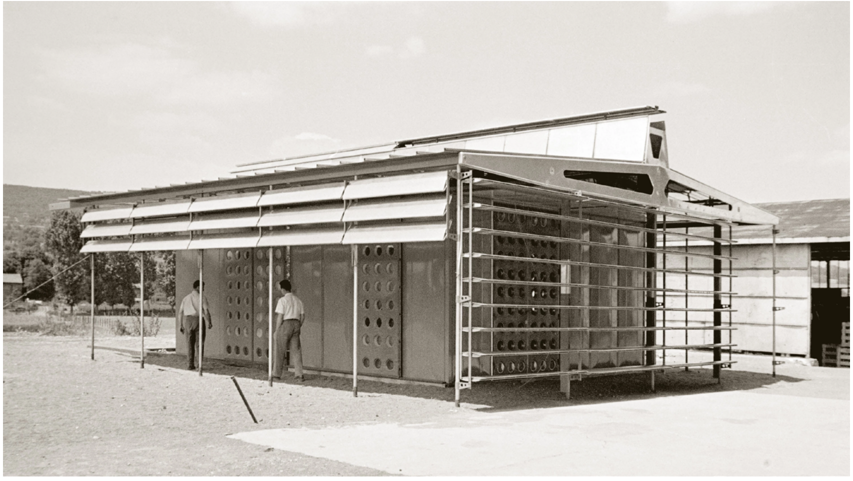

Image: Jean Prouvé, Maison Tropicale, 1949.
Source: Arquitecturaviva.com

Notable figures include Le Corbusier, Jean Prouvé, and Walter Gropius and Charles Eames, who, by adopting and reinterpreting technical and formal advancements, influenced many of their contemporaries and helped shape this new architectural style. Iconic examples from this period include Le Corbusier's Maison Dom-ino (1914), Walter Gropius's experiments with the Packaged House System (1940), Jean Prouvé's Maison Tropicale (1949) and Charles and Ray Eames's Eames House (1949).

Prefabrication became increasingly widespread as it evolved into both an economic and logistical necessity, particularly during periods of high demand, such as the post-World War II era, when there was a strong need for affordable, efficient, and aesthetically pleasing homes built using industrial materials and techniques. Eames House, also known as Case Study House No. 8, was part of the influential Case Study House program to promote affordable, efficient, and aesthetically pleasing homes. The house utilized industrial materials and techniques, such us steel frames, standardized panels, and glass walls to create a space that was both highly functional and architecturally distinctive.

Later, during the economic boom of the 1950s to 1970s, prefabricated architecture proliferated across Europe, particularly in Eastern Europe and the USSR, through large-scale developments of concrete panel housing. Typologies such as the Plattenbau and Panelák became dominant in residential projects and came to symbolise communist ideology. Over time, these structures were increasingly criticised for their lack of aesthetic appeal and personalisation, leading to perceptions of alienation and a loss of urban identity.
In line with this mass-application spirit, by the late 20th century, modular construction expanded into broader sectors, including education, healthcare, commercial and infrastructure.

In the 21st century, prefabrication has evolved from simple standardised production to complete construction systems, reaching a new maturity. This transformation has been facilitated by technological progress, the mechanisation of sites, and adequate infrastructure. In the 2000s, prefabrication acquired a new image, evolving from an economical, temporary solution into a modern strategy aiming at energy efficiency and sustainability.
Several countries have distinguished themselves internationally through the adoption and development of prefabricated systems. In Japan, for example, Sekisui House has developed an advanced residential prefabrication model focusing on seismic quality and safety. In Germany, brands such as Huf Haus have developed customisable, energy-efficient wooden and glass prefab houses. In the United States, innovative, experimental, modular housing projects have been developed in response to the housing crisis. Meanwhile, in Sweden, the BoKlok project (a collaboration between IKEA and Skanska) has made sustainable homes affordable for the middle classes. Overall, the 2000s marked a turning point for prefabrication, which is now seen as a viable alternative to traditional construction methods.

The rapid growth of prefabrication in recent years has been driven largely by the widespread adoption of automation in construction processes. This transformation is supported by a range of digital technologies and advanced software solutions, including BIM, 3D printing, robotics, CNC manufacturing, artificial intelligence and so on. Together, these innovations have improved workflows, precision, and sensibly reduced construction times, making prefabrication a more efficient and an applicable cost-effective method. As a result, the construction industry has been able to shift towards more automated and digitized practices, paving the way for scalability and sustainability in building projects.

Nowadays, this construction method has undergone a conceptual rebranding: prefabrication is increasingly referred to Off-site Construction (OSC), sparking a renewed wave of interest and innovation. This contemporary rediscovery has been driven by the urgent need for transformation and innovation in the construction sector, particularly by leveraging the vast flexibility and potential of these technologies to promote environmental, economic, and social sustainability in architecture and urban development.

Off-site nowadays: a holistic approach to innovation

In today's rapidly evolving world, embracing new technologies and construction methods such as off-site construction is more important than ever. These innovations, along with broader advancements across the building industry, are reshaping how we design, build, and sustain our environments.
But why is innovation in the construction sector so critical and important today?

Environmental issues

Recent statistics show that the primary contributors to global CO_2 emissions are the energy, industry, agriculture, and waste sectors — together responsible for nearly all emissions worldwide. The energy sector alone accounts for around 73.2% of global CO_2 emissions. This data includes energy use in buildings (17.5%, with 10.9% from residential buildings), transport (16.2%), and industry (24.2%)[7].

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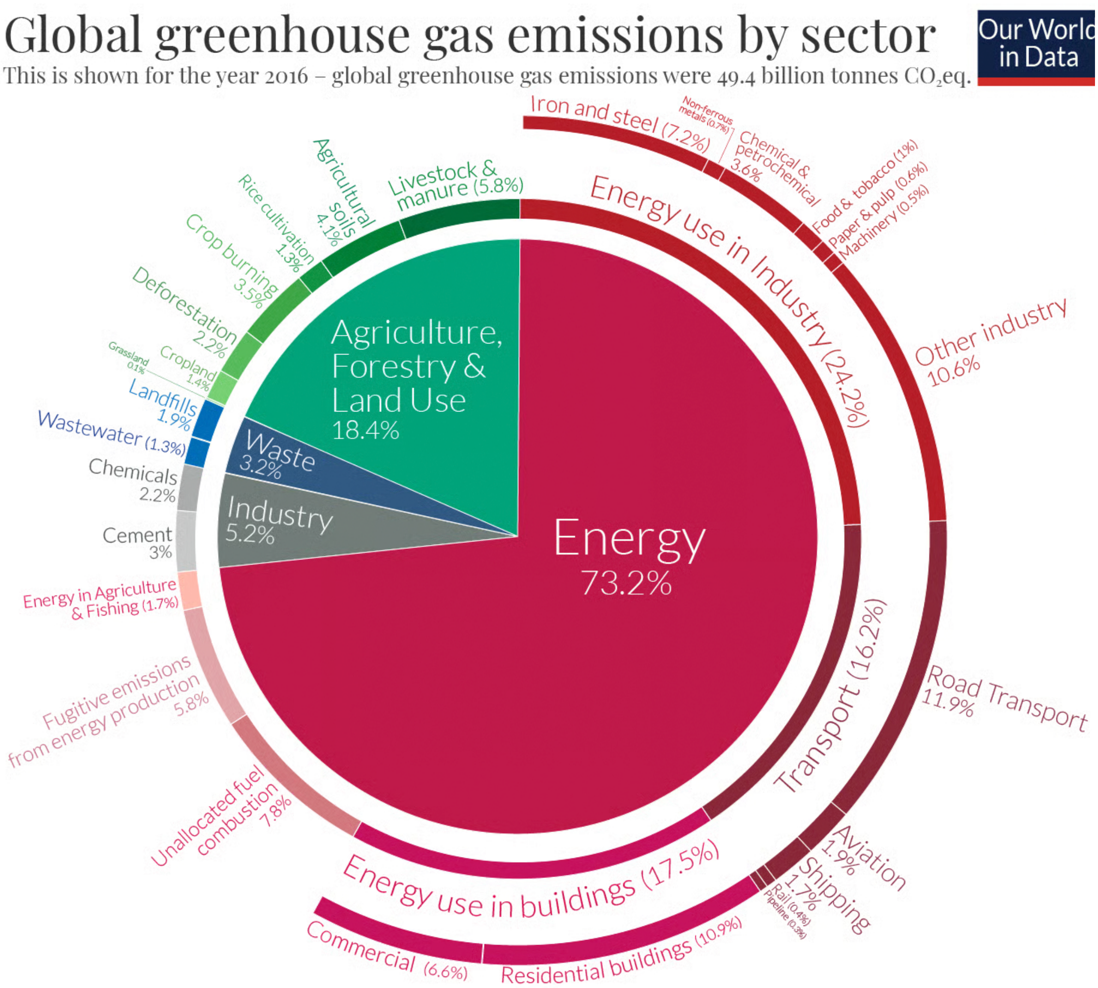
7 Global greenhouse gas emission by sector, Climat Watch - the World Reources Institute, 2020.



Among the sectors, construction plays a particularly significant role. It is responsible for approximately 37% of global energy-related CO_2 emissions and consumes over 34% of the world's total energy demand[8]. Its environmental impact spans the entire production chain — from energy use and direct emissions in buildings to resource extraction, material production, land use, and waste generation. For context, waste management contributes 3.2% of global CO_2 emissions, cement production 3%, and iron and steel production 7.2%[9].

8 United Nations Environment Programme, "Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector", Nairobi, 2022.

9 Global greenhouse gas emission by sector, Climat Watch - the World Reources Institute, 2020.

Industry issues

Moreover, when evaluating the construction sector in terms of its productivity, it becomes clear that it has been experiencing a steady decline relative to other industries. Since the early 1990s, construction productivity has been on a downward trend, culminating in its lowest point around 2010[10]. Unlike many other sectors that have seen improvements through technological advances and process optimizations, construction has struggled to enhance efficiency at a comparable rate.

This stagnation can be attributed to various factors, including the fragmented nature of the industry, reliance on traditional building methods, and challenges in adopting new technologies. In addition, the construction sector is facing a significant loss of labour force, caused on the one hand by the rapid ageing of the working population in the sector and on the other hand by the gradual disappearance of specialised skills. Statistics show that the workforce is aging significantly. Soon, more than 20% of the industry's employees will be over the age of 55, and by 2030, this figure is expected to exceed 25%[11].

Despite efforts to improve, productivity levels have remained largely unchanged since 2018, continuing to characterize the sector's performance up to 2024, according to projections. This ongoing decline presents significant challenges, especially considering the sector's substantial environmental impact and energy consumption.

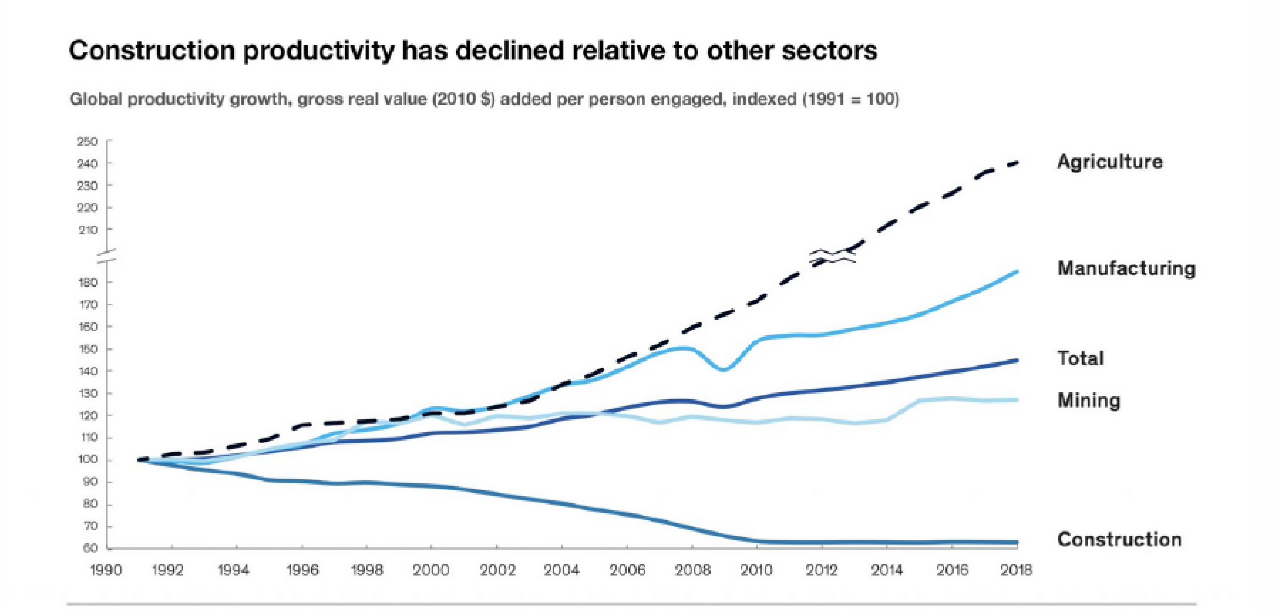


Image: World Bank, IHS, International Labour Organization.

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10 World Bank, IHS, International Labour Organization.

11 Miorin T., Stanghini C., Zanini A., Chiodero C., "Industrialized Deep Renovation Outlook", Jan. 2025, first edition.

This discussion seeks to promote the broader adoption of prefabrication in the housing sector by applying lessons from the manufacturing industry to boost efficiency, reduce waste, and increase the sector's ability to adapt to changing demands. In fact in recent years, Europe and other regions have been exploring new pathways to transition their economies and generate alternative revenue streams. A notable example is Toyota, one of Japan's most renowned car manufacturers, which has shifted from solely producing cars to entering the housing market. By leveraging its existing production expertise, Toyota is exploring new revenue opportunities. In 2019, the company launched a new division called Toyota Housing Service[12], signaling its intention to diversify beyond the automotive industry. The goal is to apply the same principles and processes used in automobile manufacturing — efficiency, precision, and scalability — to homebuilding.

By utilizing the highly optimized manufacturing techniques developed for car production, Toyota aims to deliver affordable, sustainable housing in a streamlined and cost-effective way.

In light of these considerations, it is crucial to investigate the factors affecting productivity in the industry, particularly production time and costs. Various studies show that off-site construction can reduce costs by up to 20% compared to traditional methods, while cutting construction time by up to 50%[13]. This approach also allows for high reliability in meeting both the pre-determined contractual budget and delivery schedules. A further benefit is process optimisation that reduces waste and improves overall construction quality.

12 https://global.toyota/en/company/profile/other-toyota-businesses/housing

13 Bertram N., Fuchs S., Mischke J., Palter R., Strube G., and Woetzel J. - McKinsey & Company, "Modular construction: From projects to products", Jul. 2019.

Supply chain issues

Despite its great potential, the widespread development of an off-site construction supply chain also encounters significant economic and procurement challenges of primary resources in some countries such as Italy and Poland. Among the main critical issues are the heterogeneity of the existing building stock (which complicates the standardisation of interventions), limitations in production capacity, market fragmentation and the complexity of support mechanisms for public and private actors. In fact, the off-site and building redevelopment supply chain involves a plurality of actors, each with a fundamental role: designers, raw material suppliers, component manufacturers, system builders, logistics companies and general contractors[14].
The Italian context is characterised by a limited demand but also by a limited production capacity on the part of suppliers of OSC systems and components. There is also a lack of knowledge and awareness of the available technologies and examples that allow the evaluation of costs, benefits, time and performance. It is pointed out that to date, the high cost of OSC systems is determined by limited utilisation, which is a relevant barrier from all perspectives and for all actors involved. Furthermore Italy is facing with a geographical fragmentation of production concentrated mainly in the north-west: both in the production of components for energy requalification (e.i. external thermal insulation composite system - ETICS) and wood solutions for new construction.
Addressing these challenges requires the promotion of innovative business models capable of increasing the rate of intervention in the built environment, accompanied by policies aimed at supporting these changes be aware of the cost-effectivness of OSC interventions.
The full development of the OSC sector requires an integrated approach involving companies, customers and policymakers, capable of harmonising the different needs of the actors in the supply chain. This collaborative element is central to success and recognised as crucial from all perspectives analysed. Awareness-raising actions and training programmes for companies, planners and end customers are necessary, as well as stable incentives in the long term. Demonstration installations and cost-benefit analyses are further valuable tools to promote OSC solutions, highlighting their advantages and technical aspects. The creation of technical installation standards and operating manuals can ensure quality and compliance, reducing uncertainty among designers and end customers.

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14 ENEA, "Costruire il Futuro. Off-site e Riqualificazione edilia in Italia", Dec. 2024.

Housing issues

As mentioned several times in our project publications, the European housing stock is predominantly old and energy-intensive, posing significant challenges for energy efficiency improvements and climate goals.
High energy consumption in buildings leads to high CO_2 emissions and expensive energy bills, a phenomenon known as energy poverty. This occurs when energy bills account for a significant proportion of a household's income, affecting their ability to cover other monthly expenses. It can also impact their physical and mental health when consumers are forced to reduce their energy consumption at the expense of their health.

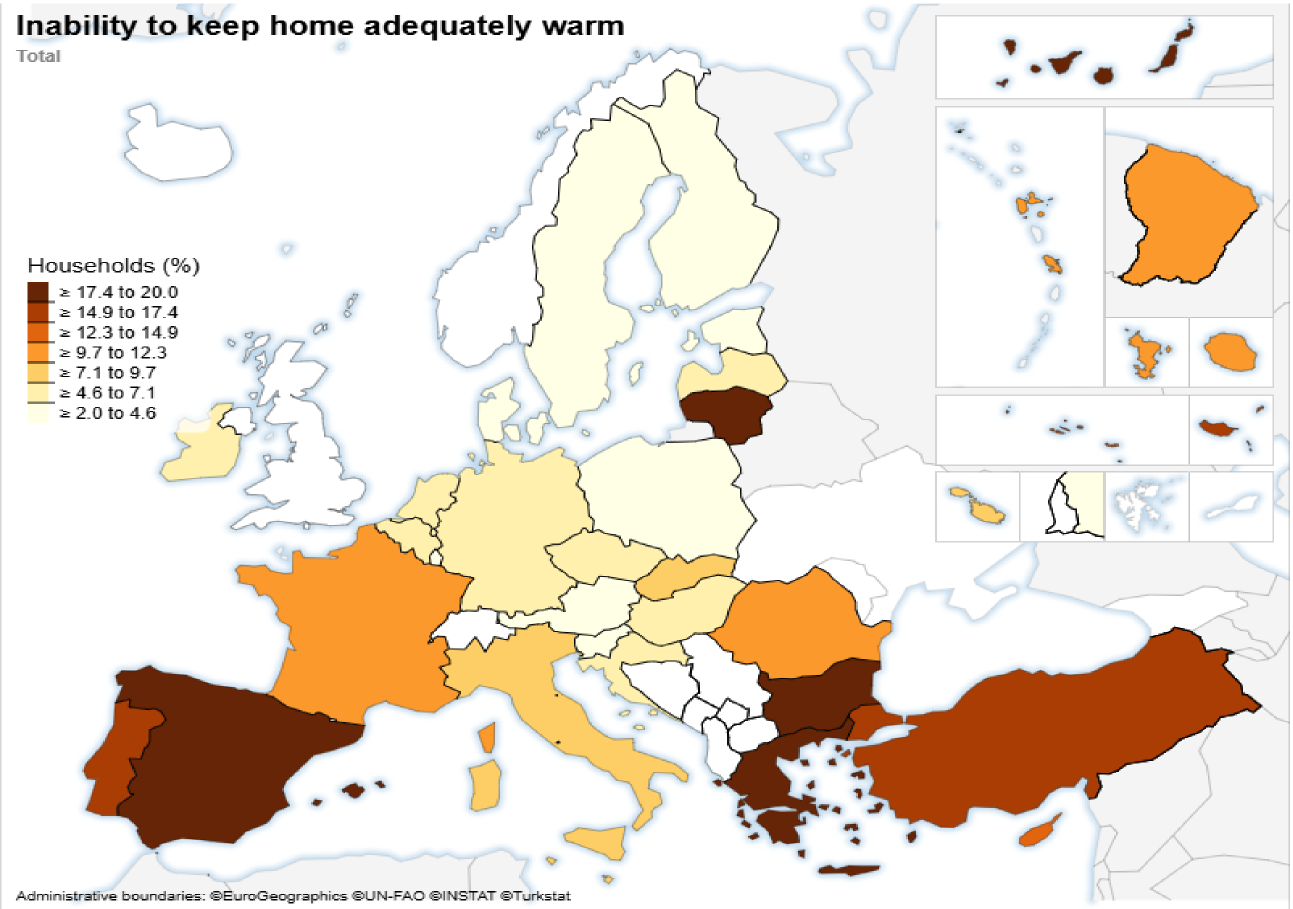

Image: Eurostat.

Eurostat data shows that in 2022, 9.3% of the EU population (about 40 million inhabitants) declared that they were unable to adequately heat their homes. This figure increased to 10.6% in 2023, before decreasing slightly to 9.2% in 2024[15].

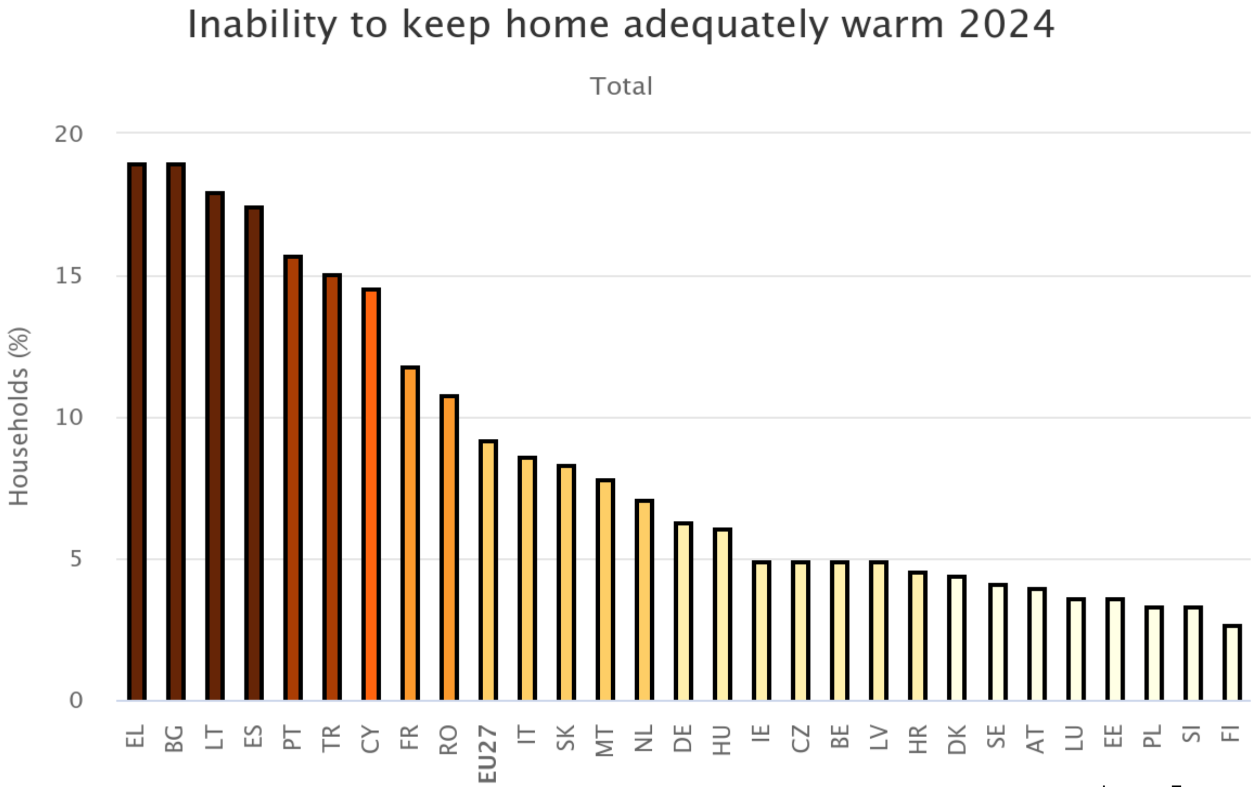

Image: Eurostat.

This issue is particularly pronounced in Italy, where approximately 12.4 million residential buildings[16] were constructed before 1976, the year when the country introduced its first energy-saving legislation[17]. These older buildings typically feature outdated construction techniques, inadequate insulation, and inefficient heating and cooling systems, all contributing to higher energy consumption, increased utility costs, and greater greenhouse gas emissions. In fact, 66% of the Italian housing stock, encompassing both private and public dwellings, is classified within the lower energy efficiency classes (E, F, and G)[18], indicating poor performance in terms of energy use. The data mentioned above are quite widespread and reflect the same features across Europe.

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15 Eurostat, 2024.

16 ISTAT, 2021. (Data confirmed in the Strategy for the Energy Upgrading of the National Building Stock (STREPIN).

17 Law No. 373 of March 30, 1976.

18 SIAPE - ENEA.

Tackling the energy inefficiency of this significant portion of the housing stock is both urgent and essential, not only to reduce overall energy demand and lower residents' utility costs, but also to meet national and European climate goals.

In order to achieve the decarbonisation targets, European and national policies have outlined a clear path, which includes large-scale interventions on the entire existing building stock, with the aim of significantly improving its efficiency. In this context, European directives, as part of the Renovation Wave strategy, have introduced the concept of "Deep Retrofit". This is an approach to retrofitting that follows the principles of energy efficiency and aims to significantly reduce greenhouse gas emissions throughout the building's life cycle.

A deep retrofit involves improving the energy class of a building with the ultimate goal of achieving an NzEB rating. The intensity of the retrofit depends on the level of energy savings achieved. A light retrofit is defined as one in which savings do not exceed 30%; a medium retrofit is one in which a reduction in consumption of between 30 and 60% is achieved; and a deep retrofit is one in which savings are 60% or more[19].

Currently, deep renovations represent only 0.2% of all renovations, accounting for one-fifth of the total. In fact, the weighted annual renovation rate is calculated as 1.0% when light, medium and deep renovations are considered in total.

It seems that we are still far from the final target. In order to achieve climate neutrality by 2050, the renovation rate will need to increase to 3% per year, with deep renovations accounting for 70% of the total. This is compared to the approximately 12% of the residential building stock that has been renovated in line with European targets so far[20].

Thanks to off-site construction technologies, it is now possible to carry out retrofit interventions more easily. These technologies offer a valuable opportunity to support growth in the construction sector, both for low- and high-density buildings. A possible alternative to the deep retrofit carried out in a single phase is the so-called "Staged Renovation", whereby interventions are spread out over time. This approach allows costs to be spread over several years, making the overall investment more sustainable[21].

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19 UE Building Stock Observatory.

20 European Commission, "Renovation Wave - The European Green Deal", Oct. 2020.

21 Miorin T., Stanghini C., Zanini A., Chiodero C., "Industrialized Deep Renovation Outlook", Jan. 2025, first edition.

Economic issues

The economic dimension is equally important. Since the 2000s, Italy's GDP has experienced several downturns compared to other EU countries. Even today, it records one of the lowest growth rates among major European economies, trailing behind Germany, France, the Netherlands, Spain and the United Kingdom, and remaining well below the EU average.

This situation directly impacts the purchasing power and financial well-being of households, particularly those in the middle classes. Many families are finding it increasingly difficult to maintain their standard of living and invest in their properties. Furthermore, purchasing or renovating energy-efficient homes can cost up to three times more than properties in lower energy classes, creating a significant financial barrier for many families. These factors contribute to the slow adoption and limited spread of energy efficiency measures within the European housing market. Without targeted economic incentives or structural reforms aimed at improving affordability, the transition towards a more sustainable housing stock is likely to remain slow and unsystemic.

Digital issues

In addition, the construction sector continues to be stagnant and structurally challenged, remaining unreceptive to innovation. As various researches show, one of the main causes is the low level of digital integration[22]. Digital technologies today offer unprecedented flexibility in the production chain, allowing mass production of different components and a considerable variety in manufacturing. This approach is particularly effective in the design and realization of complex systems, such as the retrofit of large housing estates, where modules and elements converge into an integrated system.
The growth of the off-site and construction sectors today is inseparable from the advancement of cutting-edge digital and technological applications that enable faster, safer, and more precise results.

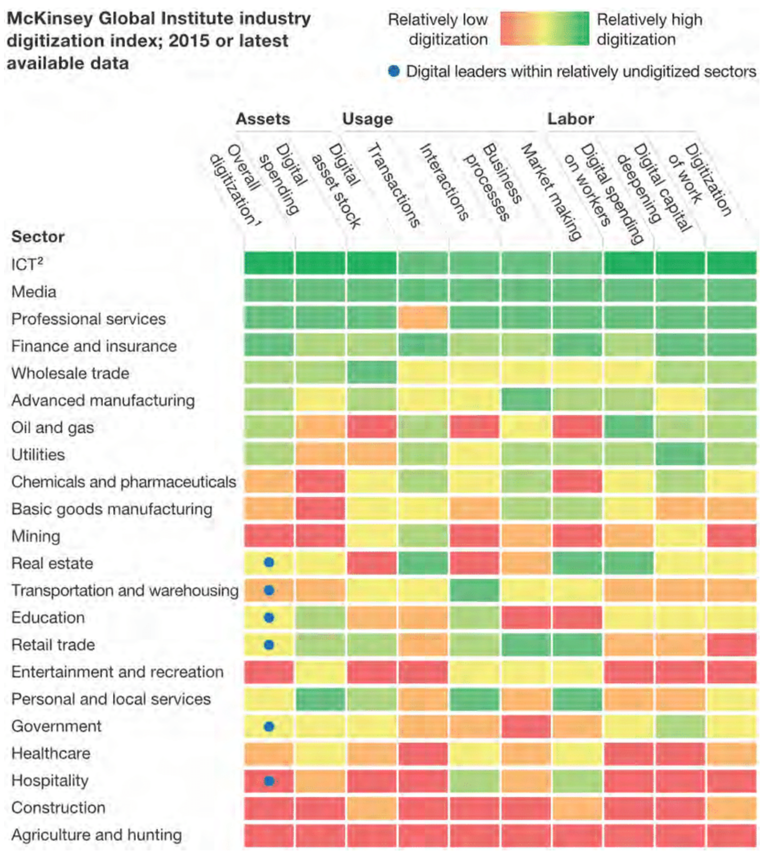

Image: The construction industry is among the least digitized according to the McKinsey Global Institute, 2016[23].

22 McKinsey Global Institute, 2016.

23 Agarwal R., Chandrasekaran S., Sridhar M., "Imagining construction's digital future", McKinsey Productivity Sciences Center, Singapore, 2016.

In conclusion, the construction industry requires radical transformation involving structural and organisational reinvention. To tackle the urgent environmental, social, and economic challenges of our time, we must embrace radical change by investing in innovation and digitalization throughout the way we design, build, and manage our built environment. Over the past decade, the construction industry has embarked on real a process of renewal, requiring us to examine other industries, such as manufacturing and automotive, to learn valuable lessons about maximising productivity. Innovating business models and the value chain enables intervention throughout the production process: from analysis and design to prefabrication, creation and management of digital models, assembly, monitoring and site management. Adopting new management and contracting systems, especially off-site techniques, enables us to comply almost entirely with agreed schedules and budgets.

Although off-site construction offers low-cost, high-quality solutions ideally suited for urban rehabilitation and regeneration, the architectural field has yet to fully embrace these opportunities. Aligning value with economic considerations is therefore crucial, as systemic investment and innovation in the sector can reduce production costs and unlock its significant potential for growth and transformation. To achieve this effectively, there must be a systemic alignment between economic factors and values, i.e. between the economic sustainability of investments and the social and environmental mission of the construction sector. Investing in technological innovation and new business models is therefore not an expense, but a strategic means of reducing production costs, increasing competitiveness, and enhancing the transformative potential of a traditionally conservative sector. Only in this way can future challenges be addressed in an integrated manner, helping to build more resilient, efficient and sustainable cities.

EU objectives and regulatory framework

In response to the global urgency of tackling climate change, the European Union has undertaken several efforts to align member countries, with the ***Paris Agreement*** standing as a milestone in international cooperation. Adopted in 2015 by nearly every country in the world, the treaty aims to limit the global temperature increase to well below 2°C, while pursuing efforts to stay within 1.5°C.
To achieve this goal, the signatory countries committed to submitting Nationally Determined Contributions (NDCs)—national climate action plans outlining concrete measures to reduce greenhouse gas emissions and adapt to climate impacts. The Agreement also establishes a regular review and update mechanism to progressively raise the level of global climate ambition. Through this collective approach, the Paris Agreement represented a turning point in the fight for a more sustainable, equitable, and resilient future.

Since 2015, the number of countries referencing efforts to address building-related emissions in their Nationally Determined Contributions (NDCs) has grown from 90 to 136. Similarly, the adoption of building energy codes — regulations that establish minimum energy efficiency requirements for residential and commercial buildings — has increased from 60 to 80. Investment in energy efficiency has also seen a significant rise, up by 40%, with most of this funding coming from a limited group of European nations. Despite this progress, major challenges remain. Excluding the temporary impact of the COVID-19 pandemic, the level of decarbonization achieved by 2020 represents only 40% of the benchmark needed to stay on track with the Paris Agreement targets (United Nations Environment Programme, 2021)[24].

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24 Miorin T., Stanghini C., Zanini A., Chiodero C., "Industrialized Deep Renovation Outlook", Jan. 2025, first edition.

To significantly cut emissions from buildings, a three-pronged strategy is essential:

- **Lowering energy consumption** by implementing energy efficiency measures and encouraging behavioral shifts;
- **Transitioning to low-carbon energy sources** through electrification and increased reliance on renewables;
- **Tackling embodied carbon in construction materials** by promoting low-carbon alternatives.

In line with this approach, future policies and incentive programs should prioritize the large-scale renovation of existing buildings, guided by principles of sustainability and a comprehensive lifecycle perspective[25].

Following this pioneering and widely adopted European legislation, many other laws and policies have emerged to support the global effort to give the planet a moment to breathe in the face of the Anthropocene.

Among them, the ***European Green Dea***l stands out as a particularly significant initiative.
The European Green Deal is the European Union's ambitious plan to make Europe climate-neutral by 2050 aiming at reduce greenhouse gas emissions, promote clean energy, protect biodiversity, and foster a sustainable economy that benefits all citizens. This transformative agenda focuses on creating jobs, improving health, and ensuring a just transition to a greener future.
The programme is built around three main goals: making Europe the first climate-neutral continent by 2050, reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, and planting 3 billion additional trees across the EU by 2030.
In response to the increasing environmental crisis, achieving climate neutrality has become one of the most urgent and complex challenges. Within the construction sector, the Green Deal focuses attention on new builds and redevelopment projects, addressing the widespread use of unsustainable methods and non-renewable resources. Instead, it promotes the adoption of circular economy principles to drive a more sustainable and resource-efficient approach.

25 Ibid.

A key focus is also the renovation of social housing, with targeted interventions aimed at lowering energy bills for those who struggle most to afford them. Additionally, the plan seeks to triple the renovation rate of all buildings, significantly reducing the pollution generated throughout their operational lifecycle[26].

Image: The European Green Deal Strategy.

A key part of this effort is the ***Renovation Wave Strategy***, presented in October 2020 which targets the building sector as a responsible for a significant share of energy use and emissions. The programme contains a 2030 action plan to improve energy efficiency, boost the economy and deliver better living standards. Specifically, the plan sets clear targets for the building sector (based on 2015 levels) to help achieve the 55% emissions reduction goal. It focuses on three key areas: tackling energy poverty, renovating public buildings, and improving heating and cooling systems.

The concrete objectives include a 60% reduction in greenhouse gas emissions, a 14% decrease in final energy consumption, and an 18% reduction in energy use for heating and cooling[27].

26 Stacy J., "European Green Deal: 8 key policy areas" in enhesa., Nov. 2023.

27 European Commission, "Renovation Wave - The European Green Deal", Oct. 2020.

The strategy aims to double the renovation rate of buildings across Europe, making them more energy-efficient, sustainable, and comfortable. It highlights the need for a comprehensive approach in which the entire supply chain is considered, integrated, and innovated to develop feasible models and strategies for retrofitting.

In recent years, Europe has been strongly committed to defining and proposing strategies to address climate change, while also responding to economic and social needs. The goal is to establish common guidelines across European countries, united in the pursuit of a shared objective: achieving climate neutrality by 2050.

Besides the three main directives that set clear targets for national laws — the ***Energy Performance of Buildings Directive*** (EPBD)[28], the ***Energy Efficiency Directive*** (EED)[29], and the ***Renewable Energy Directive*** (RED)[30] — the European Commission has also established a broader initiative: the ***New European Bauhaus*** (NEB), which focuses on sustainability and urban regeneration.

The NEB Facility is a European Commission instrument designed to accelerate the transformation of neighbourhoods through sustainable and inclusive design, thereby translating the European Green Deal into tangible improvements in daily life[31].
Officially introduced in 2021 through a collaborative co-creation phase, the NEB promotes sustainable, inclusive, and aesthetically enriching solutions for reimagining the built environment and lifestyle choices. Its mission is to foster spaces that are not only environmentally conscious but also reflect the rich diversity of Europe's places, cultures, and traditions with the aim of inspiring similar transformation beyond its borders by strongly encouraging citizen participation. The NEB Facility will run from 2025 to 2027, providing financial support and a strategic framework to achieve the NEB objectives.

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28 Energy Performance of Buildings Directive (EPBD)

29 Energy Efficiency Directive (EED)

30 Renewable Energy Directive (RED)

31 European Commission, "Roadmap for the New European Bauhaus Facility", Mar. 2025.

The NEB has three specific objectives[32]:

- **Transforming places with communities:** enhancing social acceptance of the clean transition and democratic processes at local level;
- **Supporting innovation:** providing circular and regenerative solutions for the clean transition;
- **Enabling change:** exploring new business and funding models, and developing skills.

The NEB Facility consists of two components: Research and Innovation, which develops novel and digital solutions aligned with NEB values, and Roll-out, which implements and scales up NEB initiatives.

Aligned with NEB objectives, off-site construction offers features across both components that strongly support NEB principles, driving tangible progress and improvements in the construction sector.
In fact, off-site construction can contribute to delivering beautiful, sustainable, and affordable housing through regeneration strategies applied to the existing housing stock across Europe, as well as on a local scale in Italy and Poland. The potential of off-site construction is especially evident in relation to objectives 2 and 3, particularly by embracing a new construction culture, supporting innovative materials and products, promoting the circular economy, and enhancing digital and sustainable construction skills, as illustrated in the following image.

32 Ibid.

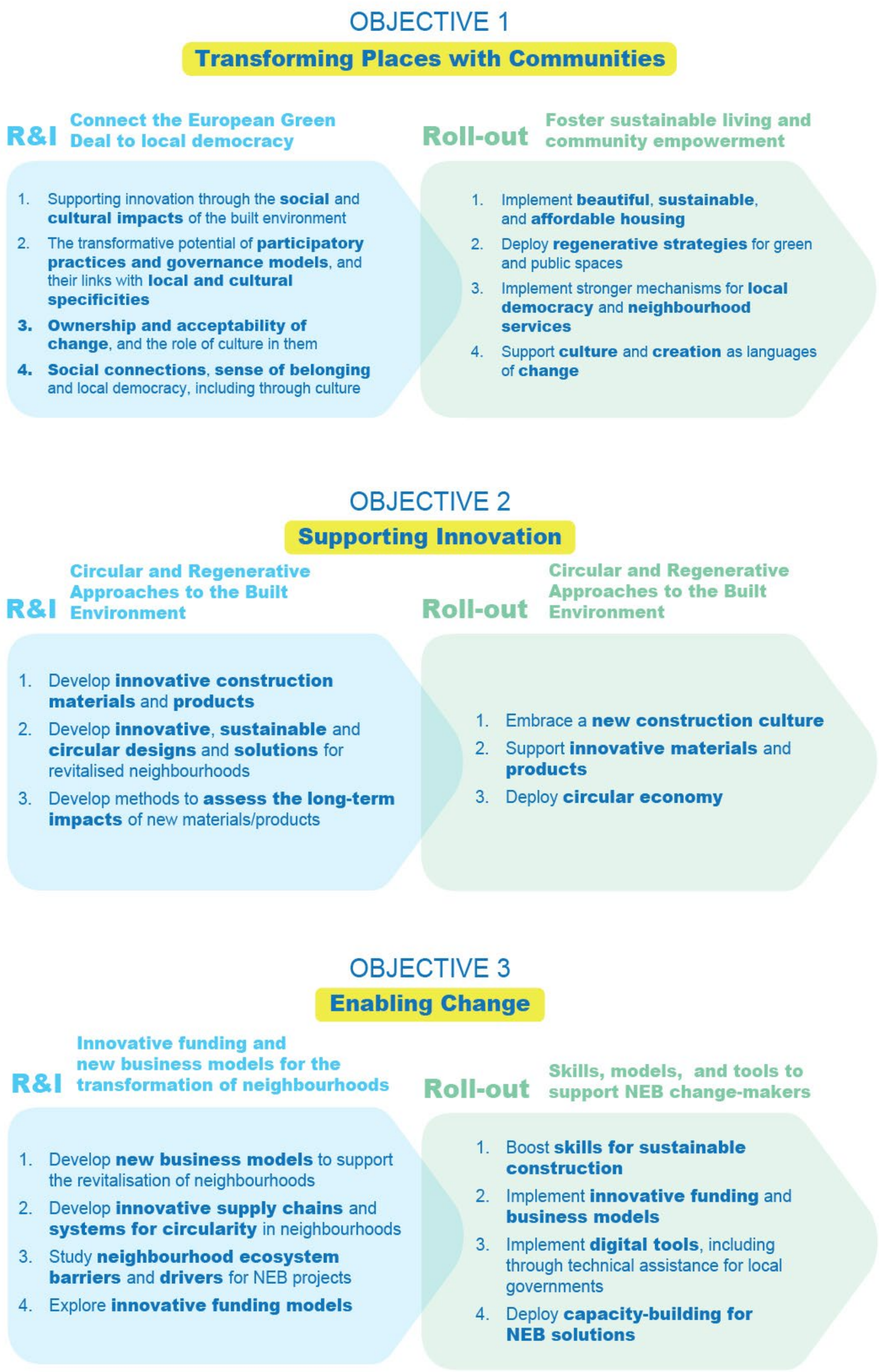

Image: NEB Facility multi-programme structure.

Prefabrication in Polish law: regulatory framework, potential, and limitations

Prefabrication in Poland as in many countries is not governed by a single, dedicated legislative act, but rather comes under the general provisions of construction law, technical building conditions, environmental regulations, and European product standards[33]. The Polish legal system treats prefabricated buildings similarly to traditionally built structures, which has both advantages and drawbacks in terms of regulatory clarity and innovation potential.

The core legal act regulating all types of construction activity in Poland is the Construction Law (Prawo Budowlane), enacted in 1994 and amended multiple times since[34]. This law provides the general definition of construction works, specifies the responsibilities of developers, designers, and contractors, and outlines procedures for obtaining permits. Prefabricated buildings, though manufactured off-site, are still considered construction projects and thus are subject to the same permitting procedures as conventional buildings[35]. As a result, the off-site production process does not exempt the investor from fulfilling the full range of administrative and legal requirements associated with a standard building project. The only exception is in the case of temporary structures, which may be erected without a building permit if their use does not exceed 180 days[36]. However, this provision is of limited use for large-scale or permanent housing projects based on modular systems.

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33 World Economic Forum, Shaping the Future of Construction: A Breakthrough in Mindset and Technology, 2020.

34 Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane [Act of 7 July 1994 – Construction Law], Dz.U. 1994 nr 89 poz. 414, with later amendments.

35 Ibid.

36 Ibid.

In addition to the Construction Law, prefabricated buildings must comply with the "Regulation on Technical Conditions to be Met by Buildings and Their Location", issued in 2002 by the Minister of Infrastructure[37]. This continuously updated on a yearly basis regulation sets out detailed requirements concerning safety, thermal insulation, ventilation, structural integrity, fire protection, acoustics, and other technical parameters. Although these provisions are not tailored specifically to prefabricated or modular systems, any building—regardless of how it was constructed—must fully meet these standards[38]. This creates a level playing field in terms of safety and performance but does not account for the unique features or advantages of industrialised construction methods, such as repeatable modules, transport logistics, or foundation interfaces.

On the European level, prefabricated components are treated as construction products and must therefore comply with the Construction Products Regulation (CPR), including CE marking and conformity with relevant harmonised EN standards[39]. In cases where a particular element or system does not fall under an existing harmonised standard, the manufacturer must obtain a national technical assessment (Krajowa Ocena Techniczna), which can be time-consuming and burdensome[40]. Furthermore, the prefabrication process must include factory production control (FPC) systems and quality assurance in accordance with Polish and European standards, such as PN-EN 13369 for concrete products[41], PN-EN 1090 for steel elements[42], or PN-EN 14081 for timber structures[43].

Despite these regulatory complexities, prefabrication offers significant opportunities for the Polish construction sector. It enables faster delivery times, higher quality control, and reduced

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37 Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie [Regulation of the Minister of Infrastructure of 12 April 2002 on the Technical Conditions to Be Met by Buildings and Their Location], Dz.U. 2002 nr 75 poz. 690, with later amendments.

38 Ibid

39 Ustawa z dnia 16 kwietnia 2004 r. o wyrobach budowlanych [Act of 16 April 2004 on Construction Products], Dz.U. 2004 nr 92 poz. 881.

40 Ibid.

41 Polish Committee for Standardization (PKN). PN-EN 13369: Common Rules for Precast Concrete Products.

42 Polish Committee for Standardization (PKN). PN-EN 1090-1: Execution of Steel Structures and Aluminium Structures – Part 1.

43 Polish Committee for Standardization (PKN). PN-EN 14081-1: Timber Structures – Strength Graded Structural Timber.

environmental impact due to less waste and lower energy consumption on-site[44][45]. These characteristics align well with both EU and national policy priorities related to sustainability, circular economy, and housing accessibility[46]. Prefabrication is particularly promising in the context of affordable housing, student accommodation, and social infrastructure, where repetition, scale, and speed are critical. Moreover, it matches the strategic goals of various EU funding mechanisms, including the European Green Deal, Just Transition Fund, the New European Bauhaus initiative or the KPO funding for modern green housings[47].

In Poland, however, the uptake of prefabrication has been slowed by several structural limitations. One of the most significant is the lack of a streamlined administrative path for modular construction. Because prefabricated buildings must go through the same permitting and approval procedures as traditional buildings, many of the potential time savings from off-site production are neutralised by bureaucratic inertia[48]. Additionally, the interpretation of construction law and technical regulations often varies between local authorities and building inspectors, which introduces uncertainty into the process and discourages innovation. The fire protection requirements are also rather outdated when allowing only 4 levels of timber construction to be built[49].

Another barrier lies in the financial sector. Polish banks and insurance companies still regard modular and prefabricated buildings as atypical or higher-risk investments, leading to increased premiums or outright refusal of financing. This is compounded by the fact that valuation models and cost assessment tools used by financial institutions may often rely on conventional cost metrics, which can overlook longer-term benefits of prefabrication with its quality, sustainability, and productivity[50].

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44 McKinsey & Company, "Modular Construction: From Projects to Products", 2019.

45 Arup, "DfMA: Design for Manufacture and Assembly – Guide for Clients and Project Teams. Arup Group Report", 2019.

46 European Commission, European Construction Sector Observatory – Country Profile: Poland, 2021.

47 European Commission, "New European Bauhaus Funding Guide – Just Transition Mechanism and KPO Poland", 2022.

48 Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane [Act of 7 July 1994 – Construction Law], Dz.U. 1994 nr 89 poz. 414, with later amendments.

49 Dz.U. 2002 nr 75 poz. 690.

50 Arup, "DfMA: Design for Manufacture and Assembly – Guide for Clients and Project Teams. Arup Group Report", 2019.

Implementing prefabrication and DfMA approaches requires a shift in traditional construction practices and project workflows, which many stakeholders in the sector may not yet be fully familiar with. The successful adoption of such methods depends on early engagement, industry education, and overcoming ingrained process habits[51], As a result, there is a shortage of trained professionals capable of designing and delivering high-quality prefabricated projects.

To unlock the full potential of prefabrication in Poland, several measures could be considered. A targeted amendment of the Construction Law to explicitly define prefabricated and modular construction could help create a more favourable legal environment[52]. This should be complemented by the development of national technical guidelines that reflect the specific characteristics of industrialised building systems[53]. At the same time, public institutions could play a leading role by launching pilot projects for student housing or social infrastructure, financed through EU grants, and based on model typologies[54]. These initiatives would not only demonstrate feasibility but also help build trust and familiarity among key stakeholders.

In conclusion, while the current Polish legal and regulatory framework does not prohibit the use of prefabrication, it also does not actively facilitate it. The absence of clear definitions, tailored regulations, and dedicated procedures limits the sector's ability to scale. Nonetheless, the alignment of prefabrication with broader environmental, economic, and social policy goals suggests a strong potential for growth—provided that institutional support and regulatory reform accompany market interest and technological capacity.

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51 Gibb A., Pendlebury M., "Design for Manufacture and Assembly (DfMA): A Guide for Construction", CIRIA Report C686, 2006.

52 Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane.

53 Dz.U. 2002 nr 75 poz. 690.

54 European Commission, "New European Bauhaus Funding Guide – Just Transition Mechanism and KPO Poland", 2022.

The regulatory landscape of off-site construction in Italy

Currently, Italy has no legislation dedicated exclusively to prefabrication and off-site construction. This construction method is instead regulated through the general building regulatory framework, at both the national and European levels. Although there is no comprehensive legislative framework dedicated to off-site construction, it is still applied within various technical provisions and general regulations that indirectly govern its use.

In Italy, prefabrication is effectively regulated through the coordinated application of general building, technical, and safety regulations. These regulations cover structural design, building materials, energy efficiency and site safety, thereby integrating off-site construction into the existing regulatory framework:

- Norme Tecniche per le Costruzioni (NTC 2018)
- Eurocodici e Norme UNI EN
- Regolamento UE 305/2011 (CPR) e Marcatura CE
- Codice degli Appalti (D.Lgs. 36/2023)
- Normativa edilizia (D.P.R. 380/2001)
- Requisiti energetici e ambientali

The fundamental technical regulations are ***Norme Tecniche per le Costruzioni***, approved by Ministerial Decree on 17 January 2018. These standards set out the criteria for ensuring the durability, seismic safety, and quality of materials. These standards apply to all buildings, including those constructed using industrialised elements, and stipulate that prefabricated components must be designed and verified in accordance with the same regulations as traditional constructions.

These provisions are complemented by the ***Eurocodici***, the European technical standards that have also been adopted in Italy, which provide detailed design guidance for structures

based on the materials used, such as reinforced concrete, steel or wood.
Prefabrication is also subject to European Regulation No. 305 of 2011 (the Construction Products Regulation), which requires **CE marking** for all construction products. This means that prefabricated components must be accompanied by a **Declaration of Performance** (DoP) and, where required, a **European Technical Assessment** (ETA) to demonstrate compliance with the relevant technical specifications and essential requirements.

From an administrative perspective, prefabrication does not constitute an exception to national building and urban planning regulations. In fact, Presidential Decree 380 of 2001 (***Testo Unico dell'Edilizia***) stipulates that any construction work, even if carried out using prefabricated systems, must comply with urban planning requirements and obtain the necessary building permits. Regarding public works involving prefabrication, the new ***Codice dei Contratti Pubblici*** (Legislative Decree 36 of 2023) applies. This enhances the adoption of modern methods of construction in line with the European standard for innovation in the technological sector. It encourages off-site processes and the use of BIM for an integrated design approach.

Finally, regulations on **energy efficiency and environmental sustainability** also apply to prefabricated buildings, albeit not specifically. In particular, decrees issued in 2015 on the energy performance of buildings impose minimum standards, such as the obligation to equip each building with an **energy performance certificate** (APE) outlining its energy class, and to ensure adequate thermal and acoustic insulation.

In Italy, it could be argued that the regulatory effort to innovate within the construction sector has focused primarily on digitisation rather than the industrialisation of building processes and construction methods. In recent years, however, some steps have been taken in this direction, indicating a growing interest by public administrations in promoting innovation across the entire construction sector.
For example, the use of BIM has become progressively mandatory for public procurement under the provisions of Ministerial Decree No. 560 of 2017 (also known as Decreto BIM). The legislative goal is to gradually digitise the sector, starting with the most complex projects and, by 2025, extending to all new public works regardless of the project size. As of 1 January 2025, BIM use will be mandatory for all new public works, providing for its use throughout the life cycle of the work in

the design, construction, operation and maintenance phases, thereby ensuring greater transparency, traceability and cost optimisation.
It should be noted that this requirement only applies to the public sector. Currently, there is no regulatory constraint for private projects, although BIM adoption is growing in this area as well, due to the efficiency and control it offers over the construction process.
In order for public contracting stations to properly adopt BIM, the decree also requires them to equip themselves with suitable digital tools, train their staff, set up a data-sharing environment and define the key figures involved in the BIM process, such as the BIM manager.

Following the 2019 pandemic and the substantial European funding provided by the National Recovery and Resilience Plan (PNRR), Italy launched a series of policies and tools to promote the energy efficiency upgrades of existing housing, particularly social housing. These interventions are supported by national funds, including the PNRR itself and the Programma Innovativo Nazionale per la Qualità dell'Abitare (PINQuA), as well as tax incentives such as the Ecobonus and Superbonus. This strategy was also supported and complemented by regional and local projects. The main goal is to improve existing housing, particularly public housing, to enhance quality of life and alleviate housing deprivation in disadvantaged urban areas.
Unlike other European countries such as the Netherlands, Germany, the United Kingdom and France, Italy has not yet introduced specific regulatory obligations for the adoption of off-site technologies. Current regulations merely encourage their use without making them binding, thereby missing an important opportunity to steer companies and designers more decisively towards innovative, industrialised construction models.

Off-site: the modular approach in practice

How to design and build off-site: systems and strategies for sustainable prefabrication processes

Modern Methods of Construction

While terms like off-site, industrialized, prefabricated, and modular are often used interchangeably, "Modern Methods of Construction" (MMC) refers to a broader and slightly different concept that originated in the United Kingdom around the year 2000. In fact, according to the Ministry of Housing, Communities & Local Government (MHCLG) Joint Industry Working Group, Modern Methods of Construction (MMC) encompass a range of approaches, including off-site, near-site, and on-site pre-manufacturing, as well as process enhancements and the application of advanced technologies. MMC, is a generic term used to describe a building process which uses prefabrication and factory assembly as a fast way of delivering new buildings, maximising the efficient use of building materials, construction workforce and resources[55].

Within the UK building sector there are seven main categories of modern methods of construction, and the use of this regularised terminology allows the wide range of MMC construction type to be better understood. The definition framework spans all types of premanufacturing, site assembly, material use and innovative processes, illustrating the spectrum of prefabrication levels from low to high[56].

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55 Ministry of Housing, Communities & Local Government, "Modern Methods of Construction: Introducing the MMC Definition Framework", Mar. 2019.

56 Governement of Jersey, "Modern Methods of Construction: Housing Delivery Innovation", Oct. 2022.

MMC categories[57]:

1 - Pre-Manufacturing (3D volumetric structural systems)
This approach relies on a systematic method of volumetric construction, in which three-dimensional units are manufactured in a factory and delivered to the site as complete, ready-to-install modules.
These volumetric units can range in complexity, from basic structural shells to fully finished modules that include internal and external finishes, fixtures, and pre-installed systems.
The system is always engineered to meet structural performance standards. For larger projects, such as apartment buildings, these complete volumetric units can also accommodate non-residential spaces and shared areas, including internal corridors and balconies.

acau architecture sa, Rigot Collective Dwelling Centre, Genève - Swtizerland, 2019.
Photo credits: © Marcel Kultscher © acau architecture SA

57 Ibid.

2 - Pre-Manufacturing (2D primary structure systems)

This is a systemised approach that uses flat panel units for basic floor, wall, and roof structures. These components are manufactured in a factory environment and then assembled on-site to form a three-dimensional structure. The most common method involves the use of open panels or frames, which consist of a skeletal structure only; services, insulation, external cladding, and internal finishes are all added on-site. More advanced options, such as closed panels, involve greater factory-based fabrication and may include lining materials, insulation, and even pre-installed services, windows, doors, internal wall finishes, and external cladding.

Wooden trusses installed to complete the roof structure.

3 - Pre-Manufacturing (non systemised structural components)

The use of pre-manufactured structures made from framed or mass engineered timber, cold-rolled or hot-rolled steel, or precast concrete is the most common form of this construction method. Load-bearing components such as beams, columns, walls, core structures, and slabs are typically not cast in situ but are instead assembled on site. While this approach primarily focuses on superstructure elements, it can also include key substructure components, such as prefabricated ring beams, pile caps, driven piles, and screw piles.

Prefabricated load-bearing wall featuring a wooden structure.

4 - Additive manufacturing (structural & non-structural)

This involves remote, site-based, or final workplace-based 3D printing of building components, using specialized materials along with advanced digital design and manufacturing techniques.

Ricehouse, Torri Risorsa, Milano - Italy, 2023.
Photo credits: © Beatrice Arenella

5 - Pre-manufacturing (non-structural assemblies & subassemblies)

This category includes a range of pre-manufactured elements, such as unitised non-structural wall systems, roof finish cassettes or assemblies, and non-load-bearing mini-volumetric units (commonly known as 'pods'). These pods are typically used for highly serviced and repeatable areas like kitchens, bathrooms, utility cupboards, risers, and plant rooms. The scope can also extend to include integrated components such as wiring looms and mechanical engineering hardware.

6 - Traditional building (Product led site labour reduction/ productivity improvements)

This category includes traditional single-building products manufactured in large formats, pre-cut configurations, or with simplified jointing features, all designed to reduce the amount of on-site labour required for installation.

7 - Traditional building (Site process led labour reduction/ productivity improvements)

This category is intended to capture innovative site-based construction techniques that drive process improvement but are not covered in Categories 1–6. It includes on-site technical advancements such as 3D printing, robotics, and technology-driven plant and machinery.

According to this classification, categories 1–5 represent off-site and near-site pre-manufacturing, while categories 6 and 7 focus on site-based process improvements.

Off-site construction is therefore considered a subcategory of MMC, encompassing only the pre-manufacturing categories 1, 2, 3, and 5, where components are fabricated away from the construction site. More than just a technological process, off-site construction represents a holistic approach to building that integrates design, materials, and methods. It involves the prefabrication of elements away from the final construction site, ranging from simple components and materials to fully assembled modules.

For energy efficiency renovation projects, the most commonly used MMC are non-structural assemblies and sub-assemblies (category 5), typically in the form of integrated wall and roof panels that may include photovoltaic systems, windows, and other technical ducts or equipment. On the other hand, for new construction, categories 1, 2 and 3 are the most widely applied methods. When buildings have specific technical constraints or irregular surfaces, site-based processes (categories 6 and 7) are employed to optimize the work.

Off-site Construction (OSC)

Recently, the use of lightweight and flexible materials, such as wood and steel, has driven significant advances in techniques involving prefabricated and site-assembled components. In Europe, the most commonly used materials in OSC are wood, steel, and concrete, with wood and steel emerging as the most promising solutions.
According to recent research by ENEA[58], 51 major companies were identified as key players in the production of off-site technological solutions at a European level. These solutions include 2D sandwich panels, 2D multilayer panels, and 3D volumetric modules[59]. The study shows that 32 of these companies use steel as their main material where 31 companies produce 2D panels, while only 1 produces 3D modules. The remaining 22 companies use mostly wood, with 20 focusing on producing 2D panels and 3 producing 3D volumetric modules.
The same research shows that the market is currently dominated by steel solutions, although many of these can only be considered partially off-site. In contrast, although less widespread, timber solutions are more advanced in terms of technological development and design for disassembly characteristics. Indeed, the majority of companies in the wood industry are responsible for product installation, whereas only 23% of steel companies offer this service. 2D systems are prevalent in both categories and are mainly used for new buildings rather than the upgrading of existing ones.

OSC in both timber or steel represents a transformative approach to how buildings are conceived, developed, and delivered. It is not merely a change of materials or methods but a complete redefinition of the architectural process — shifting the logic from traditional site-based thinking to an industrial, manufacturing-oriented mindset.
Off-site construction takes into account the whole building lifecycle and different stakeholders' categories: owners, tenants, workers and society. This reorientation requires architects and engineers to think like product designers, integrating spatial, structural, and technical systems from the earliest stages, not sequentially but simultaneously. Every decision — about layout, material, technical infrastructure, and aesthetics — must anticipate the constraints and opportunities of factory

58 Italian National Agency for New Technologies, Energy and Sustainable Economic Development.

59 ENEA, "Costruire il Futuro. Off-site e Riqualificazione edilia in Italia", Dec. 2024.

production and the precision it demands.
Modular projects may be composed of a combination of volumetric and non-volumetric components, and projects may utilize a combination of off-site and on-site construction, depending on the specific requirements of the design, program, and/or site.
The process begins with establishing a modular grid, typically defined by standardized transport dimensions — modules of around 3.5 meters in width and up to 18.5 meters in length. These units are fully prefabricated, with interior finishes and MEP (mechanical, electrical, and plumbing) systems pre-installed, reducing the need for wet trades and noisy construction activity on-site. Modules are manufactured under controlled conditions with millimeter-level precision using CNC machines and laser-guided scanning, ensuring a consistency unachievable on conventional building sites. Before full production begins, 1:1 scale mock-ups are fabricated to verify design intent, buildability, and the performance of interfaces between systems — both within the module and in its connections on-site.

Because of the industrial nature of off-site construction, the project must reach a full design freeze before manufacturing begins. Any changes beyond this point create delays and costs that ripple across the tightly scheduled logistics chain. This requires early and intensive collaboration between all stakeholders — architects, structural engineers, MEP coordinators, sustainability consultants, factory planners, and logistics managers. The entire team works in a unified digital environment, typically a BIM model that serves as both a coordination tool and a source of production data.

Timber and steel each offer distinct advantages in this context. Timber modules, often built from cross-laminated timber (CLT) or light-frame elements, provide a warm, sustainable, and carbon-storing solution that is well-suited for housing, education, and small-scale offices. Steel modules, by contrast, allow for greater spans, higher stacking, and more flexible internal layouts — often preferred for hotels, student housing, or complex mixed-use buildings. Both systems rely on repetition and standardization to achieve efficiency, but this does not imply monotony. On the contrary, when designed well, modular architecture can offer high-quality, expressive buildings that reflect their context and purpose.

Installation on-site is rapid and largely dry. Modules arrive just-in-time, lifted by crane into place, often within days rather than months. Weather delays are minimal, and disruption to neighbors is dramatically reduced. Construction becomes assembly. The entire process — from first sketch to final delivery — can be shortened by up to 40% compared to traditional building methods.

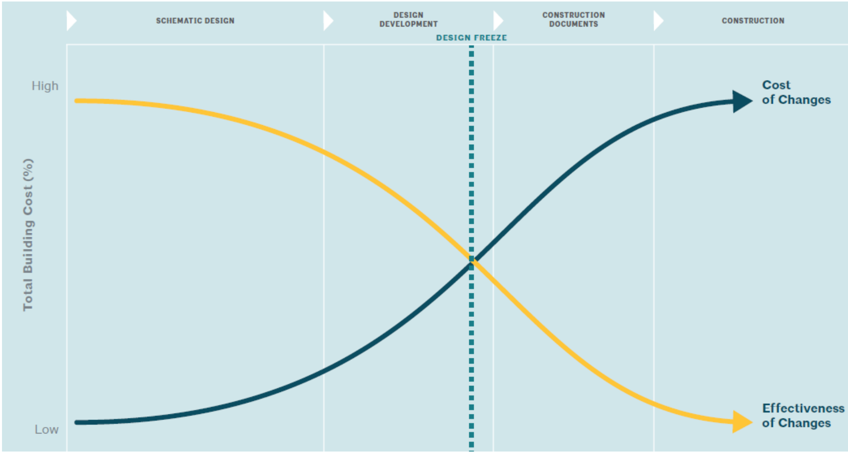

Image: Wilson J., Costs vs effectiveness of design changes, p.28.[60]

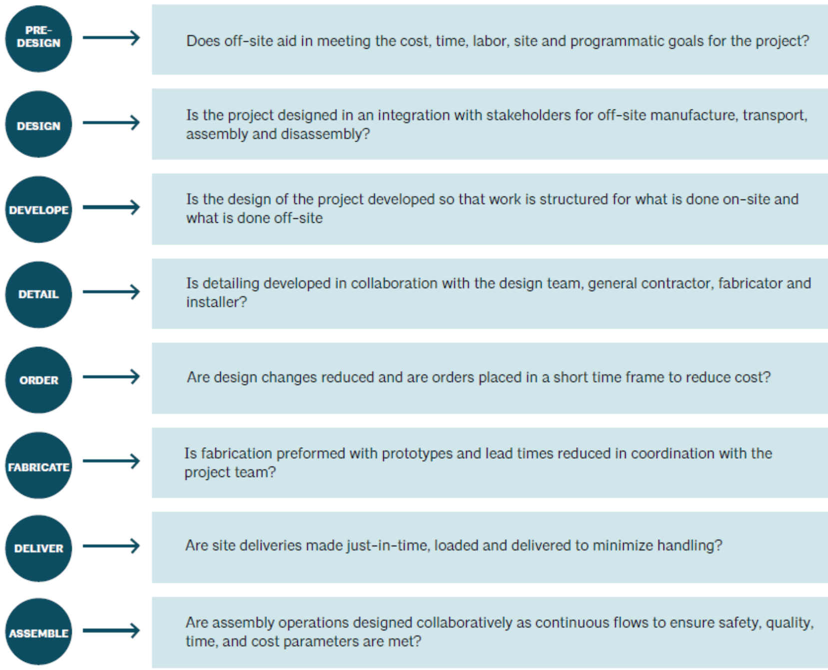

Image: Wilson J., Key questions to consider during the design process, p.31.[61]

60 Wilson J. - BuildingGreen, Inc., Design for modular construction: an introduction for Architects, 2019.

61 Wilson J. - BuildingGreen, Inc., Design for modular construction: an introduction for Architects, 2019.

TOP TIPS

for designing and building an effective off-site project

Modular thinking is implemented from the concept phase, with standard module sizes, grid spacing, and vertical coordination defined early;

Photo credits: MOD21

Shape repetition is essential because repeatable layouts can be efficiently stacked into grids, simplifying both structure and production;

Designs are developed for **disassembly and repeatability,** focusing on standardization while allowing limited customization (mass-customization);

Early design freeze is essential to ensure smooth stakeholder coordination and prevent costly disruptions caused by late changes;

Understand **wall and floor thicknesses** carefully, every millimeter counts, so never underestimate build-ups;

Structural coordination between modules is vital, every junction must align, as exceptions cause delays;

Rectangular modules are ideal, as irregular shapes complicate framing and raise costs;

Photo credits: MOD21

A layered approach is applied, with modules composed of load-bearing cores, infill elements, and finish layers coordinated simultaneously;

Details are compatible with prefabrication, avoiding complex on-site joints in favor of dry connections and prefabricated interfaces;

Standardization boosts efficiency by **sharing details** between components and modules, accelerating manufacturing and minimizing risk;

Early MEP integration in the digital model is essential: service routes must be locked in during early design stages;

Photo credits: MOD21

Respect transport and crane limits by sizing your modules or components appropriately;

Digital software, such as BIM, are used to coordinate the project throughout all phases;

Diverse stakeholders — including architects, engineers, factory planners, structural engineers, MEP specialists, and fire protection experts — are involved early in the design process.

How to ensure good aesthetic quality in off-site construction?

One of the main challenges limiting the full deployment of off-site architecture in the contemporary design landscape is achieving an attractive, quality aesthetic. Many designers are sceptical because they believe that the need for speed in design and construction, combined with the requirement for regularity and standardisation of components, hinders creative freedom and compromises the aesthetic outcome.

However, this preconception appears to stem from a limited contemporary perspective, given that the history of architecture provides numerous examples of significant experimentation by renowned architects of the past. These architects were able to interpret prefabrication and industrialisation not as limitations, but as opportunities for innovation, creating architecture that was rich in cultural, social and aesthetic value[62]. Therefore, we believe it is wrong to consider off-site architecture as synonymous with monotony. Although it implies repetition and standardisation by its very nature, this by no means excludes the possibility of creating buildings that are expressive, have identity and are contextualised. When well designed, modular architecture can produce works of significant visual and qualitative impact that can engage with the context and respond effectively to contemporary needs.

To achieve this, the designer can make use of dear basic architectural principles through intelligent use of rhythm, proportion and detail. The visible grid of modules can then become an architectural element, offering structure and cadence. Façades can be articulated through variations in depth, texture, material and colour without interrupting the logic of factory production. Materiality can also play a decisive role in prefabricated architecture. Natural materials such as wood, mineral coatings and textiles help to make buildings more welcoming, while precise detailing ensures clean joints,

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62 Fondazione per l'Architettura / Torino, Laboratory for Urban Reserach & Education, "Handbook of Good Practices in Off-site Construction for Social Housing", 2025.

weather resistance and durability. Factory production also allows for quality control of interiors, resulting in straight walls, clean finishes and efficient, integrated technical systems.

Off-site construction is not just a stylistic trend; it represents a strategic change. The optimisation of construction processes, a hallmark of off-site architecture, provides a means of addressing the urgent challenges facing contemporary architecture, such as housing shortages, climate change, labour constraints, and the demand for speed, without compromising on the quality of space or materials. Embracing modular logic as a source of creativity rather than limitation enables architects to develop a new building language that is efficient and expressive, rational and rich, and standardised yet unique.

TOP TIPS

for ensuring appealing architectural features in off-site construction projects

Modularity doesn't limit creativity: strong, expressive design can emerge through thoughtful repetition;

Variation within repetition is achieved through diverse window types, recesses, and changes in material orientation within the modular grid; (abbinare foto 3)

dquadro architecture & Engeeneering - Italy, 2024.
Photo credits: © Jana Sebestova

Introduce smart variation — even subtle changes can add rhythm, depth, and richness to the design;

Use depth and shadow: recesses and projections help avoid flat, monotonous façades;

The modular core can serve as a **foundation for external architectural expression**, supporting façades, balconies, shading devices, and sculptural elements that reflect both creative and traditional design values;

Select cladding materials carefully: texture and layering can either highlight or soften the modular rhythm;

Straddle3, Eulia Arkitektura, Yaiza Terré Estudi d'Arquitectura, APROP - Ciutat Vella, Barcelona - Spain, 2019.
Photo credits: © Adrià Goula

Address façade design and massing from the outset: avoid treating aesthetics as an afterthought;

Durable, **high-quality façade materials** such as fiber cement panels or timber rainscreens are chosen to ensure longevity and consistent visual appeal;

Natural materials like timber are paired with **precise detailing**, including vertically oriented cladding with concealed fixings,

Material samples and **full-scale mock-ups** are reviewed with clients to confirm the intended appearance and craftsmanship;

Aesthetic decisions are coordinated **with structural and technical constraints** to maintain both visual harmony and buildability.

acau architecture sa, Rigot Collective Dwelling Centre, Genève - Swtizerland, 2019.
Photo credits: © Marcel Kultscher © acau architecture SA

Technical innovation and digital progress in off-site construction

The success of offsite construction methods depend immensely on adopting digital technologies, however a study conducted in 2020 found that only 12.8% of the overall research published around offsite construction involves digital technologies[63].
One of the most impactful concepts enabling effective implementation of MMC is Design for Manufacture and Assembly (DfMA). DfMA, involves designing buildings in a way that simplifies both the factory production of components and their efficient assembly on site. By optimizing the design, components can be manufactured and assembled more quickly, safely, and cost-effectively.
Traditionally, DfMA has been used in sectors such as the automotive industry and for consumer products, both of which need to produce high quality products in large numbers. More recently, construction contractors have begun to adopt DfMA for the off-site prefabrication and on-site construction of components such as concrete floor slabs, structural columns, beams, and so on[64].

The DfMA approach provides a range of economic, sustainable, and social benefits, making it a key driver in the advancement of modern construction practices:

- Most of the work is carried out in a controlled factory environment, ensuring **safer working conditions** and **enhanced quality control** compared to traditional on-site construction;
- The limited on-site activities are **faster, cleaner, and less labor-intensive**, contributing to improved efficiency and reduced disruption on construction sites;

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63 Oconnell S., Arsalan, H., Hampton P., "Impact of emerging digital technologies on offsite construction: insights from literature", Conf. proceed. May 2023.

64 DfMA Overlay to the RIBA Plan of Work, "Mainstreaming Design for Manufacture and Assembly in Construction", 2nd Edition, 2021.

- Thanks to the high level of precision in prefabrication, **material waste is significantly reduced**, and **overall performance is enhanced**, as it is less reliant on variable manual work carried out on-site;
- **DfMA components** are designed for easier disassembly at the end of their lifecycle, allowing them to be **reused or recycled** more efficiently, supporting circular economy principles.

The DfMA approach employs a range of tools to optimize the efficiency of both manufacturing and assembly processes, including:

- MTM (Methods-Time Measurement);
- Cost analysis software;
- Cost-oriented design guidelines;
- Industrial cost analysis tools;
- Standardization of components.

Underpinning this new approach to architectural design is a rapidly evolving suite of digital tools used in the DfMA process, such as:

- **Building Information Modeling** (BIM) is the design tool for process digitalization that allows one model for a full coordination and a precise alignment of architectural, structural, and MEP systems across multiple disciplines and project stages. BIM environments host not only the geometry but also data on material quantities, thermal performance, cost, and lifecycle impact. In fact BIM softwares integrate design, manufacturing, and assembly activities, improving efficiency and reducing costs in construction projects and errors in quantity estimation;

- **Digital twins** enable real-time simulation for each module before construction begins, while capturing production status, delivery data, and lifecycle information. Digital twins are essential for monitoring and maintenance, as they mirror the physical asset in real time and reflect the building's daily operating conditions;

- **AI configurators** are highly valuable throughout both the design and production phases. During the design stage, AI facilitates automatic layout creation, space planning, automates detailing and clash detection, allowing designers to quickly generate multiple design variants and visualize different options with ease. In the production phase, AI supports quality tracking, predictive maintenance, and process optimization. Additionally, AI tools help optimize scheduling and logistics, leading to more efficient production planning and timely delivery;

- **Parametric design tools** allow architects to explore complex geometries within simpler modular rules. Parametric tools are employed to reach dynamic adaptation of layouts and modules to site or client-specific requirements. Parametric modeling and modular design platforms allow for the creation of multiple similar modules based on a single "master" module, significantly reducing design time and minimizing errors. Automated nesting and cutting softwares optimize the use of materials, such as sheathing boards, improving efficiency and reducing waste;

- **Robots** are increasingly integrated into factory workflows to enhance precision, speed, and safety. In controlled environments, they automate repetitive tasks such as cutting, welding, assembly, and material handling with high accuracy and consistency. This automation reduces human error, accelerates production, lowers labor costs, and improves worker safety by taking over hazardous operations. The use of robotics enables scalable, efficient, and high-quality modular construction. Common examples include robotic arms and manipulators, CNC machines, 3D printers, and Automated Guided Vehicles (AGVs);

- **Drones** are used for site surveying, progress and production monitoring, inventory management, and quality inspections.

Benefits and challenges

Benefits

Off-site construction offers significant advantages over traditional methods, both for new buildings and for retrofit interventions for architectural and energy upgrades.
For a comprehensive overview, the following outlines both the direct benefits — those that occur in the short term, from the design phase to on-site construction work — and the indirect benefits, which unfold over the entire life cycle of the building and involve various stakeholders: property owners, tenants, workers, and society as a whole.
The benefits of off-site construction, therefore, emerge at various stages of the project and impact multiple areas, including design, manufacturing, transport, and construction[65].

Learning
Off-site is not just a construction method, but also a valuable educational opportunity for the new generation of architects and designers. OFC represents a transformative approach to how buildings are conceived, developed, and delivered, offering a complete redefinition of the architectural process. It shifts the logic from a traditionally site-based mindset to an industrial, production-oriented perspective.
In addition, it enables the experimentation with various technologies and the integration of digital skills into the process, supporting continuous professional development and knowledge updates;

High project quality
The integration of highly efficient installations and innovative solutions in new buildings and off-site renovations optimises energy efficiency, seismic safety and air quality contributing to a better indoor comfort. Furthermore, producing components in a factory ensures greater quality and precision in both the products used and the construction details ensuring long-term performance;

High project performance
OFC construction easily integrates highly efficient installations, components, and materials that lower buildings' energy consumption and reduce operational energy needs, contributing to lower bills. The resulting reduction in energy usage provides a tangible benefit to residents by directly lowering their monthly utility bills;

Cost-effectivess
Offsite construction is not necessarily cheaper than traditional methods, but it is more cost-effective. By manufacturing components in a controlled factory

65 European Commission, "Research Note on Offsite Construction", Dec. 2024.

environment, it streamlines processes, optimizes material use, and minimizes disruptions—resulting in significant savings in time, labor costs, material waste, and overall project timelines;

Durability
The prefabrication process results in more robust and reliable components, thereby extending the operational lifespan of buildings;

Work-site
Prefabrication brings several advantages that make construction easier for everyone involved. With less activity happening onsite, there's a noticeable reduction in noise and disruption, which means residents can enjoy more peace and quiet. Because the construction timeline is shorter, tenants don't have to worry about relocating, saving both time and money. Using prefabricated components also cuts down on the need for temporary structures like scaffolding and onsite facilities, simplifying the whole process;

Transportation
Thanks to its centralised production, the prefabrication process enables better planning and organisation of component transportation, reducing the number of trips to the site. In addition, fewer transport trips to work-sites decrease traffic congestion and CO2 emissions;

Schedule
OFC prefabrication ensures, in almost all cases, adherence to budget and contractual deadlines. Thanks to a high level of planning and industrialization, the combination of offsite manufacturing and onsite preparation offers greater certainty in the construction schedule and significantly reduces the risk of delays;

Safety
Thanks to its highly controlled production environment, which minimizes on-site operations, OFC construction offers safer working conditions compared to traditional methods. Factory-based processes reduce hazards on site, enhance worker safety, and make construction less physically demanding;

Sustainalbility
Off-site construction is an excellent way to adapt resiliently to the rapid changes in our society, providing multiple benefits for environmental sustainability.
By focusing on dry assembly techniques, it significantly reduces resource consumption and waste, making it especially well-suited for the use of natural and bio-based materials. The controlled production process minimizes material waste and facilitates the easy reuse or reallocation of components across different projects and timelines. In addition, optimized logistics and the adoption of energy-efficient products help lower emissions, further decreasing environmental impact. These advances not only promote a greener construction approach but also offer financial benefits, such as reduced carbon taxes through certifiable energy efficiency and lower emissions.

Challenges

Off-site construction for industrialised renovation offers several benefits and advantages, but still faces several key challenges that hinder its widespread adoption within the construction market and public administration vision and policies.
It is urgent today to unlock this feature in order to enable the wider adoption of these technologies and apply the knowledge on a large scale, especially for the energy retrofitting of social housing stock available.

These challenges have different origins and refer to several categories, such as financial, technical, demand-related, and legislative aspects[66].

Upfront costs
Although the total construction process might be more cost-effective, the upfront spending required for OFC production facilities and logistics (such as prefabrication, materials, technology, and transportation) can be quite large. This considerable initial outlay often acts as a major barrier for both private and public clients or investors;

Risk regarding financial gains
Since offsite renovation is a relatively recent approach, it is associated with uncertainty regarding the return on investment, which may discourage again investors and property owners;

New financial model
New financial models are needed to support the application of OSC and sustainable retrofitting, such as green loans or performance-based payment systems, which could guarantee high-quality results for retrofitting projects rather than for new builds only.;

Increased effort during early-stage planning
The OFC method requires the application of a new perspective in the workflow and implies structural changes in task subdivision and design, resulting in lower design flexibility;

Digitalization processes
To be effective, OFC demands financial resources and specialized skills in digital tools and software, requiring considerable investment;

Supply chains fragmentation
The lack of standardized procedures and real coordination between stakeholders hinders the ability to scale up OFC projects;

66 European Commission, "Research Note on Offsite Construction", Dec. 2024.

Skills gap
OFC requires advanced renovation techniques and specialized training in sustainable processes and digital tools, skills that are currently not fully aligned with the availability of professionals in the construction sector;

Cultural resistance
Many architects, investors, and tenants remain hesitant to adopt modular and prefabricated solutions due to perceived risks related to quality, architectural limitations, lack of adaptability and costs investment;

Weak policy framework
OSC struggles to compete in today's market because procurement rules still favor traditional construction. On top of that, there's a lack of incentives, subsidies, and supportive legislation to help new approaches become widespread. Building codes are also often geographically fragmented and don't align with the real specific needs of OSC.

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