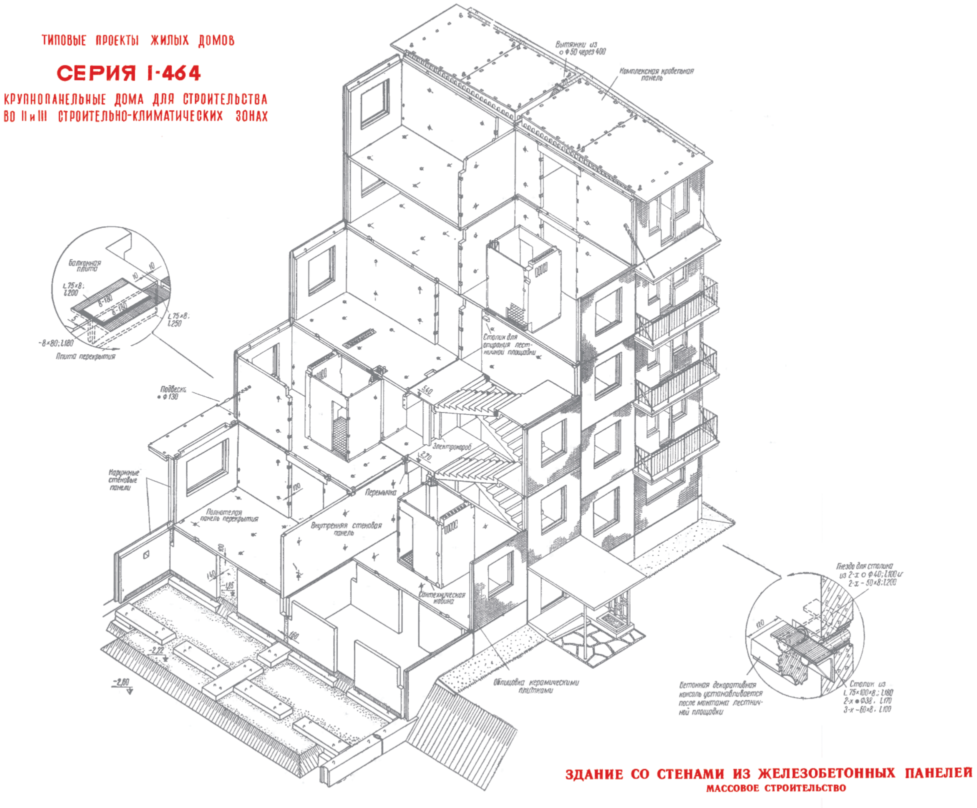
EDILIZIA

ANGELO BERTOLAZZI, GIORGIO CROATTO,
UMBERTO TURRINI

REFURBISHMENT OF PREFABRICATED BUILDINGS BY INNOVATIVE STRATEGIES

The case of Soviet I-464 and I-464A series



FRANCOANGELI

FrancoAngeli
Edizioni La passione per le conoscenze

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Cover image: I-464 series, axonometric view from original Russian technical document (1958).

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Refurbishing Versus Demolishing

by *Giorgio Croatto*

Refurbishing the built environment has become more and more relevant, as the result of the guidelines laid down by the European Economic Community underlying European projects. Moreover, for many years international studies have underlined the positive benefits involving construction as a whole thanks to a transdisciplinary approach and to the opportunity of developing and integrating the new technologies with the existing buildings, so as to cut the environmental impact of buildings[1]. Such priority has suggested the European Union to resort to guidelines involving the whole sector of construction, planning as end-result zero-consumption buildings, but above all focusing on the amount of upgrading of existing buildings, on cutting soil consumption and recycling waste materials resulting from constructing and demolishing.

The built heritage of residential housing has been rapidly downgraded owing to a merely quantitative demand for houses, to market economic laws and the resort to innovative technological though not subjected to the test-of-time solutions; as a result such houses no longer comply with the new standards required in order to cut energy consumption. As a result, prefabrication has played a relevant role as the main means through which both

1 Latham D., *Creative Re-Use of Buildings*, Donhead Publishing Ltd, Shaftesbury, 2000, 26-31; Pearce A.R., *Rehabilitation as a strategy to increase the sustainability of the built environment*, 2004, [http://maven.gtri.gatech.edu/sfi/resources/pdf. (Access on 19/12/2022)]; Myers D., Wyatt P., "Rethinking urban capacity: Identifying and appraising vacant buildings", «Building Research and Information» 32 (2004), 285-292; Rovers R., *Existing buildings: A hidden resource ready for mining*, 2004, [http://www.sustainbalebuilding.info.(Access on 21/06/2022)]; Power A., *Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?*, «Energy Policy» 36 (2008), 4487-4501; Saleh T., Chin A., "Building green via design for deconstruction and adaptive reuse", in «Proceedings of CIB W115 Lifecycle Design of Buildings, Systems and Materials, Enschede», The Netherlands, 12-15 June, 29-34 2009, 161-172.

eastern and western bloc European countries have been trying to meet the growing demand for housing after World War II. In socialist countries resorting to prefabrication in residential buildings was even strictly connected to setting up a communist society[2].

As regards prefabricated residential buildings, on the one hand issues related to energy-saving environment-friendly-and-social-related issues are greater, on the other they afford sizable economic advantages thanks to the reuse of the existing buildings. Such refurbishment process is however hindered by the huge amount of prefabricated residential housing itself as well as by the limited assessment of its material and construction-related features. This results in making it difficult to address upgrading economically and efficiently and to lay down criteria and guidelines underlying the choice of the materials and technologies to resort to, as well as recycling and disposing of waste materials.

This work, resulting from a research developed within the Padua University Civil, Architectural and Environmental Engineering Department[3], aims to suggest a methodology leading to an analysis of prefabricated buildings, focusing especially on Soviet ones (widely popular in former socialist countries) with a view to their refurbishing/upgrading so as to retrieve them as far as architecture, functions and environment are concerned or otherwise to demolish them.

To enact a sustainable refurbishment of the buildings, the research has aimed to establish a logical and methodological connection between the data collected (technical data and archive results) and their analysis, so as both to assess the technological boundaries of prefabricated buildings in socialist

2 The concern of the research focusing on retrieving soviet-patterned prefabricated residential housing was suggested by the admission or the sympathies towards the European Union of several ex-soviet-bloc countries (Eastern Germany, Poland, Czech Republic, Slovakia, Estonia, Latvia, Lithuania, Romania, Bulgaria and Albania). In these countries – owing to obvious political commitments - the development of residential housing has diligently followed the tracks laid down by real socialism; this has resulted in a building stock made up of 95% prefabricated buildings, according to the data provided by the Building Performance Institute Europe (BPIE).

3 The research has been developed through the projects “Prefabricated Building Refurbishment. Individuazione di criteri e linee guida per il recupero funzionale e l’adeguamento strutturale dell’edilizia residenziale prefabbricata multipiano degli anni ’60 e ’70” (P.I. prof. U. Turrini, and A. Bertolazzi, 2017-2018) and “Architettura residenziale edificata nel periodo del socialismo albanese. Linee guida per il recupero funzionale ed energetico” (P.I. prof. G. Croatto, and U. Turrini, A. Bertolazzi, 2018-2019), which in the first case has focused on finding the technological and cultural features of prefabricated residential housing, in the second on the analysis of a specific study case, i.e. the 70s and 80s residential housing in Albania. Both were targeted on tracing criteria and guidelines regarding prefabricated residential housing refurbishment.

Fig. 1 – *Demolition. Moscow district in 2012: in the former Soviet Union and other countries the main strategy is destroy the old prefabricated buildings to leave free space for new residential neighborhood.*

Fig. 2 – *Refurbishment. Halle district in 2015: in many European countries the strategy is quite different since the upgrading of existing buildings is preferable than the demolition.*

countries and to analyse their structures with a view to digitizing them in a digital model. Then, focusing on facade panels, the research has laid down a first set of intervention criteria as regards improving energy performances in prefabricated buildings. The first chapter traces the state of art in Europe of the research and of the main projects aimed to refurbish 1950-2000 buildings, underlining a few shortcomings concerning both methodological and operational features. In parallel, both the quantitative and technological and production-related features of prefabrication have been surveyed, underlining how far it differs from reinforced-concrete-framework building; this requires a different approach when tackling prefabricated residential building refurbishment.

Then in the second chapter, the research focuses on the I-464 and its main derivatives (I-464A and I-44D) prefabricated items; planned in the Soviet Union in the late 50s, they were employed as late as the end of the 80s. Such choice has been prompted by quantitative considerations, since this series enjoyed widespread success both in the USSR and in COMECON European countries. The research has underlined both the geometrical, material and construction-related features and the layout-related and functional ones of the buildings planned according to each construction series.

The aim has been to organize the data collected with a view to digitizing the refurbishment interventions and to provide a methodological approach to data mining that would prove essential in the following data managing step in the buildings upgrading. The analysis of the models and construction techniques developed in the Soviet Union is the essential prerequisite when studying and assessing residential housing in socialist countries leading to its refurbishing. The series planned n the Moscow and Leningrad research centres make up the material and ideological foundation, the reference model exported in eastern Europe[4] and various satellite countries (i.e. Cuba, China).

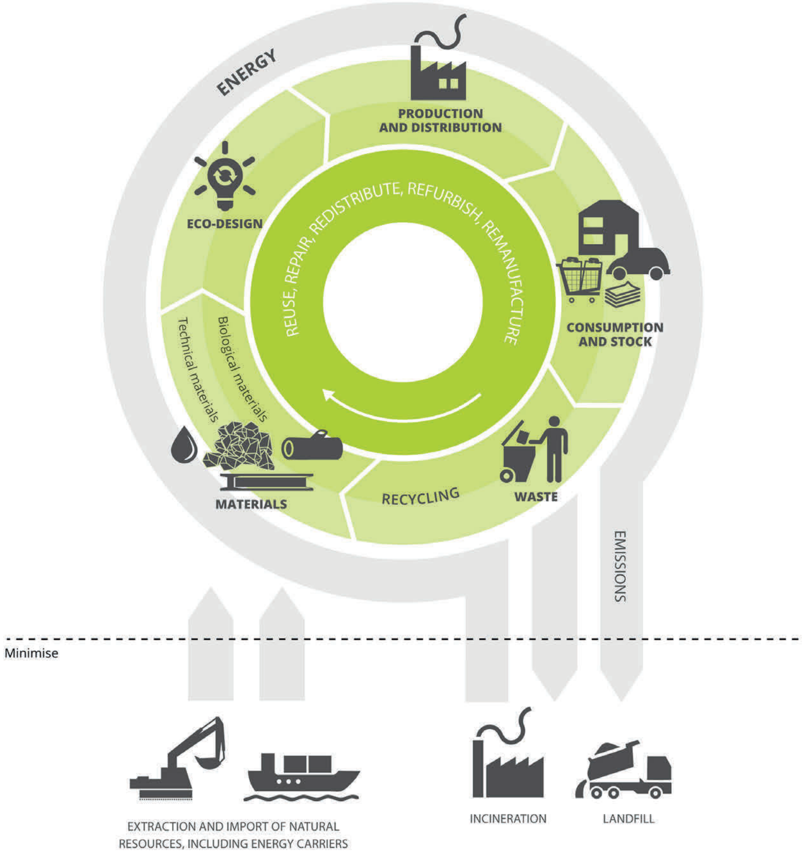
The third chapter analyses the thermal-hygrometric properties of the I-464 envelope, taking the Vilnius (Lithuania) climatic parameters as reference: they were regarded as meaningful both as regards the "cold" climatic conditions of central and northern Europe and thanks to there being several residential blocks built since the early 1960s according to Soviet materials and techniques in the Baltic republics[5]. With reference to the analysis in

4 The choice has been made owing to the direct employment in the former soviet bloc European countries (Czechoslovakia, Eastern Germany, Poland, Hungary and Bulgaria) and to the Russian model (from a technological, ideological and productive point of view) underlying national solutions.

5 Gentile M., "The Rise and Demise of the Soviet-Made Housing Shortage in the Baltic Countries", in Baldwin Hess D., Tammaru T. (eds.), *Housing Estates in the Baltic Countries, The Legacy of Central Planning in Estonia, Latvia and Lithuania*, Springer, Berlin, 2019, 51-70.

the second chapter, the data have been classified and organized in order to perform energy-focused analyses both on the as built building and testing various refurbishing outer shell scenarios. The object has been both to assess the original features of the panel (namely three construction solutions: the single-layer concrete panel, the three-layer one, the panel featuring insulation achieved by means of lightened concrete and mineral wool). The results were then matched with the features analysis of the various interventions, so as to identify the best-performing ones that would provide a useful benchmark for energy modelling in prefabricated buildings (accounting for the data derived from the lack of material and performance-related maintenance, global behaviour of the residential building).

At a more general level, the present research work is the first step towards defining criteria and guidelines for the refurbishment of two-dimensional-element prefabricated residential buildings. Such criteria are to combine together the technical as well as the economic and social requirements of refurbishing by means of a transdisciplinary process that must take quantitative as well as qualitative analyses into account, in order to achieve an environmental, social and economic sustainability.



11.5 tonnes of materials per person were extracted in the EU in 2014 (direct material consumption).

3.0 tonnes of materials per person were imported to the EU in 2014 (direct flows).

0.3 tonnes of waste per person were incinerated in the EU in 2012.

2.2 tonnes of waste per person were sent to landfill in the EU in 2012.

Data: Eurostat, 2015, 'Material flow accounts' and 'Treatment of waste', ec.europa.eu/eurostat.

European Commission

1. Refurbishment and Prefabrication: Models and Tools

by *Angelo Bertolazzi*

Western countries identified Circular Economy as the new paradigm of technological development; this leads to focus on the upgrading, refurbishment and reuse of buildings and to look for new cultural and technical coordinates[1]. Formerly, sustainable development meant resorting to various processes involving society, the environment and the economy with a greater awareness of the need to preserve natural resources; such processes, however, aimed at a linear progress, based on the production-consumption-waste disposal pattern, whereby unavoidably each product gets to the end of its life-cycle. In the last few years, instead, linear economy has started being regarded as unsustainable, since it was based on the (albeit virtuous) exploitation of resources. The only viable option was deemed transforming the waste produced by linear economy into new resources that could be newly exploited and marketed[2]. That is why in the past years whole production chains relying on this circular approach have been developed: each

1 Circular economy can be defined as an economic system devised so that it can self-regenerate, according to the definition of the Ellen MacArthur Foundation. "In a circular economy two types of materials flow: biological materials that can be fed back into the biosphere and technical materials that can be reused without impacting on the biosphere". The definition refers both to an approach to production and consumption of goods posing an alternative to the linear model (for example by resorting to renewable energy sources rather than fossil fuels) and to the role of diversity as the unavoidable feature of resilient production systems. In circular economy the role of money and of finance is challenged: some of its pioneers have suggested the instruments for measuring economic performances should be modified so as to take into account more aspects than those determining the gross national product. Ellen MacArtur Foundation, *Towards the circular economy*, Ellen MacArthur Foundation, Chicago, 2013, 22-25.

2 Almost 15 tonnes of materials are used per person in the European Union each year, while each EU citizen generates an average of over 4.5 tonnes of waste per year, almost half of which is disposed of in landfills. Allwood J.M., *Squaring the Circular Economy: The Role of Recycling within a Hierarchy of Material Management Strategies*, Elsevier, Amsterdam, 2014, 445-477.

single element is projected so as to last longer than its life cycle[3]. However, this approach is hampered by being mainly (though not entirely) focused on consumption goods and on virtuous production chains; what has already been produced has been disregarded and the problem of disposing of waste materials and their marketable reuse not tackled.

The construction field has not been properly assessed, though it has been found to be an important asset for European economy on which to focus in order to make economic growth sizable and long-lasting. The circular approach has been adopted for new buildings and for separate building components (plants, doors and windows), whereas existing buildings as a whole have been disregarded. They, in fact, are the main producers of greenhouse gases, consume large amounts of raw materials resulting in heaps of waste, though their environmental, social and architectural retrieval has been assessed as potentially being the main factor in the economic recovery of European countries. Since existing buildings are so many – residential buildings even more so, as it will be assessed further on – it is essential to resort to the circular model, applying it to the buildings refurbishment, bypassing the traditional categories of specialized intervention and resorting to a holistic approach, able to provide innovative project-related and technical solutions.

As already hinted at in the introduction, prefabricated residential buildings are a sizable slice of the built heritage as a whole, though – owing to their construction and production-related features – they require an approach different from traditional XX-century building techniques, which featured reinforced-concrete framework and brick-infill buildings. The following paragraphs will analyse critically the intervention strategies enacted by the European Union, according to the 2050 community goals and of the quantitative data of European prefabricated construction. In parallel, the focus has been on the technological horizon of prefabricated construction, the basis of any urban, social and construction-related urban refurbishment, underlining its innovative features when compared with traditional XX-century construction, which require a different methodological approach to the project of refurbishment.

3 In particular the sectors of cars, ships and clothing have resorted to this kind of economic development, finding a committed support in the European Union, both thanks to a series of norms that make it easier to shift from a linear to a circular model, and to the support given to research projects focusing on circular economy.

1.1 Refurbishing Existing Buildings in the European Union

For several years international studies have been proving the viability of refurbishing in comparison with demolishing, as far as it affords more job opportunities thanks to its transdisciplinary approach and to its capability to develop and integrate the new technologies within the existing buildings and therefore to reduce the amount of waste material produced by demolition, which in its turn results in a less marked environmental impact[4]. Refurbishing existing buildings has therefore become more and more relevant, above all as far as European research projects are concerned. Such priority has suggested the European Union to resort to special plans (Energy Efficient Europe Roadmap – 2011) that involve construction as a whole, focusing on zero-consumption buildings and above all on increasing the refurbishment rate of existing buildings, reducing soil consumption and recycling construction and demolition waste[5]. The activities undertaken according to the 7PQ had allowed important results as far as norms are concerned to be reached, which set rules regarding energy upgrading or substitution of the external cladding. Apart from rules, now also a wide gamut of new cladding options is available (*Bardage isolant pour murs extérieurs*, ventilated wall cladding), which have already been resorted to in European countries, as witnessed by the "Technical Guide" for the release of ETA to ETICS (External Thermal Insulation Composite Systems) or the "Guidelines for European Technical Approval of External Thermal Insulation Composite". Beside the above, even thanks to structural funds, pilot projects have been financed; they aimed to refurbish existing residential buildings (e.g. SOLANOVA and INNOVA) or tourist facilities (XENIOS) and to share good practices.

4 Latham D., *Creative Re-Use of Buildings*, Donhead Publishing Ltd, Shaftesbury, 2000; Myers D., Wyatt P., *Rethinking urban capacity: Identifying and appraising vacant buildings*, «Building Research and Information», 32 (2004), 285-292; Power A., *Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?*, «Energy Policy» 36 (2008), 4487-4501; Highfield D., Gorse G., *Refurbishment and Upgrading of Buildings*, Taylor & Francis, New York, 2009, 23-24.

5 Though such objectives had been thought to apply to new buildings, they prove suitable also for the new plans devised by the UE aiming to refurbish/upgrade even existing buildings (in particular the underlined ones), even in keeping with the recent paradigm of circular economy. As regards the above-mentioned case, circularity proves to be even wider: on the one hand, the environmental impact can be reduced by allowing the building to last longer (refurbishing), on the other, it can be turned into recyclable waste building material (demolition) (Roadmap, 2011). The interventions enacted thanks to Roadmap concern the whole field of construction, both as regards building zero-consumption buildings, but above all raising the upgrading rate of existing buildings, reducing soil consumption and recycling construction and demolition waste. *Roadmap to a Resource Efficient Europe*, [http://eur-lex.europa.eulegal-content/IT/TXT/?uri=CELEX:52011DC057. (Access on 19/06/2023)].

Tab. 1 – *Goals up to 2050 regarding construction laid down by the Road Map for Efficient Europe (2011).*

RESOURCE/ SECTOR	BUILDINGS
Fossil fuels	• Reduce fossil fuels use via better energy efficiency and renewable energy use in buildings • ***Build zero energy buildings and increase the renovation rate of existing buildings***
Materials and minerals	• Optimise material use • ***Use sustainable materials***
Water	• Improve water efficiency of buildings and appliances
Air	• ***Reduce GHG emissions from buildings*** • Improve indoor air quality
Land	• ***Avoid additional land take (e.g. for urban sprawl)*** • Remediate contaminated sites
Soils	• ***Avoid urban sprawl on fertile soil*** • Minimize soil sealing
Ecosystems: Biodiversity	• Ensure sufficient and connected green spaces as part of green infrastructures
Marine resources	• Reduce acidification resulting from GHG emissions
Waste	• ***Recycle construction and demolition waste (70% till 2020)***
EU Policy Initiatives	• Strategy for the sustainable competitiveness of the EU construction sector (2011) • Communication on sustainable buildings (2013) • Initiative on water efficiency in buildings (2012)

Relying on the results of 7PQ, the now-ended Horizon 2020 planning has instead focused its efforts on the nZEB processes and instruments concerning existing residential buildings (e.g. SouthZEB, HELIMED, ABRACADABRA), rather than for instance RePublic ZEB, concerning the upgrading of public buildings, in particular thanks to the Energy-efficient Buildings program[6]. Even in this case projects aimed at sharing good

6 In particular, during the planning, several calls have been promoted; they dealt with developing innovative methods and strategies (AeB 5 – Innovative design tools for refurbishment at building and district level), with tools supporting decisions and refurbishment projects (EeB 7 – New tools and methodologies reducing the gap between predicted and actual energy performances regarding buildings and blocks of buildings). This has allowed the subject to be examined both focusing on one building and on the whole quarter. What is more, interventions aimed at an integrated approach to refurbishment have been fostered (EeB

practices among European regions and cities have been financed (such as EU-GUGLE and SINFONIA), aimed at the development of low CO_2 emission cities).

Among the projects financed thanks to 7PQ and H2020 aimed to develop tools, TABULA[7] and EPISCOPE[8] have proved to be particularly relevant. In the former case the result has been the publication of a file describing the structure according to typology developed within the TABULA project, with particular reference to the construction typology of each nation. Particular attention has been paid to the definition of building-types within the typological classification. Moreover, the data referring to Italian typology of construction and systems. An *ad hoc* section of the file, devised as a series of explanatory data sheets, concerns the energy-consumption analysis of the standard buildings and provides the figures of the amounts of the energy saved as the result of refurbishing the external envelope and the heating systems.

8 – Integrated approach to retrofitting of residential buildings). *Energy Efficiency Building Renovation Challenge: practical approaches, EASMESs Bruxelles*, 2016, [www.ec.europa.eu/easme/files. (Access on 12/04/2023)].

7 The TABULA project (Typology Approach for Building Stock Energy Assessment 2009-12) aimed to create a compatible structure of European building typologies that, starting from residential buildings, have also been applied to other building categories. Each partner has laid down its "National Building Typology", made up of a series of standard residential buildings with typical energy-consumption features. The building typology is classified according to well-defined categories (region, climatic zone, time of building, size). The elements leading to the classification of any given building typology make up the co-ordinates of the so called "Matrix of the Building Typology". Each cell of the matrix hosts a "staple building" that is regarded as representative of that specific condition (climatic area/ period of building/ size). Each staple building represents a certain period and has a pre-set size. The staple buildings have been used in each country has the means to assess energy performances and the foreseeable energy savings achieved through upgrading the building shells and heating systems. Two tiers of upgrading staple buildings have been analyzed: a standard upgrading, resorting to methods commonly used within each country, and an advanced upgrading, resorting to the best available technologies. Further information regarding how frequently given building and system typologies have been resorted to have led to formulate a typological classification as a model for evaluating the overall energy performance of the buildings in the country, [https://areeweb.polito.it/ricerca/episcope/tabula/ (Access on 22/05/2023)].

8 The EPISCOPE project (Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks, 2013-16) aimed to make energy saving processes of European residential buildings more straightforward and efficient, so as to make sure that the results aimed at should really be reached, or to provide the necessary adjustments. Purposely, the common typological staple has been widened, so as to include even cells regarding new buildings exemplifying the energy performances required by present-day national standards, or even more upgraded standards as high as almost-zero-energy buildings (NZEB), [http://episcope.eu/monitoring/overview/ (Access on 22/05/2023)].

In the second case – as a development of the TABULA project – simulations of scenarios have been carried out regarding residential buildings of different typologies in various European countries. Some of the case studies based on "national typology" have been focused on locally-selected real estate portfolios, others on real estate data-base regarding either single regions or the whole country. The results of the trends and the scenarios regarding CO_2 emissions reduction have been compared with European and/ or each country's reference parameters, so that the steps leading to reach the performance objectives chosen could be identified[9].

Another instrument supporting the upgrading of buildings is the Building Performance Institute Europe (BPIE) which since 2010 has been providing data and quantitative/qualitative analyses of the existing stock of buildings based on tests regarding the buildings' energy performances, in order to meet the requirements of each country's as well as Europe's policies[10]. In particular, BPIE has furthered several instruments within the scope of projects financed by the European Union, gathering data about the European building stock from 2010 onwards[11]. In 2012, the information collected were made available in BPIE database portal, including the technical data on the performance of buildings throughout the European Union. The Data Hub platform provides each country's statistics about the buildings, information on the policies and access to the sources of information supplied by organizations working in partnership: the European Union Observatory of building stock has relied on Data Hub's wealth of information and models[12].

9 The monitoring procedures and the energy performance indicators agreed upon during the implementation of the project have allowed the stakeholders to evaluate the quality and feasibility of energy upgrading by a wide range of cases, and to devise economically sustainable interventions.

10 Born out of a European project during 7PQ, BPIE has bloomed into a hub of expertise ranging from energy efficiency to renewable sources of energy and to the assessment of the energy performances of existing buildings in Europe. BPIE focuses on analysing and promoting innovative approaches according to good practices, in order to improve buildings` energy performances, [http://bpie.eu/ (Access on 13/05/2022)].

11 The results of this analysis have been collected in a report, first published in 2012 which is regularly updated. Amasiu B., Despret C., Economidou M., Maio J., Nolte I., Ralf O. Europ's buildings under microscope. A country-by-country review of the energy performance of buildings, Building Performance Institute Europe (BPIE), 2011, [http://bpie.com (Access on 21/03/2023)].

12 This project, financed by the European Union, started on 30/11/2016. It was meant to monitor the implementing of the policies in European Union member countries, each country being assigned ad hoc indicators. The Observatory of the buildings supplies a wide-ranging view of the features of the building stock; it collects data from EU projects, statistics from the various countries, EPC database, sustainable energy implementation plans, sector data and other sources, supplying information sheets on precise subjects regarding

Malý bytový dům 1961-1980 (CZ.N.MFH.04.Gen)

OBLAST	**NÁRODNÍ**
POČET PODLAŽÍ	**3**
POČET BJ	**6**
VYTÁPĚNÁ PLOCHA	**540m²**
VYTÁPĚNÝ PROSTOR	**1.688m³**

Syntetický objekt s vlastnostmi stanovenými na základě odborného odhadu vycházejícího ze znalosti bytového fondu. Zpravidla typizované řešení, dvou až třípodlažní budova zděná z cihel nebo zdících bloků, většinou podsklepená. Strop nejčastěji z železobetonových prefabrikátů. Okna typizovaná zdvojená. Plochá jednoplášťová střecha.

KONSTRUKCE OBÁLKY BUDOVY

Prvek	Původní	Standardní opatření	Progresivní opatření
Strop / střecha	Plynosilikátové desky 150 mm, cement. potěr 30 mm, hydroizolace.	Přidání 120 mm polystyrenu + nové hydroizolační vrstvy	Přidání 200 mm polystyrenu + nové hydroizolační vrstvy
Součinitel prostupu tepla U [W/m²K]	0,85	0,23	0,15
Obvodová stěna	Sendvičový panel - ŽB 150 mm, EPS 60 mm, ŽB 50 mm	Vnější kontaktní zateplení 100 mm fasádního polystyrenu nebo minerálního vlákna	Vnější kontaktní zateplení 120 mm fasádního polystyrenu nebo minerálního vlákna
Součinitel prostupu tepla U [W/m²K]	1,08	0,29	0,25
Podlaha / strop nad suterénem	ŽB strop tepelná izolace 10 mm	Přidání 40 mm izolace z pěnového polystyrenu zdola	Přidání 60 mm izolace z pěnového polystyrenu zdola
Součinitel prostupu tepla U [W/m²K]	1,03	0,50	0,40
Okno	Dřevěné okno zdvojené	Plastové okno s izolačním dvojsklem	Plastové okno s izolačním trojsklem
Součinitel prostupu tepla U [W/m²K]	2,80	1,10	0,80
Vstupní dveře	Dveře s kovovým rámem a jednoduchým zasklením	Plastové dveře s izolačním dvojsklem	Plastové dveře s izolačním trojsklem
Součinitel prostupu tepla U [W/m²K]	6,50	1,60	1,30

PRŮMĚRNÝ SOUČINITEL PROSTUPU TEPLA

[W/m²K]	Původní	Standardní opatření	Progresivní opatření
Průměrný součinitel prostupu tepla U_{em}	1,34	0,51	0,37

TEPELNÉ MOSTY, INFILTRACE

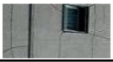
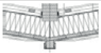
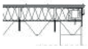
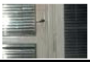
	Původní	Standardní opatření	Progresivní opatření
Vliv tepelných mostů ΔU [W/m²K]	0,10	0,10	0,05
Infiltrace [1/h]	0,40	0,20	0,10

Fig. 1 – *Page from the Czech Republic national typology booklet concerning a r.c. prefabricated panel building, chosen as representative of a certain period (1961-1980) [TABULA, 2012].*

Kod budynku : PL.N.AB.03.gen

Dane ogólne

typ budynku	wieżowiec
okres budowy	1972
Ilość pięter	15
Ilość mieszkań	98
Kubatura ogrzewana:	17 893 m^3
Powierzchnia ogrzewana	4 995 m^2

STAN WYJŚCIOWY (przed modernizacją)				
PRZEGRODY ZEWNĘTRZNE				
			wartość U	
ściany		wielka płyta	1,16	W/m^{2}K
dach		dach płaski , wentylowany, bez ocieplenia	0,8	W/m^{2}K
podłoga		podpiwniczony	1,6	W/m^{2}K
okna		drewniane, jednokomorowe	3,1	W/m^{2}K

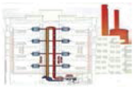
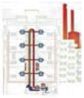
SYSTEMY		
OGRZEWANIE		
wytwarzanie	*regulacja*	*przesył*
centralne ogrzewanie	brak	rury nieizolowane
η=0,95	η=0,75	η=0,88
		
CIEPŁA WODA		
wytwarzanie	*zasobnik*	*przesył*
scentralizowane	standard lat 70tych	piony nieizolowane
η=0,92	η=0,59	η=0,4
		

Fig. 2 – *Page from the Poland national typology booklet concerning a prefabricated r.c. panel building (1972). As in the previous case, the analysis concerned both the transmittance of the main construction elements and an initial verification of the performance of the systems [TABULA, 2012].*

This determined activity of research and the ensuing regulations[13] undertaken by the European Community have however failed to produce the desired results as regards upgrading buildings: on average, yearly less than 1% of the European building stock gets upgraded, with a percentage ranging from 0,4 and 1,2%[14]. This may be ascribed not only to the structural differences between Northern and Southern Europe[15], but also to the dearth of suitable financial instruments that could withstand market failure, to the limited know-how of both owners, construction companies and professionals, and finally to the absent economic support that would make upgrading economically affordable to all the people living in the country[16].

each country, as well as mapping energy-shortage-prone countries, thus providing useful data for taking private and public policy- strategies

13 The 2011/31 UE European Parliament and Council guidelines about energy performances in buildings have provided the main set of rules, together with the 2009/ 125/CE directive and the (UE) 2017/1369 rules as regards the energy efficiency of buildings within the guidelines set for energy efficiency by 2030. The 2012/27 UE directive (Energy efficiency) on the other hand has immediately focused on the existing building stock and has set itself two complementary objectives: speeding up the refurbishment of existing buildings by 2050 and promoting the upgrading of all the buildings by resorting to smart technologies as well as to clearer connections with clean mobility. Such trend was confirmed in 2018 by the (UE) 2018/844 directive that modified the 2010/31/UE and 2012/27 UE ones, by introducing specific tools aimed to boost and speed up the energy-related and structural refurbishment of European Union buildings. In particular, the 2bis article of the (UE) 2018/844 directive lays down a framework for action as regards long-term refurbishment strategies (SRLT) aiming to support the building stock refurbishment thanks to highly-energy-efficient and de-carbonized buildings by 2050, making upgrading cost-friendly in all existing buildings, even so that they might qualify as NZEB (Nearly Zero-Energy Building). In conformity with the directive, the strategies will be supported by financial actions for mobilizing the investments in refurbishing the buildings, so as to reach the planned objectives. European Union, Commission Directive (EU) 2018/844 on building renovation, Bruxelles, 9/07/2018.

14 European Commission, Energy Efficiency in Building, 2020 [https:// ec.europa.eu/info/news/focus-energy-efficiency-building-2020-lut-17-it (Access on 24/03/ 2023)].

15 Such difference is evident in the economic means (more plentiful in the North than in the South) to be compared with the existing building stock (more plentiful in the South than in the North). Add to this the difficulty in applying normative and operational instruments devised for northern climates to temperate and Mediterranean climates.

16 Many are the stakeholders involved in refurbishing: some fall short of the know-how and of the awareness that would allow them to make consistent and rational decisions leading to efficient refurbishment. This implies that some decisions do not take risks properly into account, which rarely relates to the real economic risk of the investment. As far back as 2011, the THINK project underlined how this was one of the main drawbacks, together with the lack of clarity besetting the energy market and the market failures, when tackling European building stock refurbishing. Kaderjak P., et al., *THINK, How to Refurbish All Buildings by 2050*, Bruxelles, 2012, pp. 3-7, [http://think.eui.eu (Access on 11/11/2022)].

Beside faster renovation rates, also deep restorations need to be sizably increased throughout the Union, through implementing clearly-targeted national strategies and surveying the interventions aiming at verifying and sizing the objectives to be pursued[17].

Such awareness led to the formulation of the (EU)2019/780 European Recommendation on 08/05/2019; beside laying down strategies and objectives aimed at achieving economic accessibility and environmental sustainability in building refurbishment, it also clearly mentions the concept of circular economy within an integrated and consistent approach. The alterations introduced by the (EU) 2018/844 directive have blazed a clear path towards reaching the n/ZEB Union objectives by 2050, staged through national road maps and pit stops marking the benchmarks reached and to be supported by public funding and private loans[18].

In order to be certain that the financial measures concerning energy efficiency are applied in the best possible way to the refurbishment of the buildings, the (EU) 2018/844 directive, as revised by the recent Recommendation, dictates that the above-mentioned financial measures should be anchored to the efficiency of the refurbishing interventions, reckoning how far the foreseen energy-saving objectives have been reached[19].

Concerning the present work, the most interesting aspect of the (UE) 2018/844 directive is its requirement to achieve high-performance data from the building stock; they can in part be obtained from the energy performance certificates, available in most European countries, in part by means of implementing the assessment of the building stock as regards materials, con-

17 The 2bis article of the (EU) 2018/844 directive underlines the need of national strategies providing equal access to funding even to each country's building stock evidencing dismal performances for consumers faced with energy poverty, for social housing and for families beset by the problems posed by the fragmentation of incentives; economic accessibility ought obviously to be taken into account. European Union, *Commission Recommendation (EU) 2019/786 on building renovation*, Bruxelles, [https://op.europa.eu.en/publication:detail/-/publication/4adcc303-77a 6-11e9-9f05-01 aa75ed71aI/language-en/format-HTML (Access on 08/06/2023)].

18 To achieve this – and conform with the (UE) 2018/844 directive – long- term refurbishment national strategies are needed; they should be backed by reliable financing, so as to allow the refurbishing of the existing buildings, in order to make them highly energy efficient and de-carbonized by 2050, furthering the economically sustainable NZEB transformation of the whole existing building block

19 This makes it necessary for each country to abide by the rules of article 10 of the (EU) 2018/844 directive, in order to secure energy-efficiency financing should be connected with energy performances as assessed by certification, energy evaluation or by the improvement achieved thanks to refurbishment, assessed by comparing the energy performance certificates before and after the intervention, issued by applying a reliable and proportionate method.

struction and function which should integrate energy and structure-related performances as well as environmental questions (air quality, comfort) and social issues (human connections and inclusion)[20].

The reliability of the data in the assessment of the building stock and the definition of its performance are essential to ensure the economic sustainability of the refurbishment intervention: reducing the discrepancies between the condition of things (real performances) and the conditions of project (planned performances) avoids overestimating the intervention and so allows the economic resources to be more efficiently employed. As regards the 60s, 70s and 80s prefabricated residential buildings, the above acquire a fundamental role, as it will be expounded further on. Such buildings cover in fact large areas in rather downgraded quarters, which means they become an important case study for the development of a methodology capable of achieving the EU 2050 objectives.

1.2 Prefabricated Residential Buildings: Quantitative Aspects

In the aftermath of World War II, European countries witnessed a never-before soaring in the amounts of their urban residential buildings. Such growth – limited to some few years and to precise areas – was triggered by well-known factors: economic and industrial development, population growth, the shift of people from rural areas and agricultural activities to industrial ones, from depressed to potentially prosperous areas, from countries outside Europe to EU ones. The growth of the building stock has therefore been the answer focused on merely quantitative objectives to the need of houses caused by strong social and economic demands.

The most evident result has been urban growth: in 1950 only 29% of people lived in towns, whereas nowadays the percentage has grown to more than 50, and a foreseen 70% in 2050[21]. In Europe today about 41% of people live

20 Such stores of information can be used to check conformity and produce statistics on real estate stocks in EU regions or countries. It is however necessary to abide by article 10 of the (UE) 2018/844 directive to allow the collection of data regarding energy consumption of certain buildings as well as the availability of collective and anonymous data, to safeguard privacy.

21 In the next decades in Europe the urban population will grow slightly (from 920 millions in 2010 to 1.2 millions in 2030); in the U.S.A. urban population (now amounting to 261m.) will grow up to 30 millions in 2030. In Latin America, where the urbanization rate is one of the highest, i.e. 80% – with a 41% increase starting from 1950, urban population is estimated to rise from present-day 500m. to 661m. in 2030. In Asia, where urban population is growing more quickly than in the remaining continents, the trend of growth that started in the last century has grown stronger: from 234m.in 1950 the urban population has reached 1b. in 1990,

in urban areas, 35% in semi-urban areas and 23% in rural areas[22]. This growth has caused residential building stock to increase: according to the BPIE report, in Europe it amounts to 75% of the areas covered by buildings. About 83% of such building stock was built between 1950 and 1990 to meet two types of demand: a merely quantitative demand between 1950 and 1960, another focusing both on quantity and on a certain degree of quality, though both disregarding energy consumption entirely[23]. The European residential building stock dating back to 1950-1990 built according to merely quantitative criteria accounts for the largest amount of energy consumption and CO_2 emissions. As years have gone by, this stock has decayed, owing to its poor technological quality; the decay has involved both the materials and the performances and has caused poorer social and environmental living standards.

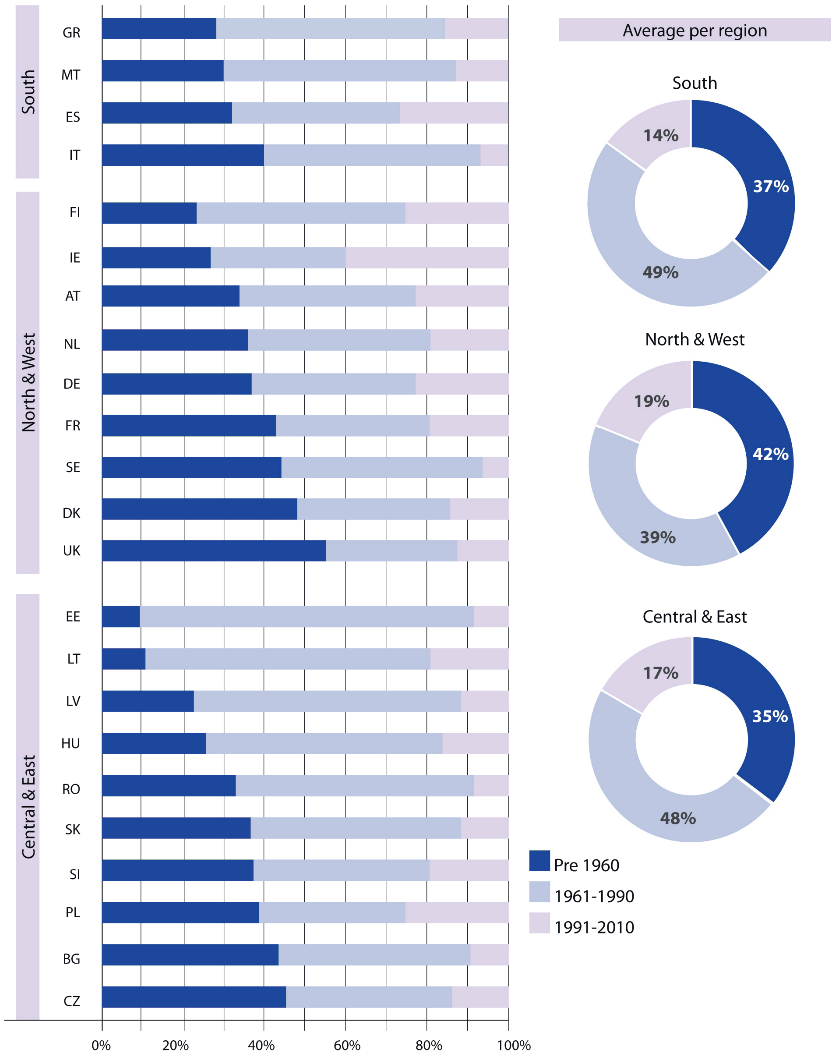
Against this background, prefabricated residential construction becomes quite relevant. As far back as the 1950s, when post-war reconstruction was over, the increase in the demand for houses sped up industrialization in construction dramatically, also thanks to a wide resort to prefabrication; this led to the birth of "house-building factories": leaving aside the traditional approach to construction – made up of projects and building yards – such "factories" furthered the resort to new residential housing typologies, the experimentation of materials, technologies and new production cycles[24].

and it is estimated that it will grow as high as 3.8 billions in 2030. In Africa, on the other hand, where urban population only accounts for 40%, urbanization rate is rapidly increasing. [*United Nations Population Fund*, 2015].

22 Eurostat data reveal the following situation: the countries with the highest percentage of urban population are Malta (100%, The Low Countries and the United Kingdom (71%) and Belgium (68%); they are followed by Sweden (56%), Estonia (52%) and Bulgaria (45%). On the other hand, the countries in which most people live in rural areas are Ireland (73%), Slovakia (50%), Estonia (48%) and Hungary (47%). In Italy the figures are rather levelled: 36% of the population lives in urban areas, 44% in in-between areas and 20% in rural areas. Almost all UE countries, have witnessed a greater increase of population in urban areas than in in-between and rural areas, except in Ireland, where the rural population has grown dramatically, whereas urban population has dropped considerably. [*Eurostat*, 2022].

23 The 2011 report, issued by the Building Performance Institute Europe (BPIE) analysed the European building stock, highlighting its relevant complexity, mainly resulting from the different European technical, project-and-construction-related and urban policies approaches between 1950 and 2000. As regards Italy, for example, the BPIE report highlights residential housing accounts for 83% of the building stock, 85% of which relates to buildings dated between 1950 and 1990, when the regulations concerning energy consumption started being mandatory. Amasiu B., Despret C., Economidou M., Maio J., Nolte I., Ralf O., *Europ's buildings under microscope. A country-by-country review of the energy performance of buildings*, Building Performance Institute Europe (BPIE), 2011 [http://bpie.com (Access on 21/03/2023)].

24 The basis characterising this growth in the different countries (even though the ways and the times varied) was the process of industrialization applied to construction, meant as



NOTES

BG: Based on estimations
EE: Data from 1951 onwards.
GR: Data only till 2000.
IT: Values exclude heritage buildings before the 1950.
LT: Data from 1941 onwards.
MT: Based on a sample survey with data until 2002.
PL: Based on estimations
ES: Based on primary residences (i.e. excluding secondary houses)
SE: Data only from 1921 till 2005

Fig. 3 – *The age of the European building stock: on average about 45% of buildings were built in the period 1961-90, with mainly quantitative criteria, while for the period before 1960 the situation of the stock in the different countries can vary greatly. [BPIE, 2011].*

Fig. 4 – *Residential district under construction in Bratislava (Slovakia) in the 1970s. The common urban planning, technological and material choices have made the residential districts of the European suburbs very similar to each other, with fairly comparable architectural, material and performance degradation phenomena. Due to the lack of immigration from non-European countries since the 1970s, today in the main cities of Eastern Europe the inhabitants are originally from the place and are generally the owners of the apartment in which they live.*

Fig. 5 – *Residential district Plaine d'Ozon in Châtellerault (France) in the 1960s. In Western European countries, the problems that have developed in the suburbs are linked to phenomena of social segregation, which add up to environmental and architectural degradation.*

Tabs. 2-3 – *Multi-storey dwellings in Eastern Europe (top) and Western Europe (bottom) in relation to the construction date. Of particular interest are the data relating to the period 1945-1990 (the data are to be considered 1 Unit = x1000) [BPIE, 2018].*

Country	**Unit**	**< 1945**	**1945-1969**	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2008**
Bulgaria	1000	69.25	335.04	251.94	273.46	172.51	282.78
Czech Rep.	1000	354.19	873.22	360.44	407.62	148.66	153.78
Estonia	1000	49.62	139.12	125.59	119.26	30.56	25.19
Finland	1000	116.89	275.60	288.61	148.40	133.24	123.25
Hungary	1000	595.26	389.99	179.70	84.39	137.56	162.10
Latvia	1000	115.01	250.75	202.72	195.68	61.25	988.21
Lithuania	1000	229.21	264.38	198.26	198.26	58.49	48.77
Poland	1000	1,569.00	1,705.77	1,121.79	1,170.63	1,170.63	1,256.19
Romania	1000	81.74	752.20	966.24	1,215.26	31.11	126.72
Slovakia	1000	135.89	320.05	132.05	150.84	56.49	84.68
Slovenia	1000	157.57	109.27	95.73	39.26	39.26	46.78
Serbia	1000	145.68	332.60	248.32	209.87	102.87	128.35
Croatia	1000	66.58	132.56	112.40	88.24	43.65	116.74

Country	**Unit**	**< 1945**	**1945-1969**	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2008**
Austria	1000	478.00	520.00	230.00	190.00	252.00	101.00
Belgium	1000	422.36	234.64	152.38	152.38	136.74	94.50
Cyprus	1000	0.15	3.47	10.70	18.22	12.92	38.67
Denmark	1000	447.54	260.13	147.10	61.40	62.86	112.66
Finland	1000	116.89	275.60	288.61	148.40	133.24	123.25
France	1000	3,480.06	2,121.53	2,419.03	1,439.26	976.53	1,349.88
Germany	1000	3,906.37	7,683.33	4,034.40	2,612.56	2,201.42	690.70
Greece	1000	187.89	683.81	544.87	417.10	280.60	176.48
Ireland	1000	23.79	15.45	8.99	12.13	28.47	97.12
Italy	1000	4,137.27	7,186.28	4,030.65	2,785.00	1,063.30	842.50
Lux.	1000	11.61	18.30	9.10	7.80	7.54	13.64
Malta	1000	3.61	8.67	6.52	4.36	7.75	4.46
Neth.	1000	443.66	587.91	358.73	295.73	273.74	151.05
Portugal	1000	136.26	249.22	356.75	282.85	371.58	158.77
Spain	1000	1,098.21	2,846.36	2,536,.09	1,333.08	1,368.85	2,598.08
Sweden	1000	760.57	731.23	359.20	223.60	259.20	61.20

The growing demand was met by resorting to the tools belonging to industry, namely scientific approach to the project and mass production; this has caused residential prefabricated buildings to become a relevant feature of present-day European building stock: between 1945 and 1979, out of 93 millions buildings built in UE countries as a whole, 67% belonged to prefabricated buildings (which mainly meant heavy prefabrication); percentages reached 92-93% in the most highly industrialized countries (France, West Germany and Scandinavian countries) and 97-98% in former East Europe countries (East Germany, Poland, Czech Rep., Slovakia, Estonia, Latvia, Lithuania, Romania, Bulgaria, Albania and former Yugoslavia Federation countries)[25].

The sheer number of whole quarters of prefabricated buildings makes tackling their management and functional, energy-related and environmental refurbishment quite arduous. Such quarters are in fact quite decayed owing to the dire poverty of their inhabitants which makes the very economic sustainability of refurbishment projects quite problematic. As regards residential housing in Eastern European countries (especially in the poorest ones) the decay can even be partially ascribed to the shift from a socialist to a communist economy, topped by the scarce economic means of the dwellers[26]. This has led to the almost total disregard for maintenance, which has by no means bettered the initial material, project-and-construction-related standards.

an economic phenomenon applied to the process of production. Started in the 1920s and 1930s, industrialization applied to construction became widespread and involved the stages of construction as a whole, starting from postbellum reconstruction. Between 1945 and 1965, in fact, industrialization applied to construction – together with the introduction of new materials, the resort to new construction techniques and new production cycles – became a priority.

25 In former ex-soviet-bloc countries – on which this research focuses – the 97-98% of the building stock, amounting to 39,062,310 apartments built between 1945 and 1999 is prefabricated. The high percentage of the buildings built according to the techniques typical of prefabrication and the renewed interest in the life-cycle of buildings generally forbid demolition and preferentially opt for refurbishment.

26 The preferential resort to prefabrication was strictly linked to setting up the new communist society, in the same way as the development of the city regarded as the specific element and functional space of the new society funded on production; this could not help mirroring its functional and structural matrixes. Smith M. B., *Property of Communists: The Urban Housing Program from Stalin to Khrushchev*, Northern Illinois University Press, DeKalb, 2010, 19-21; Harris S., *Communism on Tomorrow Street: Mass Housing and Everyday Life after Stalin*, Woodrow Wilson Center Press/Baltimore, Washington D.C., 2013, 27-31.

1.3 Prefabrication: Technical and Production-Related Aspects

As it has been underlined above, refurbishing the existing building stock has become increasingly relevant, above all as the result of the recently issued EU guidelines[27]. For several years international studies have evidenced how refurbishing proves more rewarding than demolition, leading to transdisciplinary studies and the development of new technologies fitted into the building stock, and at the same time furthering circular economy. As regards prefabricated residential buildings, on the one hand energy-related, environmental and social issues are greater, on the other, so are the even economic opportunities refurbishing the existing building stock affords. However, refurbishing is hindered by both the sheer amount of the prefabricated building stock and by the poor knowledge of its material and construction-related features. This makes refurbishing interventions difficult from the point of view of economy and efficiency, as far as choosing the materials and the technologies, the recycling and disposal of waste are concerned.

The need to improve the levels of knowledge (LC) makes it mandatory to study in detail the theoretical reference framework of prefabricated residential construction. It is in fact necessary to understand the differences between the words “industrialization” and “prefabrication”, since their meanings have become blurred over the years.

Industrialization in construction has been prompted by a better organization, namely by resorting to new production cycles and has relied on a new approach that has gradually transformed construction: from a craft-based activity to a full-fledged “housing industry”, with results that from the point of view of the organization and technologies it requires can be compared to the most sophisticated sectors. This has however caused construction to be subject to the essential rules regulating any industrial activity: resort to serial production and a market that demands and regularly consumes the items produced[28].

27 This priority was translated by the EU into specific actions contained in the Energy Efficient Europe Roadmap (2011), concerning the entire building sector and which are focused both on the construction of zero-consumption buildings, but above all on increasing the redevelopment of existing buildings, the reduction of soil consumption and the recycling of construction and demolition waste. Roadmap to a Resource Efficient Europe, [http://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX:52011DC0571) (Access on 19/06/2023)].

28 The connection between resorting to industrialized techniques in construction and the creation of a “housing market” have been analyzed starting from the late 50s. Ciribini G., *Architettura e industria*, Tamburini, Milan, 1958, 11; Oliveri, G.M., *Fabbricazione e metaprogetto edilizio*, Etas Kompass, Milan, 1968, 12; Zambelli E., *Processo edilizio industrializzato*, FrancoAngeli, Milan, 1971, 27-30; Chemillier P., *Les techniques de bâtiment et leur avenir*, Moniteur, Paris, 1977, 35-36.

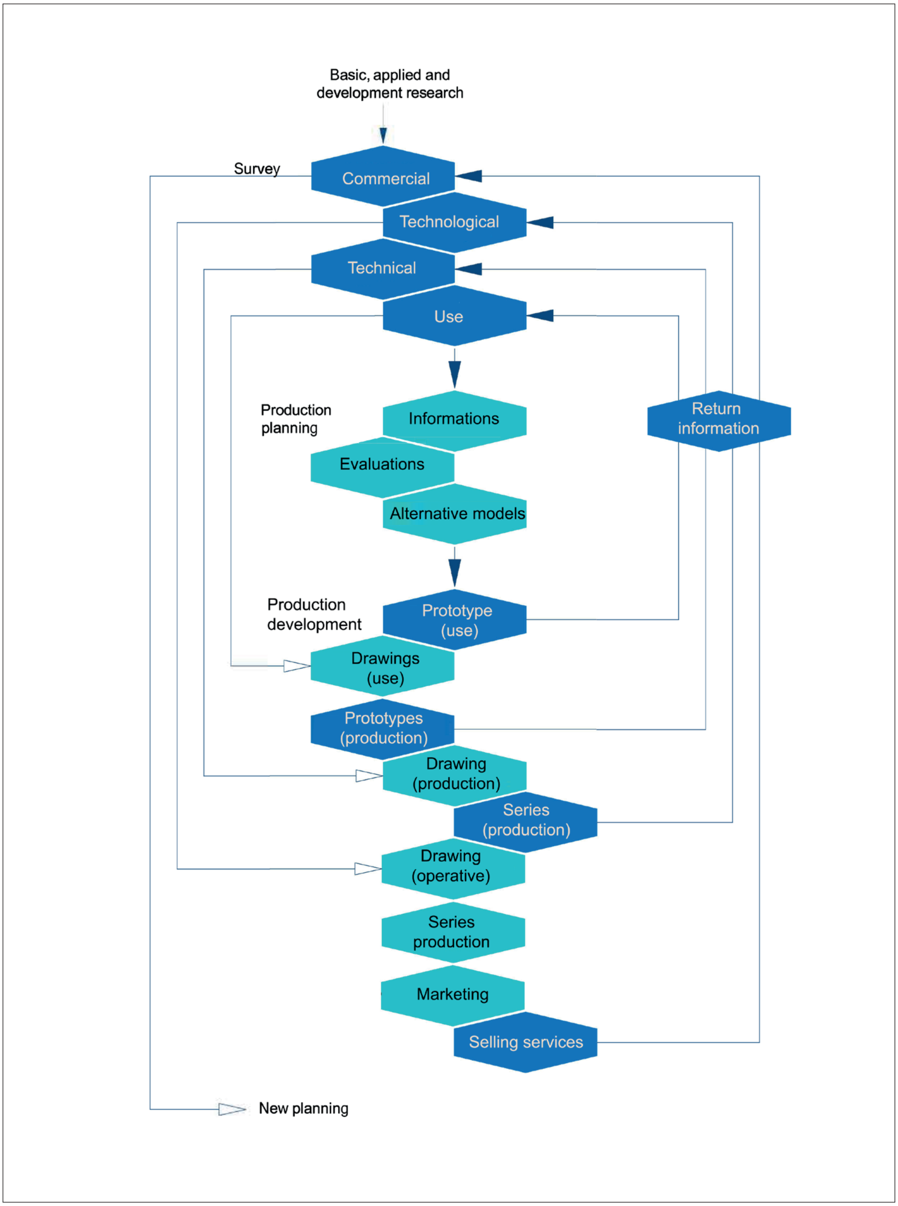


Fig. 6 – *Industrial new product cycle: the blue cells indicate the moment of industrialization of the model. The decision by the company management puts an end to the planning actions to start the development ones. On the "usage prototypes" (crafted by hand) decisions are made to plan production; with the "prototypes for the series" (composed of parts manufactured but not assembled on the assembly line) we try to solve manufacturing problems; the pre-production series (made up of serial pieces assembled on the assembly line) offers a check on the entire process. [from Ciribini, 1965]*